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COMPUTER MANUAL SERIES

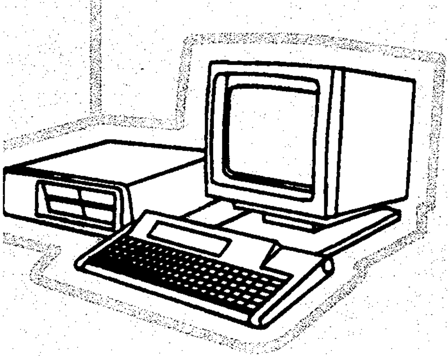
No.8

Wien Automatic System Planning (WASP) Package

A Computer Code for Power Generating System Expansion Planning

Version WASP-III Plus
User's Manual

Volume 1: Chapters 1–11



International Atomic Energy Agency, 1995

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INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1995

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WIEN AUTOMATIC SYSTEM PLANNING (WASP) PACKAGE
A COMPUTER CODE FOR POWER GENERATING SYSTEM EXPANSION PLANNING
VERSION WASP-III PLUS USER'S MANUAL
VOLUME 1: CHAPTERS 1–11
IAEA, VIENNA, 1995
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FOREWORD

As a continuation of its effort to provide comprehensive and impartial guidance to Member States facing the need for introducing nuclear power, the IAEA has completed a new version of the Wien Automatic System Planning (WASP) Package for carrying out power generation expansion planning studies.

WASP was originally developed in 1972 by the Tennessee Valley Authority and the Oak Ridge National Laboratory in the USA to meet the IAEA's needs to analyze the economic competitiveness of nuclear power in comparison to other generation expansion alternatives for supplying the future electricity requirements of a country or region. The model was first used by the IAEA to conduct global studies (Market Survey for Nuclear Power Plants in Developing Countries, 1972-1973) and to carry out Nuclear Power Planning Studies for several Member States.

From the experience gained from its application in the above studies, the WASP system developed into a very comprehensive planning tool for electric power system expansion analysis. This experience also permitted the production of new, improved versions of the program, which took into consideration the needs expressed by the users of the program in order to tackle important problems being faced in electric power system expansion planning.

Following these developments, the so-called WASP-III version was produced in 1979. This version introduced important improvements to the system, namely in the treatment of hydroelectric power plants. Similar to previous versions of the program, WASP-III has been distributed to many Member States and International Organizations, which have reported using this program for conducting many WASP studies. Through its widespread use, WASP-III has established itself as a very important tool for generation expansion planning.

The WASP-III version has been continually updated and maintained in order to incorporate needed enhancements. In addition, efforts have been directed to the improvement of the analysis that can be accomplished using this tool. This has been performed mainly by incorporating new models to the catalogue of IAEA's planning methodologies.

In a first step, in 1981, the Model for Analysis of Energy Demand (MAED) was developed in order to allow the determination of electricity demand, consistent with the overall requirements for final energy, and thus, to provide a more adequate forecast of electricity needs to be considered in the WASP study. MAED and WASP have been used by the Agency for the conduct of Energy and Nuclear Power Planning Studies for interested Member States. The MAED model has also been transferred to many Member States and International Organizations.

More recently, the VALORAGUA model was completed in 1992 as a means for helping in the preparation of the hydro plant characteristics to be input in the WASP study and to verify that the WASP overall optimized expansion plan takes also into account an optimization of the use of water for electricity generation. VALORAGUA aims at determining the optimal operating strategy of a mixed hydro-thermal power system, taking into account the operating characteristics of the system and the stochastic nature of some of the variables involved (inflow energy to the reservoirs, forced outages of the power plants, etc.). The combined application of VALORAGUA and WASP permits the determination of the optimal expansion of combined thermal and hydro power systems, taking into account the optimal operation of the hydro reservoirs throughout the year.

Microcomputer (PC) versions of WASP-III and MAED have also been developed as stand alone programs and as part of an integrated package for energy and electricity planning called ENPEP (Energy and Power Evaluation Program). A PC version of the VALORAGUA model has also been completed in 1992.

With all these developments, the catalogue of planning methodologies offered by the IAEA to its Member States has been upgraded to facilitate the work by electricity planners, WASP in particular is currently accepted as a powerful tool for electric system expansion planning. Nevertheless, experienced users of the program have indicated the need to introduce more enhancements within the WASP model in order to cope with the problems constantly faced by planners owing to the increasing complexity of this type of analysis.

Following the recommendations of IAEA Advisory Groups (see List of Participants at the end of this volume) on WASP Experience in Member States convened in 1990 and 1991, and in collaboration with several Member States, the IAEA has completed a new version of the WASP program, which has been called WASP-III Plus since it follows quite closely the methodology of the WASP-III model.

The major enhancements in WASP-III Plus with respect to the WASP-III version are:

- Increase in the number of thermal fuel types (from 5 to 10)
- Verification of which configurations generated by CONGEN have already been simulated in previous iterations with MERSIM
- Direct calculation of combined Loading Order of FIXSYS and VARSYS plants
- Simulation of system operation includes consideration of physical constraints imposed on some fuel types (i.e., fuel availability for electricity generation)
- Extended output of the resimulation of the optimal solution
- Generation of a file that can be used for graphical representation of the results of the resimulation of the optimal solution and cash flows of the investment costs
- Calculation of cash flows allows to include the capital costs of plants firmly committed or in construction (FIXSYS plants)
- User control of the distribution of capital cost expenditures during the construction period (if required to be different from the general "S" curve distribution used as default).

The WASP-III Plus version of the code may be released, under special arrangements, to Member States which have the necessary analytical and computer capabilities. The present document has been produced to support use of the WASP-III Plus computer code and to illustrate the capabilities of the program. Mr. P.E. Molina, assisted by Mr. P. Heinrich, both staff of the Division of Nuclear Power of the IAEA, were responsible for the compilation of this document.

Special recognition is due to: Mr. Abilio Seca Teixera of Electricidade de Portugal (EDP), who made a valuable contribution in developing the enhancements introduced in the REPROBAT Module, Mr. Gary Stuggins of the Asian Development Bank (ABD), who developed some of the new capabilities of the MERSIM Module, and Prof. A. Parker of the University of Adelaide, Australia, who first implemented the new algorithms to control the generation by fuel-limited plants and to increase the number of thermal fuel types. Recognition is also expressed to the several experts who participated in the AGM on the subject matter as listed in the attachment. Finally, it is also acknowledged the contribution of many WASP experts who, in several opportunities, provided suggestions to the final version of the program and this document.

This Manual is organized in two separate volumes. The first one includes 11 main chapters describing how to use the WASP-III Plus computer program. Chapter 1 gives a summary description and some background information about the program. Chapter 2 introduces some concepts, mainly related to the computer requirements imposed by the program, that are used throughout the Manual. Chapters 3 to 9 describe how to execute each of the various programs (or modules) of the WASP-III Plus package. The description for each module shows the user how to prepare the Job Control statements and input data needed to execute the module and how to interpret the printed output produced. The iterative process that should be followed in order to obtain the "optimal solution" for a WASP case study is covered in Chapters 6 to 8.

Chapter 10 explains the use of an auxiliary program of the WASP package which is mainly intended for saving computer time. Lastly, Chapter 11 recapitulates the use of WASP-III Plus for executing a generation expansion planning study; describes the several phases normally involved in this type of study; and provides the user with practical hints about the most important aspects that need to be verified at each phase while executing the various WASP modules.

The second volume consists of 5 appendices giving some additional information about the WASP-III Plus program. Appendix A is mainly addressed to the WASP-III Plus system analyst and supplies some information which could help in the implementation of the program on the user computer facilities. This appendix also includes some aspects about WASP-III Plus that could not be treated in detail in Chapters 1 to 11.

Appendix B identifies all error and warning messages that may appear in the WASP printouts and advises the user how to overcome the problem. Appendix C presents the flow charts of the programs along with a brief description of the objectives and structure of each module.

Appendix D describes the main calculations performed by the WASP modules as well as the key algorithms used. Finally, Appendix E presents some auxiliary computer programs and general information which may help the user in preparing the input data for a case study and in the analysis of the WASP "optimal solution."

The reader of this manual is assumed to have experience in the field of power generation expansion planning and to be familiar with all concepts related to such type of analysis; therefore, these aspects are not treated in the manual.

Before proceeding to execute a WASP study, it is strongly recommended to read Chapter 1 very carefully in order to decide if the program is suitable to represent well the characteristics of the power system to be studied. Then, if it is decided to undertake the WASP study, Chapter 11 should be used as a guide for conducting the study. Furthermore, while executing each WASP module for the first time, it is advisable not only to concentrate on the respective section describing how to use the module, but also to read the relevant sections of Appendix D to get more insight about the calculations performed by the module and on the consequences of the input data specified.

Additional information on power generation expansion planning can be read in the IAEA publication: "Expansion Planning for Electrical Generating Systems, A Guidebook," Technical Reports Series No. 241, Vienna 1984, which may also help the user in the preparation of the input data for case studies.

Suggestions for improving this manual based on user experience should be addressed to:

Planning and Economic Studies Section
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EDITORIAL NOTE

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CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Background Information

The Wien Automatic System Planning Package (WASP) was originally developed by the Tennessee Valley Authority (TVA) and Oak Ridge National Laboratory (ORNL) of the United States of America to meet the needs of the IAEA's Market Survey for Nuclear Power in Developing Countries conducted by the Agency in 1972-1973 [1, 2].

Based on the experience gained in using the program, many improvements were made to the computer code by IAEA Staff, which led in 1976 to the WASP-II version. Later, the needs of the United Nations Economic Commission for Latin America (ECLA) to study the interconnection of the electrical grids of the six Central American countries, where a large potential of hydroelectric resources is available, led to a joint ECLA/IAEA effort from 1978 to 1980 to develop the WASP-III version [3].

The WASP-III version has been distributed to several Member States for use in electric expansion analysis. In addition, other computer models have been added to the IAEA's catalogue of planning methodologies to complement the WASP analysis. Firstly, in 1981, the Model for Analysis of Energy Demand (MAED) was developed in order to allow the determination of electricity demand, consistently with the overall requirements for final energy, and thus, to provide a more adequate forecast of electricity needs to be considered in the WASP study [4]. More recently, the VALORAGUA model for determination of the optimal operating strategy for mixed hydro-thermal power systems was completed in 1992 as a means of improving the determination of the characteristics of hydroelectric power stations to be fed into WASP [5]. Microcomputers (PC) versions of WASP-III and MAED have also been developed as stand alone programs [6, 7] and as part of an integrated package for energy and electricity planning called ENPEP (Energy and Power Evaluation Program) [8]. A PC version of the VALORAGUA model has also been completed in 1992 [9].

With all these improvements, the WASP-III model has been enhanced to facilitate the work by electricity planners and is currently accepted as a powerful tool for electric system expansion planning. Nevertheless, experienced users of the program have indicated the need to introduce more enhancements within the WASP model in order to cope with the problems constantly faced by the planer owing to the increasing complexity of this type of analysis.

Following the recommendations of an IAEA Advisory Group on WASP Experience in Member States convened in 1990 and 1991, and in collaboration with several Member States, the IAEA has completed a new version of the WASP program, which has been called WASP-III Plus since it follows quite closely the methodology of the WASP-III model. The new version of the code may be released, under special arrangements, to Member States which have the necessary analytical and computer capabilities.

Like its predecessor, WASP-III Plus is designed to find the economically optimal generation expansion policy for an electric utility system within user-specified constraints. It utilizes <u>probabilistic estimation</u> of system -production costs, -unserved energy cost, and -reliability, and the <u>dynamic method of optimization</u> for comparing the costs of alternative system expansion policies.

The modular structure of WASP-III Plus permits the user to monitor intermediate results, avoiding waste of large amounts of computer time due to input data errors. WASP-III Plus uses magnetic disc files (it could be modified to use magnetic tape files instead) to save information from iteration to iteration, thus avoiding repetition of calculations which have been previously done.

The major enhancements incorporated in WASP-III Plus with respect to the WASP-III version are:

- Increase of the number of thermal fuel types (from 5 to 10) as a means to provide more flexibility for the user, particularly when confronted with a large variety of fuel types. Earlier versions of WASP allowed the definition of only five fuel types, which somewhat constrained the analysis, as plants using similar (but not identical) fuel types had to be grouped into a single fuel type in order to meet these limits.

- Combined Loading Order from FIXSYS and VARSYS plants directly calculated by the program: The WASP-III version of the program already included information about the Basic Loading Order (L.O.) of the FIXSYS and VARSYS plants, so it seemed a logical enhancement to have the program calculate this L.O. for the combined list of FIXSYS and VARSYS plants. This feature included in WASP-III Plus greatly facilitates the preparation of input data for the MERSIM module of the program.

- Verification of which configurations generated by CONGEN have already been simulated in previous iterations with MERSIM: This enhancement was developed by the IAEA in order to facilitate the control of the conduct of the WASP study. The CONGEN module of WASP-III allows the determination of how many configurations accepted in the current run will need to be simulated by the subsequent MERSIM run, and thus to estimate the total execution time of MERSIM.

- Consideration in the simulation of system operation of physical constraints imposed to some fuel types (i.e., fuel availability for electricity generation): This improvement, together with the increase of the number of fuel types mentioned above, was developed by Mr. A. Parker of the University of Adelaide, Australia. It basically tries to find a fix to the operational problem confronted in the solution of the expansion of the power system, specifically when constraints are applicable to the amount of fuel that can be made available for electricity generation by the power plants using the "constrained" fuel type. This feature also allows for the definition of an alternative fuel type that can make up for any energy generation above the limits specified for the constrained fuel type (or types).

- Extended output of the resimulation of the optimal solution: The MERSIM module of WASP-III Plus (when working in the resimulation mode: REMERSIM) allows for the detailed calculation of some operational quantities not evaluated in previous versions of the program. These include a detailed report of energy generation and generation costs by fuel type, as well as the fuel consumption and fuel stock also grouped by fuel type. All these data are stored in two files for later use by the REPROBAT module. One of them can serve as the basis for preparation of graphical output of the results (see below).

- Generation of a file that can be used for graphical representation of the results: This feature was developed by Electricidade de Portugal as a means to enhance the reports of the WASP analysis. For this purpose, WASP-III Plus includes an output file onto which the results of the resimulation of the optimal solution and the corresponding cash flows on investment costs calculated by REPROBAT are written. No attempt has been made within WASP-III Plus to develop the necessary programs to produce actual graphs showing these data because of the lack of standardized graphics packages that could be readily available at the user's computer facilities.

- Including in the cash flows, the capital costs of plants firmly committed or in construction (FIXSYS plants): Users of previous versions of WASP often complained that the cash flows of capital costs reported by the REPROBAT module underestimated the actual expenditures to be faced by the electric utility, particularly by not considering the costs related to the committed or decided system. In certain cases, these costs can be of an order of magnitude higher than the ones arising from expansion candidates added by the optimal solution. WASP-III Plus allows for the consideration of such expenditures for the production of reports on the total expected investment costs related to a WASP solution. This improvement was developed by EDP.

- Control by the user of the distribution of capital cost expenditures during the construction period (instead of the general "S" curve assumed in WASP-III): This feature of WASP-III Plus also corresponds to a development by EDP. It responds to requests by many WASP users who often complained that the S-curve distribution did not represent the actual experience in the country.

- New Calculations of Escalation of Capital Investment Costs: For the production of reports on capital investment costs related to the WASP solution being reported on, the REPROBAT module of WASP-III Plus performs a more accurate calculation of the interest during construction (IDC) related to the construction of a candidate plant added by the solution. This takes into consideration any escalation defined for the corresponding expansion candidate

The computer time requirements to carry out a generation planning study using WASP-III Plus depend on:

(a) The complexity of the system under study;

(b) The number of hydrological conditions considered;

(c) The number of periods into which the year is divided;

(d) The number of operational constraints (fuel limitations) imposed;

(e) The total number of years considered;

(f) The accuracy required for simulating the system operation; and

(g) The total number of configurations generated during the study.

Simulation of a 20 years fixed expansion plan with 4 periods per year, 3 hydroconditions, and 20 Fourier coefficients takes about 3 seconds of computation time in the Agency's IBM 9121/320 computer (see Chapter 2 for description of the computer facilities at IAEA). The full dynamic programming study carried out for the sample problem described in this manual, involving simulation of about 8000 configurations, took as much as 17 minutes of CPU time in the same computer.

The purpose of this manual is to show the WASP-III Plus user how to undertake the following tasks: - *preparation of the control and input data cards* needed to run the WASP modules, - *execution* of the modules, - *revision* of the WASP outputs, and - *repetition of this process* until an expansion plan is identified which is optimal within the constraints imposed by the user. These aspects will be illustrated using an example (CASE93). In general, the information presented throughout the manual illustrate how this study was conducted on the IAEA's computer facilities. In some cases, particularly for some of the input data and computer printouts, the information presented in this manual has been compressed to facilitate their description and to reduce the size of the manual. The sample problem has been selected to demonstrate the input and output capabilities of the code and it is not meant to represent a typical system or a typical power planning study.

1.2 Summary description of the WASP-III Plus Computer Code

The WASP-III Plus code permits finding the optimal expansion plan for a power generating system over a period of up to thirty years, within constraints given by the planner. The optimum is evaluated in terms of minimum discounted total costs. A simplified description of the model follows. For matters of convenience, the symbols used in this description are not the same as in the various WASP modules and the different expressions presented have been simplified.

Each possible sequence of power units added to the system (expansion plan or expansion policy) meeting the constraints is evaluated by means of a cost function (the objective function) which is composed of:

- Capital investment costs (I)
- Salvage value of investment costs (S)
- Fuel costs (F)
- Fuel inventory costs (L)
- Non-fuel operation and maintenance costs (M)
- Cost of the energy not served (O)

The cost function to be evaluated by WASP can be represented by the following expression:

$$B_j = \sum_{t=1}^{t} [\bar{I}_{j,t} - \bar{S}_{j,t} + \bar{F}_{j,t} + \bar{L}_{j,t} + \bar{M}_{j,t} + \bar{O}_{j,t}] \quad (1.1)$$

where:

B_j is the <u>objective function</u> attached to the expansion plan,

t is the time in years (1, 2, ... , T),

T is the length of the study period (total number of years).

and the bar over the symbols has the meaning of discounted values to a reference date at a given discount rate i.

The <u>optimal expansion plan</u> is defined by:

$$\textbf{Minimum } B_j \textbf{ among all } j \tag{1.2}$$

The WASP analysis requires as a starting point the determination of alternative expansion policies for the power system. If $[K_t]$ is a vector containing the number of all generating units which are in operation in year t for a given expansion plan, then $[K_t]$ must satisfy the following relationship:

$$[K_t] = [K_{t-1}] + [A_t] - [R_t] + [U_t] \tag{1.3}$$

where:

$[A_t]$ = vector of committed additions of units in year t,

$[R_t]$ = vector of committed retirements of units in year t,

$[U_t]$ = vector of candidate generating units added to the system in year t, $[U_t] \geq [0]$

$[A_t]$ and $[R_t]$ are given data, and $[U_t]$ is the unknown variable to be determined; the latter is called the system configuration vector or, simply, the system configuration.

Defining the critical period (p) as the period of the year for which the difference between the corresponding available generating capacity and the peak demand has the smallest value, and if $P(K_{t,p})$ is the installed capacity of the system in the critical period of year t, the following constraints should be met by every acceptable configuration:

$$(1+a_t) \cdot D_{t,p} \geq P(K_{t,p}) \geq (1+b_t) \cdot D_{t,p} \tag{1.4}$$

which simply states that the installed capacity in the critical period must lie between the given maximum and minimum reserve margins, a_t and b_t respectively, above the peak demand $D_{t,p}$ in the critical period of the year.

The reliability of the system configuration is evaluated by WASP in terms of the Loss-of-Load Probability index (LOLP). This index is calculated in WASP for each period of the year and each hydrocondition defined. The LOLP of each period is determined as the sum of LOLP's for each hydrocondition (in the same period) weighted by the hydrocondition probabilities, and the average annual LOLP as the sum of the LOLP's for the periods.

If $LOLP(K_{t,a})$ and $LOLP(K_{t,i})$ are the annual and the period's LOLP's, respectively, every acceptable configuration must respect the following constraints:

$$LOLP(K_{t,a}) \leq C_{t,a} \tag{1.5}$$

$$LOLP(K_{t,i}) \leq C_{t,p} \quad \textbf{(for all periods)} \tag{1.6}$$

where $C_{t,a}$ and $C_{t,p}$ are limiting values given as input data by the user.

If an expansion plan contains system configurations for which the annual energy demand E_t is greater than the expected annual generation G_t of all units existing in the configuration for the corresponding year t, the total costs of the plan should be penalized by the resulting cost of the energy not served. Obviously, this cost is a function of the amount of energy not served N_t, which can be calculated as:

$$N_t = E_t - G_t \tag{1.7}$$

The user may also impose tunnel constraints on the configuration vector $[U_t]$ so that every acceptable configuration must respect:

$$[U_t^0] \leq [U_t] \leq [U_t^0]+[\Delta U_t] \tag{1.8}$$

where $[U_t^o]$ is the smallest value permitted to the configuration vector $[U_t]$ and $[\Delta U_t]$ is the tunnel constraint or tunnel width.

The problem as stated here corresponds to finding the values of the vector $[U_t]$ over the period of study which satisfy expressions (1.1) to (1.8). This will be the "best" system expansion plan within the constraints given by the user. The WASP code finds this best expansion plan using the dynamic programming technique. In doing so, the program also detects if the solution has hit the tunnel boundaries of expression (1.8) and gives a message in its output. Consequently, the user should proceed to new iterations, relaxing the constraints as indicated in the WASP output, until a solution free of messages is found. This will be the "optimum expansion plan" for the system.

1.2.1 Calculation of Costs

The calculation of the various cost components in expression (1.1) is done in WASP with certain models in order to account for:

(a) Characteristics of the load forecast;

(b) Characteristics of thermal and nuclear plants;

(c) Characteristics of hydroelectric plants;

(d) Stochastic nature of hydrology (hydrological conditions); and

(e) Cost of the energy not served.

In the above list and throughout this manual, the word plant is used when referring to a combination of one or more units (for thermal) or to one or more projects (for hydro).

The load is modelled by the peak load and the energy demand for each period (up to 12) for all years (up to 30), and their corresponding inverted load duration curves. The latter represents the probability that the load will equal or exceed a value taken at random in the period (for computational convenience, the inverted load duration curves are expanded in Fourier Series by the computer program).

The models for thermal and nuclear plants are described, each of them, by:

- Maximum and minimum capacities;
- Heat rate at minimum capacity and incremental heat rate between minimum and maximum capacity;
- Maintenance requirements (scheduled outages);
- Failure probability (forced outage rate);
- Capital investment cost (for expansion candidates);
- Variable fuel cost;
- Fuel inventory cost (for expansion candidates);
- Fixed component and variable component of (non-fuel) operating and maintenance costs; and
- Plant life (for expansion candidates).

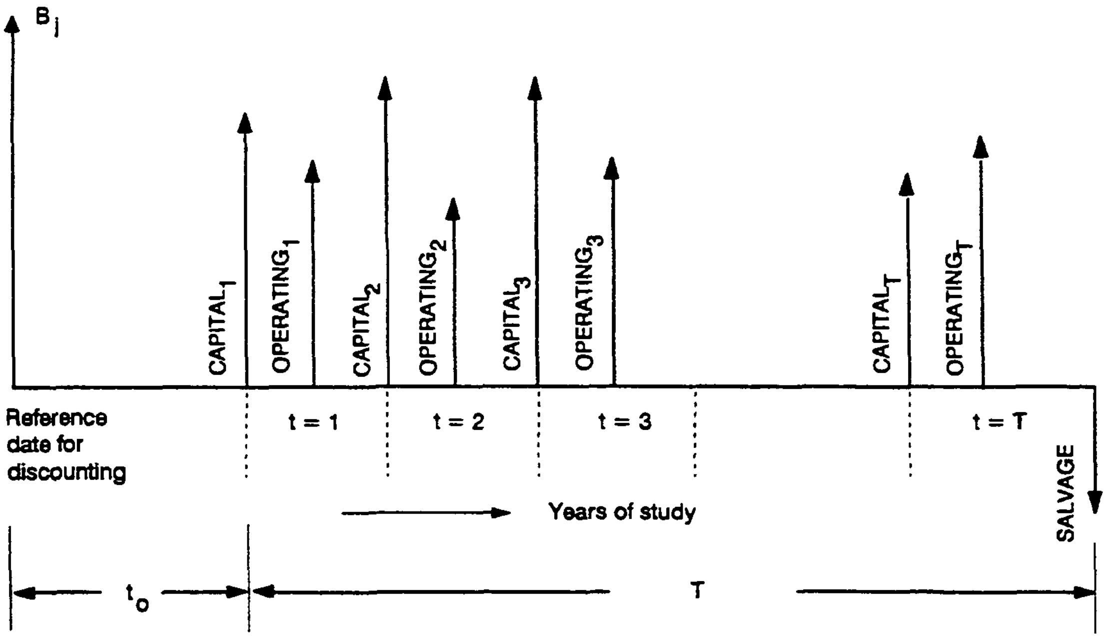
The models for hydroelectric projects are for run-of-river, daily peaking, weekly peaking and seasonal storage regulating cycle. They are defined, identifying for each project:

- Minimum and maximum capacities;
- Energy storage capacity of the reservoirs;
- Energy available per period;
- Capital investment cost (for projects considered as expansion candidates);
- Fixed operating and maintenance (O & M) costs; and
- Plant life (for projects considered as expansion candidates).

The hydroelectric plants are assumed to be 100% reliable and have no associated cost for the water. The stochastic nature of the hydrology is treated by means of hydrological conditions (up to 5), each one defined by its probability of occurrence and the corresponding available capacity and energy of each hydro project in the given hydrocondition.

The cost of energy not served reflects the expected damages to the economy of the country or region under study when a certain amount of electric energy is not supplied. This cost is modelled in WASP through a quadratic function relating the incremental cost of the energy not served to the amount of energy not served. In theory at least, the cost of the energy not served would permit automatic definition of the adequate amount of reserve capacity in the power system.

In order to calculate the present-worth values of the cost components of Eq. (1.1), the present-worth factors used are evaluated assuming that the full capital investment for a plant added by the expansion plan are made at the beginning of the year in which it goes into service and that its salvage value is the credit at the horizon for the remaining economic life of the plant. Fuel inventory costs are treated as investment costs, by full credit is taken at the horizon (i.e. these costs are not depreciated). All the other costs (fuel, O&M, and energy not served) are assumed to occur in the middle of the corresponding year. These assumptions are illustrated in Figure 1.1.



Notes:

B_j	=	objective function (total cost) of the expansion plan
$CAPITAL_1$	=	sum of the investment costs of all units added in the first year of study
$OPERATING_1$	=	sum of all system operating costs (fuel, O&M, and energy not served) in the first year of study
SALVAGE	=	sum of the salvage values at horizon of all plants added during the study period
t_o	=	number of years between the reference date for discounting and the first year of study
T	=	length (in number of years) of the study period

Figure 1.1 Schematic Diagram of Cash Flows for an Expansion Program

According to the above, the cost components of B_j in expression (1.1) are calculated as follows:

(a) Capital investment cost and salvage values:

$$\bar{I}_{j,t} = (1+i)^{-t'} \cdot \sum [UI_k \cdot MW_k] \tag{1.9}$$

$$\bar{S}_{j,t} = (1+i)^{-T'} \cdot \sum [\delta_{k,t} \cdot UI_k \cdot MW_k] \tag{1.10}$$

where:

Σ	=	sum calculated considering all (thermal or hydro) units k added in year t by expansion plan j,
UI_k	=	capital investment cost of unit k, expressed in monetary units per MW,
MW_k	=	capacity of unit k in MW,
$\delta_{k,t}$	=	salvage value factor at the horizon for unit k,
i	=	discount rate,
t'	=	$t + t_0 - 1$
T'	=	$T + t_0$

and t, t_0, and T follow the same definitions given in Figure 1.1.

(b) Fuel costs:

$$\bar{F}_{j,t} = (1+i)^{-t'-0.5} \cdot \sum_{h=1}^{NHYD} [\alpha_h \cdot \psi_{j,t,h}] \tag{1.11}$$

where α_h is the probability of hydrocondition h, $\psi_{j,t,h}$ the total fuel costs (sum of fuel costs for thermal and nuclear units) for each hydrocondition, and NHYD represents the total number of hydroconditions defined.

The energy generated by each unit in the system is calculated by probabilistic simulation. In this approach the forced outages of thermal units are convolved with the inverted load duration curve and, consequently, the effect of unexpected outages of thermal units upon other units is accounted for in a probabilistic way. The net effect is an increase of peaking units generation in order to make up the reduction of base units generation due to scheduled outages for maintenance and unit failures. Thus, increasing the expected generating costs of the system. Obviously the fuel cost of a particular block of energy generated by a unit is calculated as the amount of generation times the unit fuel cost times its heat rate.

If for a certain fuel type used by some thermal power plants, the amount of fuel that can be used is subject to specified constraints (fuel limitations), the generation of these plants is verified by the program, and if it exceeds the specified limit, a substitution process is undertaken by the program, whereby the generation of the associated thermal plants is reduced in an iterative manner until the fuel limits are respected. As an option, the user can define an alternative fuel type and an associated thermal plant that can make up for the reduction of the generation by limited fuel type plants.

(c) Fuel inventory cost:

$$\overline{L}_{j,t} = [(1+i)^{-t'} - (1+i)^{-T'}] \cdot \sum [UFIC_{kt} \cdot MW_{kt}] \tag{1.12}$$

where the indicated sum(Σ) is calculated over all thermal units kt added to the system in year t, and $UFIC_{kt}$ is the unitary full inventory cost of unit kt (in monetary units per MW).

(d) Operation and maintenance costs:

$$\overline{M}_{j,t} = (1+i)^{-t'-0.5} \cdot \sum [UFO\&M_{\ell} \cdot MW_{\ell} + UVO\&M_{\ell} \cdot G_{\ell,t}] \tag{1.13}$$

where:

Σ = sum over all units (ℓ) existing in the system in year t,

$OFO\&M_{\ell}$ = unitary fixed O&M cost of unit ℓ, expressed in monetary units per MW-year,

$OVO\&M_{\ell}$ = unitary variable O&M cost of unit ℓ, expressed in monetary units per kWh,

$G_{\ell,t}$ = expected generation of unit ℓ in year t, in kWh, which is calculated as the sum of the energy generated by the unit in each hydrocondition weighted by the probabilities of the hydroconditions.

(e) Energy not served costs:

$$\overline{O}_{j,t} = (1+i)^{-t'-0.5} \cdot \sum_{h=1}^{NHYD} [a + \frac{b}{2} \cdot (\frac{N_{t,h}}{EA_t}) + \frac{c}{3} \cdot (\frac{N_{t,h}}{EA_t})^2] \cdot N_{t,h} \cdot \alpha_h \tag{1.14}$$

where a, b, and c are constants (\$/kWh) given as input data, and:

$N_{t,h}$ = amount of energy not served (kWh) for the hydrocondition h in year t,

EA_t = energy demand (kWh) of the system in year t.

As stated in the introduction of Section 1.2, the cost components of the objective function (B_j) are presented in expressions (1.9) to (1.14) in a simplified form. In fact, the above expressions have been derived considering each expansion candidate as one single unit (hydro, thermal or nuclear) whereas in WASP-III Plus the expansion candidates are defined as plants and the number of units (or projects) from each plant to be added in each year is to be determined by the WASP study. Besides, WASP-III Plus: - combines capital investment cost and associated salvage value with the fuel inventory cost and its salvage value; - aggregates operating costs by types of (fuel) plant; - separates all expenditures (capital or operating) into local and foreign components; - permits escalating all costs over the study period; - has provisions to apply different discount rates and escalation ratios for each year, for the local and foreign cost components, and for the various types of plants defined for the case study, and to change the constants (a, b, and c) for evaluating the energy not served cost from year to year. Finally, the units of the different variables in Eqs. (1.9) to (1.14) and the variable names used in the above discussion do not correspond to the units and terminology used in the WASP modules. Table 1.1 summarizes the capabilities of the WASP-III Plus computer code and Appendix D describes the actual expressions included in the program.

Table 1.1 Principal Capabilities of WASP-III Plus

30	Years of study period
12	Periods per year.
360	Load duration curves (one for each period and for each year).
100	Cosine terms in the Fourier representation of the inverted load duration curve of each period.
12	Types of plants grouped by "fuel" types of which:
	10 types of thermal plants; and
	2 composite hydroelectric plants.
58	Thermal plants of multiple units. This limit corresponds to the total number of plants in the Fixed System plus those thermal plants considered for system expansion which are described in the Variable System.
14	Types of plants candidates for system expansion, of which:
	12 types of thermal plants; and
	2 hydroelectric plant types, each one composed of up to 30 projects.
5	Hydrological conditions (hydrological years).
300	Configurations of the system in any given year (in one single iteration involving sequential runs of modules 4 to 6).
3000	System configurations in all the study period (in one single iteration involving sequential runs of modules 4 to 6).
60 (2x30)	Discount rates on capital investment costs (one for domestic and one for foreign capital costs each year). These discount rates can be specified as single values to be applied, respectively, to all domestic and to all foreign capital investment costs or, optionally, as individual values for each plant candidate for system expansion (total 14: 12 thermal, 2 hydro)[1]
60 (2x30)	Discount rates on operating costs (one for domestic and one for foreign operating costs each year). These discount rates can be specified as single values to be applied to all domestic and all foreign operating costs, respectively, or, optionally, as individual values for each "fuel" type (total 12: 10 thermal and 2 hydro) and for the cost of the energy not served (ENS)[1]
840 (2x14x30)	Escalation ratios on capital investment costs per year (one for domestic, one for foreign capital investment costs of each expansion candidate).
780 (2x13x30)	Escalation ratios on operating costs per year (one for domestic, one for foreign operating costs of each "fuel" type (12) and of the cost of ENS).

[1] Individual discount rates on capital investment costs per candidate plant and operating costs per fuel type and ENS cost are included for flexibility, though these options are not realistic for electric system expansion studies.

1.2.2 Dimensions of the WASP-III Plus computer program

Table 1.1 provides a listing of the more important capabilities of the WASP-III Plus code. Other characteristics and limitations of second order of importance are explained in the description of the various modules of the program along the chapters of this manual. Section 8.7 (for DYNPRO) and Section 9.5 (for REPROBAT) describe special restrictions applicable to these modules.

1.3 Description of WASP-III Plus Modules

Figure 1.2 shows a simplified flow chart of WASP-III Plus illustrating the flow of information from the various WASP modules and associated data files. The numbering of the first three modules is arbitrary, since they can be executed independently of each other in any order. For convenience, however, these three modules have been given numbers in this manual. Modules 4, 5, and 6, however, must be executed in order, after execution of Modules 1, 2, and 3. There is also a seventh module, REPROBAT, which produces a summary report of the first six modules.

Module 1, LOADSY (Load System Description), processes information describing period peak loads and load duration curves for the power system over the study period.

Module 2, FIXSYS (Fixed System Description), processes information describing the existing generation system and any pre-determined additions or retirements.

Module 3, VARSYS (Variable System Description), processes information describing the various generating plants which are to be considered as candidates for expanding the generation system.

Module 4, CONGEN (Configuration Generator), calculates all possible year-to-year combinations of expansion candidate additions which satisfy certain input constraints and which in combination with the fixed system can satisfy the loads. CONGEN also calculates the basic economic loading order of the combined list of FIXSYS and VARSYS plants.

Module 5, MERSIM (Merge and Simulate), considers all configurations put forward by CONGEN and uses probabilistic simulation of system operation to calculate the associated production costs, energy not served and system reliability for each configuration. In the process, energy limitations imposed to certain fuel types are also taken into account. The module also calculates plant loading orders if desired, and makes use of all previously simulated configurations. MERSIM can also be used to simulate the system operation for the best solution provided by the current DYNPRO run and in this mode of operation is called REMERSIM. In this mode of operation detailed results of the simulation are stored on a file that can be used for graphical representation of the results.

Module 6, DYNPRO (Dynamic Programming Optimization), determines the optimum expansion plan based on previously derived operating costs along with input information on capital costs, energy not served cost and economic parameters and reliability criteria.

Module 7, REPROBAT (Report Writer of WASP in a Batched Environment), writes a report summarizing the total or partial results for the optimum or near optimum power system expansion plan and for fixed expansion schedules. Some results of the calculations performed by REPROBAT are also stored on the file that can be used for graphical representation of the WASP results (see REMERSIM above).

1.4 File handling

WASP uses magnetic disc files to pass information from one module to another and to save information from one simulation to another, thus avoiding waste of computer time on repetition of calculations previously done. These files are created and identified as follows:

LOADSY creates a file, LOADDUCU, which is used subsequently by CONGEN, MERSIM, and REPROBAT.

FIXSYS creates a file, FIXPLANT, which is used subsequently by CONGEN, MERSIM, and REPROBAT.

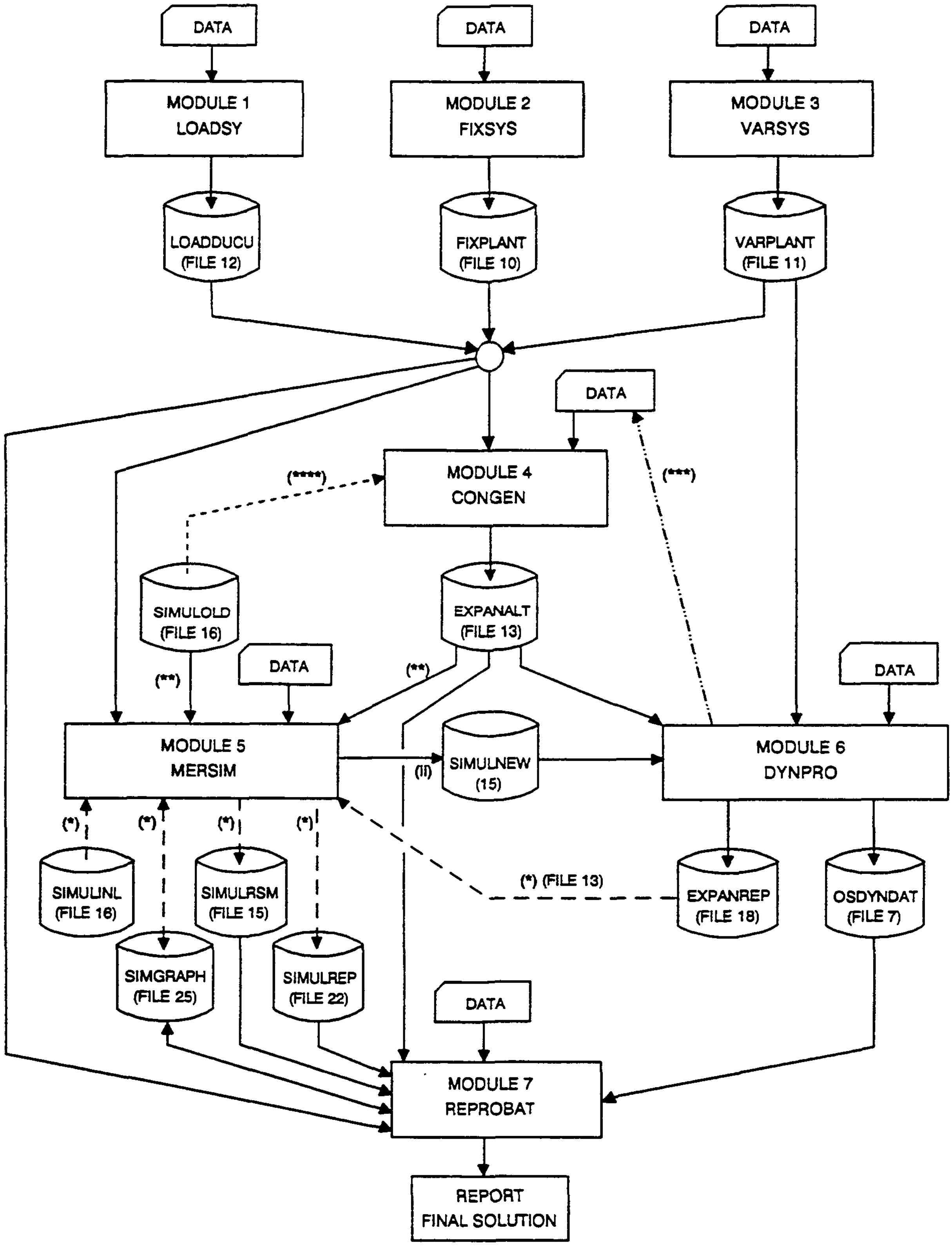
VARSYS creates a file, VARPLANT, used by CONGEN, MERSIM, DYNPRO, and REPROBAT.

CONGEN creates a file, EXPANALT, also used by CONGEN, MERSIM, DYNPRO, and REPROBAT; and uses a scratch file as a temporary work file. It also uses the current SIMULOLD file (see MERSIM below) to verify which configurations generated in the run have already been simulated in previous iterations.

MERSIM simulates system operation for any configuration read from the current EXPANALT file and that is not already listed on the SIMULOLD file created by the previous MERSIM runs (if any), and merges the new results with the old ones to produce a SIMULNEW file containing: annual operating costs, amount of energy not served and loss-of-load probability for all configurations simulated to date. This SIMULNEW file is used by DYNPRO as input, as well as by the next MERSIM run after it has been renamed as SIMULOLD. A SIMULINL file is created as a "null" file to use in place of SIMULOLD for the first MERSIM run of a case study. When working in the resimulation mode (i.e. REMERSIM), the configurations are read from the EXPANREP file instead of EXPANALT, a SIMULRSM file is used in place of SIMULNEW, and a SIMULREP is created for later use by REPROBAT. In addition, a SIMGRAPH file is created by REMERSIM to contain the detailed results of the simulation, written in a manner that facilitates retrieval of this information for graphic purposes. Furthermore, the creation of a SIMULREC file is recommended for use in recovering the results of an incomplete MERSIM run and for enlarging the simulation files.

DYNPRO considers all configurations currently on the EXPANALT file and the respective operating costs, energy not served and reliability on the SIMULNEW file, together with information on the VARPLANT file. DYNPRO has provisions for creating two output files for use by other WASP modules, files EXPANREP and OSDYNDAT; EXPANREP is the equivalent of EXPANALT except that it contains only the configurations of the optimal solution. This file is used instead of EXPANALT in a MERSIM run after DYNPRO to get a detailed simulation output for the optimal solution (see REMERSIM above). OSDYNDAT is used as input file by REPROBAT.

REPROBAT uses the files from the other six WASP modules to write a report summarizing the results for the optimal solution. It also uses three scratch files as temporary work files. The results of the calculations of cash flows of capital investment costs of the power plants included in the WASP solution under report are written on the SIMGRAPH file.



(*) FOR RESIMULATION OF BEST SOLUTION ONLY
(**) OMMIT FOR RESIMULATION OF BEST SOLUTION
(***) ITERATION PATTERN IF BEST SOLUTION STILL CONSTRAINED
(****) FOR CHECK OF CONFIGURATIONS ALREADY SIMULATED

Figure 1.2 Simplified Flow Chart of the WASP-III Plus Computer Code

REFERENCES

[1] OAK RIDGE NATIONAL LABORATORY, Wien Automatic System Planning Package (WASP): An Electric Expansion Utility Optimal Generation Expansion Planning Computer Code, Rep. ORNL-4925 (1974).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Market Survey for Nuclear Power in Developing Countries: General report, IAEA , Vienna (1973).

[3] COVARRUBIAS, A.J., HEINRICH, P. MOLINA, P.E., "Development of the WASP-III at the International Atomic Energy Agency", in Proc. Conf. Electric Generation System Expansion Analysis (WASP Conf.), Ohio State University, Columbus (1981).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Model for Analysis of Energy Demand (MAED): Users' Manual for MAED-1 Version, IAEA-TECDOC-386, Vienna (1986).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, VALORAGUA - A Model for the Optimal Operating Strategy of Mixed Hydrothermal Generating Systems, Users' Manual for the Mainframe Computer Version, IAEA Computer Manual Series No. 4, Vienna (1992).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, WASP-III Version for IBM-PC (ADB Version), IAEA Internal Document, Vienna (1987).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, MAED-1 Version for IBM-PC, IAEA Internal Document, Vienna (1988).

[8] ARGONNE NATIONAL LABORATORY, Energy and Power Evaluation Program (ENPEP), Documentation and User's Manual, ANL/EES-TM-317, Argonne (1987).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, PC-VALORAGUA Users' Guide - Microcomputer Version of the VALORAGUA Program for the Optimal Operating Strategy of Mixed Hydrothermal Generating Systems, IAEA Computer Manual Series No. 5, Vienna (1992).

CHAPTER 2

EXECUTION OF WASP-III PLUS

This chapter describes the steps required to initialize, catalog and delete the various files used by WASP-III Plus, along with the data cards, formats, etc., needed to execute the various modules. Execution of these activities depends on the operating system available at the user's computer facilities. For the purposes of the following discussion, these activities will be described based on the computer and operating system available at the IAEA. This consists of an IBM 9121/320 computer, using as operating system the MVS/ESA (Multiple Virtual Storage/Enterprise System Architecture) and under this, TSO (Time Sharing Option) is running. In addition, handling of catalogs and data sets is performed by ASM2 (Automatic Storage Management). The FORTRAN compiler commonly used is FORTVS (Release 4.1) which has also been used to compile the various modules of WASP-III Plus.

2.1 Description of Card Deck

The execution of the WASP-III Plus computer program (as performed at the IAEA) requires a batch file, containing certain instructions distributed among lines (or records) using the specific system language. Each line can be interpreted as a "card" and the complete batch as a "deck" of cards. These terms "card" and "deck of cards" are used throughout the manual for facilitating the description that follows.

The deck of cards required to execute WASP-III Plus consists of: Job cards, Control cards, Data cards, and End of job card. Data cards are standard 80-columns computer cards while all other cards depend on installation standards. All these cards must be in the proper sequence for the program to operate. The following paragraphs describe how these decks are prepared.

2.2 Job Cards

Job cards identifying the computer run and describing the type of run in terms of accounting information, user identification and estimated time are necessary since the computer automatically assigns a priority to each job, and schedules the running of the job accordingly. Job cards should be set up by the WASP system analyst since these are constantly being changed as the result of computer operational changes.

2.3 Control Cards

Control cards are used to identify the particular executable module to be executed and its location in the computer installation, as well as the location of the input and output files that are required for the particular run.

2.3.1 Initializing, Cataloguing and Deleting Files

For each study to be carried out using WASP-III Plus, it is necessary to initialize and allocate some of the files previously described in Section 1.4. The control cards for doing this are shown in Figure 2.1 for a WASP-III Plus sample problem, "CASE93" on private disc.

```
//XIHINIT3 JOB (BB,T),A2432-HEINRICH,CLASS=I
//INITIAL1 EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=A
//SYSIN   DD DUMMY
//SYSUT1 DD DUMMY,DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436)
//SYSUT2   DD DSN=XBBP.CASE93.SIMULOLD,
//      SPACE=(TRK,(1,5)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//INITIAL2 EXEC PGM=IEBGENER
//SYSPRINT DD SYSOUT=A
//SYSIN   DD DUMMY
//SYSUT1 DD DUMMY,DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436)
//SYSUT2   DD DSN=XBBP.CASE93.SIMULINL,
//      SPACE=(TRK,(1,5)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//INITIAL3 EXEC PGM=DIRACC
//STEPLIB DD DSN=XBBT.LOADLIB.TEST,DISP=SHR
//FT06F001 DD SYSOUT=A
//FT25F001 DD DSN=XBBP.CASE93.SIMGRAPH,
//      SPACE=(450,(250,5)),DCB=(RECFM=F,BLKSIZE=450,DSORG=DA),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//ALLOCATE EXEC PGM=IEFBR14
//FT10F001 DD DSN=XBBP.CASE93.FIXPLANT,
//      SPACE=(TRK,(1,2)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,
//      SPACE=(TRK,(1,2)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT12F001 DD DSN=XBBP.CASE93.LOADDUCU,
//      SPACE=(TRK,(1,2)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT13F001 DD DSN=XBBP.CASE93.EXPANALT,
//      SPACE=(TRK,(1,2)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT15F001 DD DSN=XBBP.CASE93.SIMULNEW,
//      SPACE=(TRK,(1,5)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT16F001 DD DSN=XBBP.CASE93.SIMULRSM,
//      SPACE=(TRK,(1,1)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT17F001 DD DSN=XBBP.CASE93.SIMULREC,
//      SPACE=(TRK,(1,5)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT18F001 DD DSN=XBBP.CASE93.EXPANREP,
//      SPACE=(TRK,(1,1)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT07F001 DD DSN=XBBP.CASE93.OSDYNDAT,
//      SPACE=(TRK,(1,1)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
//FT22F001 DD DSN=XBBP.CASE93.SIMULREP,
//      SPACE=(TRK,(1,1)),DCB=(RECFM=VSB,BLKSIZE=9440,LRECL=9436),
//      UNIT=DISK,DISP=(NEW,CATLG,DELETE)
```

Figure 2.1 WASP-III Plus Initialization and Cataloguing of Files

It can be seen in Figure 2.1 that the SIMULOLD and SIMULINL files are "initialized" (opened and closed), and an end of file (EOF) mark is written. These files can be merged with SIMULNEW or SIMULRSM without contributing any information to them. In addition, the SIMGRAPH file, a direct access file, is formatted, while the other files, FIXPLANT, VARPLANT, LOADDUCU, EXPANALT, EXPANREP, SIMULNEW, SIMULREC, SIMULREP, SIMULRSM, and OSDYNDAT, are "allocated," i.e. they are prepared to be written on before they are read (at this stage they will contain no information). At IAEA, names for WASP case studies must be made up of an initial alphabetic character, followed by up to five characters which can be alphabetic or numeric (this should be checked with the WASP system analyst). Examples of names for case studies are: HUNGAR, INDLOW, TURK-1, PERU95, CASE93, etc.

Sometimes it is necessary or desirable to delete files, and the control cards for doing this are shown in Figure 2.2.

```
//DELETE EXEC PGM=IEFBR14
//FT07F001 DD DSN=XBBP.CASE93.OSDYNDAT,
//      DISP=(OLD,DELETE)
//FT10F001 DD DSN=XBBP.CASE93.FIXPLANT,
//      DISP=(OLD,DELETE)
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,
//      DISP=(OLD,DELETE)
//FT12F001 DD DSN=XBBP.CASE93.LOADDUCU,
//      DISP=(OLD,DELETE)
//FT13F001 DD DSN=XBBP.CASE93.EXPANALT,
//      DISP=(OLD,DELETE)
//FT14F001 DD DSN=XBBP.CASE93.SIMULRSM,
//      DISP=(OLD,DELETE)
//FT15F001 DD DSN=XBBP.CASE93.SIMULNEW,
//      DISP=(OLD,DELETE)
//FT16F001 DD DSN=XBBP.CASE93.SIMULOLD,
//      DISP=(OLD,DELETE)
//FT17F001 DD DSN=XBBP.CASE93.SIMULREC,
//      DISP=(OLD,DELETE)
//FT18F001 DD DSN=XBBP.CASE93.EXPANREP,
//      DISP=(OLD,DELETE)
//FT22F001 DD DSN=XBBP.CASE93.SIMULREP,
//      DISP=(OLD,DELETE)
//FT25F001 DD DSN=XBBP.CASE93.SIMGRAPH,
//      DISP=(OLD,DELETE)
```

Figure 2.2 WASP-III Plus Deletion of Files

2.3.2 Execution of the WASP-III Plus Modules

Figure 2.3 lists in two separate pages the control cards required for standard execution of the seven WASP-III Plus modules: page 1 for modules LOADSY through MERSIM, and page 2 for modules DYNPRO through REPROBAT. At the end of the figure, the control cards for REMERSIM (MERSIM working in resimulation mode) and for the RENAME step are also listed for completeness of this information.

The first two cards in each case identify the particular WASP module on the private disc. These are followed by a card identifying the location of the input data set to be used in the run, with the exception of the RENAME step for which no input data is necessary. Next, the control cards identify the printer output units. The use of "SYSOUT=A" for files 6 and 8 results in standard printed output. Special request for non-standard output (e.g. on plain white paper) should be arranged through the WASP system analyst who will supply a different card to substitute for the SYSOUT=A card and who will advise on the proper job control cards so that the computer operator knows what to expect. Because of the large amount of information developed in modules 5 and 6, the output data are printed on separate print files (3 for MERSIM and REMERSIM and 2 for DYNPRO), thus more than one SYSOUT cards are required by these modules.

```
//LOADSY   EXEC PGM=LOADSY
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(LOADSY),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT12F001 DD DSN=XBBP.CASE93.LOADDUCU,DISP=OLD


//FIXSYS   EXEC PGM=FIXSYS
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(FIXSYS),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT10F001 DD DSN=XBBP.CASE93.FIXPLANT,DISP=OLD


//VARSYS   EXEC PGM=VARSYS
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(VARSYS),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,DISP=OLD


//CONGEN   EXEC PGM=CONGEN
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(CONGEN),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT10F001 DD DSN=XBBP.CASE93.FIXPLANT,DISP=OLD
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,DISP=OLD
//FT12F001 DD DSN=XBBP.CASE93.LOADDUCU,DISP=OLD
//FT13F001 DD DSN=XBBP.CASE93.EXPANALT,DISP=OLD
//FT16F001 DD DSN=XBBP.CASE93.SIMULOLD,DISP=OLD
//FT23F001 DD DSN=&&A,DISP=(,DELETE),SPACE=(TRK,(4,1)),
//        UNIT=DISK,DCB=(RECFM=VBS,LRECL=9436,BLKSIZE=9440)


//RENAME EXEC PGM=IEHPROGM
//SYSPRINT DD SYSOUT=A
//DD1      DD VOL=(PRIVATE,RETAIN,SER=DISK01),DISP=OLD,UNIT=DISK
//SYSIN    DD *
  RENAME   DSNAME=XBBP.CASE93.SIMULOLD,                                   C
               VOL=3390=DISK01,NEWNAME=DEAD
  RENAME   DSNAME=XBBP.CASE93.SIMULNEW,                                   C
               VOL=3390=DISK01,                                           C
               NEWNAME=XBBP.CASE93.SIMULOLD
  RENAME  NEWNAME=XBBP.CASE93.SIMULNEW,                                   C
               VOL=3390=DISK01,DSNAME=DEAD


//MERSIM EXEC PGM=MERSIM
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(MERSIM),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT08F001 DD SYSOUT=A,
//            DCB=(LRECL=133,RECFM=FBA,BLKSIZE=1729)
//FT09F001 DD SYSOUT=A,
//            DCB=(LRECL=133,RECFM=FBA,BLKSIZE=1729)
//FT10F001 DD DSN=XBBP.CASE93.FIXPLANT,DISP=OLD
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,DISP=OLD
//FT12F001 DD DSN=XBBP.CASE93.LOADDUCU,DISP=OLD
//FT13F001 DD DSN=XBBP.CASE93.EXPANALT,DISP=OLD
//FT15F001 DD DSN=XBBP.CASE93.SIMULNEW,DISP=OLD
//FT16F001 DD DSN=XBBP.CASE93.SIMULOLD,DISP=OLD
//FT25F001 DD DSN=XBBP.CASE93.SIMGRAPH,DISP=OLD
```

Figure 2.3 (page 1) Control Cards for Execution of the WASP-III Plus Modules

```
//DYNPRO EXEC PGM=DYNPRO
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(DYNPRO),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT08F001 DD SYSOUT=A,
//             DCB=(LRECL=133,RECFM=FBA,BLKSIZE=1729)
//FT09F001 DD DUMMY
//FT07F001 DD DSN=XBBP.CASE93.OSDYNDAT,DISP=OLD
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,DISP=OLD
//FT13F001 DD DSN=XBBP.CASE93.EXPANALT,DISP=OLD
//FT15F001 DD DSN=XBBP.CASE93.SIMULNEW,DISP=OLD
//FT18F001 DD DSN=XBBP.CASE93.EXPANREP,DISP=OLD


//REPROBAT EXEC PGM=REPROBAT
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(REPROB),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT08F001 DD DUMMY
//FT07F001 DD DSN=XBBP.CASE93.OSDYNDAT,DISP=OLD
//FT10F001 DD DSN=XBBP.CASE93.FIXPLANT,DISP=OLD
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,DISP=OLD
//FT12F001 DD DSN=XBBP.CASE93.LOADDUCU,DISP=OLD
//FT13F001 DD DSN=XBBP.CASE93.EXPANALT,DISP=OLD
//FT15F001 DD DSN=XBBP.CASE93.SIMULRSM,DISP=OLD
//FT19F001 DD UNIT=DISK,SPACE=(TRK,(1,1)),
//             DCB=(RECFM=FBA,LRECL=132,BLKSIZE=3960)
//FT20F001 DD UNIT=DISK,SPACE=(TRK,(1,1)),
//             DCB=(RECFM=FBA,LRECL=132,BLKSIZE=3960)
//FT21F001 DD UNIT=DISK,SPACE=(TRK,(5,5)),
//             DCB=(RECFM=VSB,LRECL=150,BLKSIZE=150)
//FT23F001 DD UNIT=DISK,SPACE=(TRK,(5,5)),
//             DCB=(RECFM=VSB,LRECL=150,BLKSIZE=150)
//FT22F001 DD DSN=XBBP.CASE93.SIMULREP,DISP=OLD
//FT25F001 DD DSN=XBBP.CASE93.SIMGRAPH,DISP=OLD


//REMERSIM EXEC PGM=MERSIM
//STEPLIB DD DSN=XBBP.LOADLIB.TEST,DISP=SHR
//FT05F001 DD DSN=XBBP.WASP93.DATA(REMERS),DISP=SHR
//FT06F001 DD SYSOUT=A
//FT08F001 DD SYSOUT=A,
//             DCB=(LRECL=133,RECFM=FBA,BLKSIZE=1729)
//FT09F001 DD SYSOUT=A,
//             DCB=(LRECL=133,RECFM=FBA,BLKSIZE=1729)
//FT10F001 DD DSN=XBBP.CASE93.FIXPLANT,DISP=OLD
//FT11F001 DD DSN=XBBP.CASE93.VARPLANT,DISP=OLD
//FT12F001 DD DSN=XBBP.CASE93.LOADDUCU,DISP=OLD
//FT13F001 DD DSN=XBBP.CASE93.EXPANREP,DISP=OLD
//FT15F001 DD DSN=XBBP.CASE93.SIMULRSM,DISP=OLD
//FT16F001 DD DSN=XBBP.NEUTER.SIMULINL,DISP=OLD
//FT22F001 DD DSN=XBBP.CASE93.SIMULREP,DISP=OLD
//FT25F001 DD DSN=XBBP.CASE93.SIMGRAPH,DISP=OLD
```

Figure 2.3 (page 2) Control Cards for Execution of the WASP-III Plus Modules

The control cards following the SYSOUT cards identify in each case, the files to be used for writing on, or reading from, information by the respective module. Again, owing to the large amount of information to be handled by modules 4 and 7 during their execution, some scratch fields (1 for CONGEN and 3 for REPROBAT) are used as temporary work files by these modules. Each block shown in Fig. 2.3 represents an independent step that has to be completed with the necessary Job card and End of Job card (see Section 2.5). It must be emphasized that except for the case name, everything on the control cards should be exactly as shown in Figure 2.3, including commas and periods.

At IAEA, catalogued procedures have been implemented for executing the WASP modules. Appendix A describes the main features of these procedures, along with the control cards required to execute the modules at the IAEA. The runs for the sample problem developed for this manual (CASE93) were carried out using the control cards shown in Appendix A. In the following sections, however, execution of the various WASP modules will be described according to the control cards of Fig. 2.3 as they are believed to provide a better understanding of the different input/output files used by each WASP module.

2.4 Data Cards

The data cards for each module will be discussed one at a time until all types have been covered. The format of the data is very important, as the machine will reject or misinterpret input data which are not presented in the form specified. The format specifies both, the input information and the column numbers (i.e. the "field") in which it must appear.

The "I" format specifies an integer number (e.g. 4 or 1975); no decimal point is allowed. It is necessary that the integer appear at the right-hand side of its field, i.e., it is "right-adjusted." Any blanks to the right of a number in the field will be interpreted by the computer as zeroes, e.g. a "5" punched in the third column (from left to right) of a four-column field will be interpreted as "50."

The "F" format specifies a floating point decimal number. Generally speaking, the decimal point should always be included in the field, even if there are no numbers to the right of the decimal point. This decimal point can appear anywhere in the field and it is not necessary to adjust a decimal number to the right of the field. A number which is actually an integer can be entered in an "F" field but the decimal point must be placed at its end (e.g. 4. or 1975.) and it will be handled by the computer as a decimal number.

The "A" format (Alphanumeric) specifies any combination of letters and digits; special symbols, such as asterisk [*], hyphen [-], dollar [$], etc., can also be included in this type of format with the only restriction (for the WASP code) that the first character cannot be a number.

When discussing the data cards used in each module, reference will be made to "card number" and "card type." Since some types of cards, such as index cards, may occur more than once in the deck, it is necessary to identify not only the type of card used in each case but also its position in the deck. Index cards are used to control the flow of certain input data and to identify what type of card follows. They are given as an integer number starting from 1 with the maximum number varying from module to module.

2.5 End of Job Card

The End-of-Job card is the last one to appear in the card deck. If more than one WASP module is to be run in a single job (i.e. using only one job card), the decks for the various modules would be placed one behind the other (in the same order as they are wanted to be run) with the end-of-job card appearing only once, at the end of the last deck. In other words, everything between the job card and the end-of-job card is one single "job" even though more than one module might be involved.

CHAPTER 3

EXECUTION OF LOADSY

3.1 Control Cards

The first group of "cards" listed in Figure 2.3 are the LOADSY job control cards. The first two lines identify the LOADSY program. These are followed by one card specifying the location of the input data set used for the run. The use of the DD parameter "SYSOUT=A" on the fourth line results in standard LOADSY printed output. The "LOADDUCU" on the fifth line identifies the file as a load description file; the "CASE93" on this card is the name assigned to the particular LOADDUCU file being created by the sample problem (see Section 2.3 for name and examples). "CASE93" is used to label all files created by the various WASP-III modules for the sample problem. This is, however, a matter of convenience for identifying a study, but not a necessity.

Before making a LOADSY run under the user's case name for the first time, ask the WASP analyst to make the necessary initializing run to create the WASP files for the case name. Any subsequent LOADSY run using the same case name will cause the information filed under that case name to be replaced with that generated by the current run (i.e. the previous information will no longer be on the file).

3.2 Data Cards

Table 3.1 describes the data card types used in LOADSY, and shows the fields, formats, Fortran names and descriptions of each piece of information given as input.

The type-X and type-A data cards are used only once in LOADSY, as the first two data cards, and apply to all years of the study period. For each year, the first data card is a type-B card and the last one is a type-1 card with INDEX=1 indicating end of input data for the given year.

A type-1 with INDEX=2 (3 or 4) card tells the computer that the next card to be read is a card of type equal to the INDEX number. Thus, it is necessary that the proper sequence of data cards be used; otherwise, it will lead to wrong calculations or interruption of program execution and the printing of an error message (see Section B.1 of Appendix B). Each type-1 card with INDEX=2 (3 or 4) and the corresponding type-2 (3 or 4) card(s) will constitute a group. Some of these groups must be supplied for the first year of study and are used for subsequent years only if there is a change in information for the respective year.

The group of input lines involving one type-1 INDEX=2 and one (or two) type-2 cards give the peak loads of the periods expressed as the ratio of the period peak loads to the annual peak load given in the type-B card for the same year. Each time this group of cards is used in the LOADSY input data, the corresponding type-2 card (or cards) must contain the ratios for all periods, even if the values of the ratios for one or more periods do not change from the values applicable for the preceding year.

As indicated in Table 3.1, input data on load duration curves (LDC's) must be specified for each period into which the year has been sub-divided, at least for the first year of study and may be changed every year if necessary.

Input data on LDC's are prepared using the normalized load duration curve of the period, for which load magnitudes are expressed as fractions of the peak load of the period and the respective load duration values as fractions of the total hours of the period. Input data on normalized LDC for the periods may be expressed, either in the form of a Fifth order polynomial describing the shape of the curve for each period (type-3 cards), or in a discrete form by points (load magnitude and load duration) of the curve (type-4 cards). For a given case study these two options are mutually exclusive in the same year, i.e. if cards type-3 are used for a particular year, then type-4 cards should not be used and vice-versa. It is, nevertheless, permitted to change the LDC Input Option from year to year with the only restriction that each time a change of the option is made, the complete set of LDC's input information for all periods must be included in the deck. Section 11.2 advises on LDC Input Option use for a given case study.

If the Fifth-order polynomial option for LDC input data is chosen, then type-3 cards (preceded by one type-1 INDEX=3 card) are used to give the coefficients, a_n, of the polynomial approximating the normalized LDC for each period of the year. It may happen that these coefficients are identical for two or more periods; however, it is still necessary to have a separate card for each period.

If the period LDC's are to be input by points of the curve, then groups of type-1 INDEX=4, type-4 (-4a and -4b) cards are used to give the required information. The type-4 card indicates the number of periods (NP) and the index (IPER) of the periods for which LDC data are specified in the type-4a and type-4b cards that follow. For the first year in which the LDC point-by-point option is used, the value of NP on card type-4 must be equal to the value of NPER specified in card type-A and in this case the indices (IPER(I)) are not required since one card type-4a for each period must be included as input data and their ordering (1, 2, 3, ...) is automatically handled by LOADSY. For the next and subsequent years, NP will indicate the number of periods with new LDC information and IPER the index of the respective periods. A data card type-4a is needed for each period with new LDC data.

Each type-4a card will tell the computer the number of points (NPTS) of the LDC used as input data and either that these points are to be read (IO=0) from cards type-4b which follow, or that the LDC of this period is identical to the LDC of a preceding period IO (IO > 0). For this option to be valid, the value of IO must be less than the index of the current period (e.g. if current period = 3 then IO = 1 or 2) and the value of NPTS given in card type-4a for current period must be equal to NPTS of period IO (and no card type-4b follow). Finally, cards type-4b are used to specify the points of the normalized LDC of the period using one card per point, each one containing the load magnitude (LD) and load duration (DUR) as fractions of the period peak load and the total hours of the period. It is necessary that the first point on the curve be adjusted to the period peak load [LD(1) = 1.0, DUR(1) = 0.0] and the last point to the minimum load of the period [LD(NPTS) = minimum load and DUR(NPTS) = 1.0].

Regardless of the LDC input data option used, the order in which the curves for the different periods are given must be consistent with the ordering of the period peak load ratios on data card(s) type-2. Furthermore, the order must be consistent with the ordering of hydro data for each period described in Modules 2 and 3 or the inconsistency will be manifested as wrong answers in Module 5.

Certain input data are checked up by the program to make sure that the requested calculations for the run are within the capabilities of the program and that there are no inconsistencies between input information. These checks and the corresponding error messages are described in Section B.1 of Appendix B.

Table 3.1 (page 1) Types of data cards used in LOADSY

Card type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of the study which has to be centered in the given space (columns 30-31 are the center columns).
A	1-4	I	NPER	Number of periods per year (maximum 12).
	5-8	I	NOCOF	Number of cosine terms to be used in the Fourier approximation to the inverted load duration curve (100 maximum, 50 recommended).
	9-12	I	IOPT	Printout option. "0" (zero), default value, calls for normal output. "1" calls for extended output (equal to normal output but including, in addition, the Fourier coefficients calculated by the program each time a new set of LDC shapes is read in (from cards type-3 or type-4 depending on the LDC input option selected).
B	1-8	F	PKMW	Annual peak load (MW).
	9-14	I	JAHR	Year of PKMW.
1	1-4	I	INDEX	Index number; "1" indicates end of input data for the current year; "2" indicates that one or two type-2 cards follow; "3" indicates that the periods load duration curve data are expressed in polynomial form and that one type-3 card follows for each period; "4" indicates that periods LDC data are expressed by points of the curve and that groups of cards type-4 (-4a and -4b) follow.
2	1-8	F	PUPPK	Ratio of the peak load in each period expressed as a fraction of the annual peak; up to 10 numbers per card; for 4 periods, for example, only the first four fields of one card type-2 would be used; for 11 or 12 periods per year use the first one or two fields of a second type-2 card. One of the ratios must be 1.0.
	9-16	F		
	17-24	F		
	.	.		
	.	.		
	73-80	F		

Table 3.1 (page 2) Types of data cards used in LOADSY

Card type	Columns	Format[1]	Fortran name	Information
3[2]	1-12	F	COEF	a_0 constant coefficient of the fifth-order polynomial representing the original load duration curve for the period (normally 1.0).
	13-24	F		a_1 coefficient of first order.
	25-36	F		a_2 coefficient of second order.
	37-48	F		a_3 coefficient of third order.
	49-60	F		a_4 coefficient of fourth order.
	61-72	F		a_5 coefficient of fifth order.
4	1-4	I	NP	Number of periods for which load duration curve data are changed from the preceding year. For the first year in which this card is used, NP must be equal to NPER on data card type-A.
	5-8	I	IPER(I)	Index of periods for which LDC data are to be changed from the applicable to preceding years. Leave blank for the first year in which this type of card is specified.
	9-12	I		
	.			
	.			
	49-52	I		
4a[3]	1-4	I	NPTS	Number of points representing the LDC of the period IPER (Maximum = 100).
	5-8	I	IO	Index option; if = 0 it indicates that data points for the LDC of period IPER follow on type-4b cards; if > 0, it indicates that the LDC of period IPER is identical to the LDC of a preceding period IO (where IO < IPER).
4b[4]	1-10	F	LD	Load magnitude (as a fraction of the period peak load) of each point on the LDC for period IPER.
	11-20	F	DUR	Load duration (as a fraction of total hours of the period) of LD. Note: Load points are to be given in descending order of load magnitudes. The first and last points must be adjusted, respectively, to the peak and minimum loads of the period, i.e.: LD (1) = peak load = 1.0; DUR(1) = 0.0 LD (NPTS) = min. load; DUR(NPTS) = 1.0

Notes to Table 3.1:

1 See Section 2.5 for format description
2 One card for each period (up to NPER) of the year
3 One card for each period (IPER) indicated in card type-4
4 One card for each point (up to NPTS) of LDC for period IPER

The input data to LOADSY are arranged in the following sequence:

a) For the first year:

- First card: One type-X card with the title of the study.

- Second card: One type-A card with the general information for the study.

- Third card: One type-B card with annual peak load and the first year of study.

- Next cards: One type-1 INDEX=2 card followed by one (or two) type-2 card(s) with the ratios of periods' peak load to the annual peak.

- Following cards: Depend on the option chosen for the LDC input data:

  If the polynomial option is chosen: one type-1 INDEX=3 card followed by one type-3 card per period with the coefficients of the polynomial describing the period's LDC.

  If the point by point option is chosen: one type-1 INDEX=4 card followed by one type-4 card with the number of periods (NP) of the year (NP must be = NPER on data card type-A); the rest of the card is left blank. Next, for each period, a group of one card type-4a and the necessary type-4b cards as follows: One card type-4a with the number of points (NPTS) of the LDC and a value of IO indicating what to do next. If IO=0, the card type-4a is followed by NPTS data cards type-4b with the points (load magnitude and load duration) of the LDC for the period. If IO>0, the LDC of current period is identical to the LDC of the preceding period IO.

b) Second and subsequent years:

- First card: One type-B card with the annual peak load and corresponding year.

- Group of one type-1 INDEX=2 and one (or two) type-2 cards if a change is to be introduced to the ratios of period peak load to the annual peak.

- For change in the LDC shape of one or more periods: The group of cards depend on the LDC input option chosen for the first year. If the polynomial option was selected: Group of one type-1 INDEX=3 and NPER type-3 cards (one type-3 card per period). If the point by point option was chosen: A group composed of one type-1 INDEX=4, followed by one type-4 card to specify how many periods (NP) are to be changed and the index (IPER(I)) of these periods. Next, for each of the above periods, one card type-4a with the values of NPTS and IO. If IO=0, the card type-4a is followed by NPTS cards type-4b with the points of the LDC for the period IPER. If IO > 0, the LDC for current period is identical to the one for a preceding period IO (i.e. no cards type-4b follow for period IPER considered)[1].

- Last card: One type-1 INDEX=1 card (end of the year).

---

[1] Note: the above explanation assumes that only one of the two options for definition of LDC input data is used in the run. Section 3.3 describes how the input data should be arranged when both options are used in the input data.

3.3 Input Data for the Sample Problem

Figure 3.1 shows a partial listing of the input data used to run LOADSY for the sample problem, CASE93. Some lines in Fig. 3.1 have been identified with a number or extra information (not read by the program and appearing to the right of the data fields in the respective card) in order to facilitate the discussion which follows.

The first line is the type-X card with the title of the study. This information is simply used by LOADSY for printing purposes, i.e. to produce the cover page identifying the output (see Section 3.4). The headings on the cover page have been centered to columns 30-31 of the field for the title. This "title" will not be compared to similar information given to any other module, so that in principle the title could be changed for any subsequent LOADSY run. However, it is advisable to maintain the same title along all runs of the study for reference purposes. For this reason, the title of the study of the sample problem is kept the same along all modules. Different titles could be used to identify additional studies for the same sample problem, e.g. assuming different growth rates for the electricity demand.

The second line of input data is the type-A card specifying the number of periods per year (4); the number of cosine terms to be considered in the Fourier series (50); and the printout option chosen (1). The third line is a type-B card specifying the annual peak load (6000. MW) and the year number for the first year of the study (1997). The fourth line is a type-1 INDEX-2 card indicating that a type-2 card follows giving the peak load of each period as a fraction of the annual peak.

In the sample problem, the Fifth order polynomial option has been chosen for input data on load duration curves for the periods. Thus, the 6th input line is a type-1 INDEX = 3 card indicating that it is followed by a type-3 card for each period (four in this case) with the coefficients of the polynomial representing the load duration curve of the period. Next line is a type-1 INDEX-1 card indicating that the input information for the year have been completed. It should be noticed that the information appearing to the right of this card is not read by the program and has been added here only for identification purposes.

The data for next year follow, including one type-B card with the annual peak load (6333. MW) and the year (1998), followed by a type-1 INDEX = 1 card indicating end of input information for the year. Similar groups are presented for the subsequent years (1999 and 2000). In this case, the data specified on type-2 and type-3 cards for the first year of study will apply to all these years. Again, the information appearing to the right of each type-1 INDEX = 1 has been added only for identification purposes.

The next Input line is a type-1 INDEX = 3 card indicating that type-3 cards will follow to specify new coefficients of the polynomial describing the load duration curves from this year on. In this case, the <u>new</u> polynomial coefficients on the type-3 cards are equal to the ones specified for the first year of study, so that there is no change of the load duration curves shape. In fact, these cards may have been omitted altogether, but they have been included to demonstrate the use of LOADSY data card type-3. The last type-3 card in this group is followed by a type-1 INDEX = 1 card indicating the end of input information for the current year, 2001 in this case.

The subsequent lines are groups of one type-B card and one type-1 INDEX = 1 card for the next years of study (2002, 2003 and 2004). Again, since no other cards are given for these years, all information on LDCs and period's peak load fractions will remain the same as in the preceding years.

```
CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL
4  50   1
6000.  1997
2
 0.90    0.87    0.93    1.00
3
   1.0000     -3.6000    16.6000     -36.800     36.0000     -12.800
   1.0000     -3.0000    13.8500     -31.200     31.0000     -11.200
   1.0000     -3.0000    13.8500     -31.200     31.0000     -11.200
   1.0000     -3.6000    16.6000     -36.800     36.0000     -12.800
 1           (END OF 1997)
 6333.0  1998
  1          (END OF 1998)
6725.65  1999
  1          (END OF 1999)
7109.01  2000
  1          (END OF 2000)
7496.45  2001
  3
   1.0000     -3.6000    16.6000     -36.800     36.0000     -12.800
   1.0000     -3.0000    13.8500     -31.200     31.0000     -11.200
   1.0000     -3.0000    13.8500     -31.200     31.0000     -11.200
   1.0000     -3.6000    16.6000     -36.800     36.0000     -12.800
  1          (END OF 2001)
7897.51  2002
  1          (END OF 2002)
8304.23  2003
  1          (END OF 2003)
8702.83  2004
  1          (END OF 2004)
9120.57  2005
  4
  4
 61
  1.0000    0.0000     1
  0.9964    0.0010     2
  0.9929    0.0020     3
  0.9893    0.0030     4
  0.9824    0.0050     5
  0.9656    0.0100     6
  0.9496    0.0150     7
  0.9344    0.0200     8
  0.9060    0.0300     9

     .         .         .
     .         .         .
     .         .         .

  0.4453    0.8600     54
  0.4429    0.8800     55
  0.4401    0.9000     56
  0.4364    0.9200     57
  0.4313    0.9400     58
  0.4240    0.9600     59
  0.4138    0.9800     60
  0.4000    1.0000     61
 60
  1.0000    0.0000     1
  0.9970    0.0010     2
  0.9941    0.0020     3
  0.9853    0.0050     4
  0.9714    0.0100     5
  0.9580    0.0150     6
  0.9453    0.0200     7
```

Figure 3.1 (page 1) WASP-III Plus - LOADSY Input Data for the Sample Problem

```
     0.9216     0.0300      8
     0.9002     0.0400      9

       .          .         .
       .          .         .
       .          .         .

     0.5035     0.8800     54
     0.4993     0.9000     55
     0.4940     0.9200     56
     0.4871     0.9400     57
     0.4780     0.9600     58
     0.4658     0.9800     59
     0.4500     1.0000     60
  60   2
  61   1
   1              (END OF 2005)
9558.36   2006
   1              (END OF 2006)
10017.2   2007
   1              (END OF 2007)
10488.    2008
   1              (END OF 2008)
10980.9   2009
   1              (END OF 2009)
11497.    2010
   1              (END OF 2010)
12025.9   2011
   1              (END OF 2011)
12579.1   2012
   1              (END OF 2012)
13157.7   2013
   1              (END OF 2013)
13749.8   2014
   1              (END OF 2014)
14368.5   2015
   1              (END OF 2015)
15015.1   2016
   1              (END OF 2016)
```

Figure 3.1 (page 2)   WASP-III Plus - LOADSY Input Data for the Sample Problem

The next group of input data lines correspond to the information for year 2005, starting with one type-B card, followed by one type-1 INDEX = 4 card to specify information on period's LDC using the point by point option[2].

The next line is the type-4 card with the number of periods for which new data for the period's LDC are to be specified in subsequent type-4a and type-4b cards. In this example, this card shows a 4 (note that this is equal to the total number of periods, since no previous information about period's LDC on a point-by-point basis has been specified). The rest of this line is left blank since LDC information must be given for each period.

[2] Note: This option is used here only for demonstration of the capabilities of LOADSY. In fact, the shape of the LDCs used to define the given points are identical to the respective ones used for the definition of the LDC as a fifth order polynomial used for 1997 and 2001. For a real case study, it is strongly recommended to use only one of the two options for LDC input in all years of study.)

The next input line is a type-4a card which shows in columns 3-4 that 61 points will be used to specify the LDC of the first period while the value of IO in column 8 (a blank in this case is read as a 0) indicates that these points are given next. Thus, this card is followed by 61 cards type-4b, each one with the load magnitude and load duration for each of the LDC points selected. Note that the first type-4b card must specify the peak load of the period (LD= 1.000 and DUR= 0.0) and the last one the minimum load of the period (LD= 0.4000 and DUR= 1.000). After the last LDC point, an additional type-4a card is used to specify the number of LDC points for the second period (60) and is followed by the 60 type-4b cards required for this period.

The type-4a card which follows corresponds to period 3. This gives a 2 in column 8, indicating that the LDC for this period is identical to the one specified for period 2. Therefore, the number of points describing the LDC which is given in this card (60) must be equal to the respective number of LDC points already specified for period 2. Similarly, the next line of input is a type-4a card indicating (in column 8) that the LDC for period 4 is identical to the LDC already specified for period 1. Thus, the same number of points (61) used for the LDC in period 1 is shown in this card.

In this example, the rest of the input data shown in Figure 3.1 consist of groups of one type-B card and one type-1 INDEX=1 card for the remaining years of the study, with no further changes of load duration curve shapes or period peak load factors.

3.4 Printout for the Sample Problem

Figure 3.2 illustrates the LOADSY printed output for the sample problem, CASE93, for several years of the study period (1997, 1998 and 2005). Page 1 of Fig. 3.2 corresponds to the cover page printed by LOADSY which is used to identify the run. It contains the title of the study, the number of periods defined for each year, hours in each period (in this case 2190 since the year has been sub-divided in four periods) and the number of coefficients of cosine terms used in the Fourier approximation of the inverted load duration curve (50).

Page 2 of Fig. 3.2 shows the Load System description for the first year of the study (1997). This starts with the yearly input data on annual peak load and the period peak loads as fractions of the annual peak. Next comes the load description for each period of the year, beginning with the input data for the polynomial coefficients representing the load duration curve of the period, followed by the calculated values for the period: 1) *peak and minimum load*, both in MW; 2) *energy demand* (in GWh); 3) *load factor* (in %). (Energy demand and load factor values are both given for each of the two approximations to the load duration curve); and 4) the *coefficients of the cosine terms of the Fourier approximation* to the inverted load curve (since in this case the printout option was set to 1). The constant coefficient, a_o, is given separately, and the other terms are given in groups of 10 per line. After the last period has been considered, the program prints an annual summary showing the values of the energy demand and the load factor as calculated for the polynomial (input) and Fourier (output) approximations to the load duration curve.

A similar output is given for each year of the study, but if no new LDC input data are given (on cards type-3 or type-4, depending on the option chosen), the Fourier coefficients for the periods are not printed again. Page 3 of Fig. 3.2 shows the Load System description for year 1998. An output similar to the one in page 3 will be printed for all years of the study if the printout option is set to zero ("0"), regardless of how many changes are introduced to the load duration curve shapes throughout the study period. For this reason, the use of printout option 0 is particularly advisable for WASP studies considering more than 3 periods per year and different load duration curve shapes throughout the study period, as a means to reduce the LOADSY printout.

Pages 4 and 5 of Fig. 3.2 show the (partial) results of the LOADSY run of CASE93 for year 2005, for which the point-by-option input option for LDC information has been used. At the beginning the annual peak load and year are listed, following by the data on period's LDC given as input. Only the first and last portions of the listing of these input data are shown on page 4 of the figure. Since the shape of the period's LDC has not been altered, the results on Page 5 for the Fourier Series coefficients and load factors are quite similar to the respective ones for the first year of study (Page 2), except for some minor differences, which are considered negligible. These differences, however, could have been avoided by defining a greater number of points for the period LDC's.

As mentioned in Section 3.2, certain input data are internally checked up by the program and in case of "error," they will cause interruption of the program execution, and printing of an "error message." If the message does not correspond to any of the LOADSY "error messages" described in Section B.1 of Appendix B, the user should ask the WASP analyst to interpret it. In some cases there is no error message but something is obviously wrong, such as a load factor greater than 100%. In such cases, correct the errors and consult the WASP analyst as necessary.

```
                    WASP  COMPUTER  PROGRAM  PACKAGE

                              LOADSY  MODULE

                               CASE  STUDY

        CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL


        **************************************************************
        *                                                            *
        *            NUMBER OF PERIODS PER YEAR =  4                 *
        *                                                            *
        *            HOURS IN EACH PERIOD =  2190.00                 *
        *                                                            *
        *      NUMBER OF COEFFICIENTS OF COSINE TERMS                *
        *      IN FOURIER APPROXIMATION OF THE L.D.C. =  50          *
        *                                                            *
        **************************************************************
```

Figure 3.2 (page 1)   LOADSY Printout for the Sample Problem. Cover Page

```
PEAK LOAD FOR YEAR **** 1997 **** IS :     6000.0 MW

PERIOD PEAK LOADS AS FRACTION OF ANNUAL PEAK LOAD :
  0.9000  0.8700  0.9300  1.0000

* * * * * * * * * * *  PERIOD  1  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000    -3.60000   16.60000  -36.80000   36.00000  -12.80000

PEAK LOAD :  5400.0 MW    MINIMUM LOAD :  2160.0 MW

                         ENERGY DEMAND         LOAD FACTOR
                            (GWH)                  (%)
INTEGRATION     :          7095.6                 60.00
FOURIER SERIES :           7095.9                 60.00

FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
        CONSTANT TERM -AOO- IS : 0.8571429
        COEFFICIENTS OF COSINE TERMS ARE :
 0.5914358  0.1190372 -0.1001728 -0.0637807  0.0009492  0.0119581  0.0060982  0.0110108  0.0129758 -0.0059543
-0.0213913 -0.0075546  0.0125758  0.0121567 -0.0000323 -0.0059782 -0.0036225 -0.0015444 -0.0012656  0.0026733
 0.0060277  0.0014792 -0.0051021 -0.0047674  0.0007260  0.0037691  0.0018198 -0.0005167 -0.0006604 -0.0011445
-0.0017181  0.0000382  0.0023317  0.0018547 -0.0009078 -0.0022762 -0.0006563  0.0010610  0.0008485  0.0002470
 0.0000868 -0.0003751 -0.0009006 -0.0004871  0.0007919  0.0012151 -0.0000165 -0.0010468 -0.0005940  0.0002522

* * * * * * * * * * *  PERIOD  2  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000    -3.00000   13.85000  -31.20000   31.00000  -11.20000

PEAK LOAD :  5220.0 MW    MINIMUM LOAD :  2349.0 MW

                         ENERGY DEMAND         LOAD FACTOR
                            (GWH)                  (%)
INTEGRATION     :          7430.7                 65.00
FOURIER SERIES :           7430.6                 65.00

FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
        CONSTANT TERM -AOO- IS : 0.8965517
        COEFFICIENTS OF COSINE TERMS ARE :
 0.6048022  0.0903804 -0.1289211 -0.0577438  0.0220275  0.0210460  0.0058457  0.0047452 -0.0004984 -0.0133372
-0.0116268  0.0087155  0.0162260 -0.0001980 -0.0116095 -0.0045610  0.0037899  0.0035679  0.0009932  0.0003636
-0.0009393 -0.0033337 -0.0016296  0.0035034  0.0035242 -0.0016724 -0.0033617 -0.0002237  0.0018436  0.0008765
-0.0003714 -0.0002772 -0.0002463 -0.0007512  0.0000587  0.0013826  0.0004761 -0.0012929 -0.0009248  0.0006832
 0.0010209 -0.0000234 -0.0006919 -0.0002653  0.0001136  0.0000525  0.0003344  0.0004346 -0.0003295 -0.0007820

* * * * * * * * * * *  PERIOD  3  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000    -3.00000   13.85000  -31.20000   31.00000  -11.20000

PEAK LOAD :  5580.0 MW    MINIMUM LOAD :  2511.0 MW

                         ENERGY DEMAND         LOAD FACTOR
                            (GWH)                  (%)
INTEGRATION     :          7943.1                 65.00
FOURIER SERIES :           7943.1                 65.00

FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
        CONSTANT TERM -AOO- IS : 0.8965517
        COEFFICIENTS OF COSINE TERMS ARE :
 0.6048022  0.0903804 -0.1289211 -0.0577438  0.0220275  0.0210460  0.0058457  0.0047452 -0.0004984 -0.0133372
-0.0116268  0.0087155  0.0162260 -0.0001980 -0.0116095 -0.0045610  0.0037899  0.0035679  0.0009932  0.0003636
-0.0009393 -0.0033337 -0.0016296  0.0035034  0.0035242 -0.0016724 -0.0033617 -0.0002237  0.0018436  0.0008765
-0.0003714 -0.0002772 -0.0002463 -0.0007512  0.0000587  0.0013826  0.0004761 -0.0012929 -0.0009248  0.0006832
 0.0010209 -0.0000234 -0.0006919 -0.0002653  0.0001136  0.0000525  0.0003344  0.0004346 -0.0003295 -0.0007820

* * * * * * * * * * *  PERIOD  4  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000    -3.60000   16.60000  -36.80000   36.00000  -12.80000

PEAK LOAD :  6000.0 MW    MINIMUM LOAD :  2400.0 MW

                         ENERGY DEMAND         LOAD FACTOR
                            (GWH)                  (%)
INTEGRATION     :          7884.0                 60.00
FOURIER SERIES :           7884.3                 60.00

FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
        CONSTANT TERM -AOO- IS : 0.8571429
        COEFFICIENTS OF COSINE TERMS ARE :
 0.5914358  0.1190372 -0.1001728 -0.0637807  0.0009492  0.0119581  0.0060982  0.0110108  0.0129758 -0.0059543
-0.0213913 -0.0075546  0.0125758  0.0121567 -0.0000323 -0.0059782 -0.0036225 -0.0015444 -0.0012656  0.0026733
 0.0060277  0.0014792 -0.0051021 -0.0047674  0.0007260  0.0037691  0.0018198 -0.0005167 -0.0006604 -0.0011445
-0.0017181  0.0000382  0.0023317  0.0018547 -0.0009078 -0.0022762 -0.0006563  0.0010610  0.0008485  0.0002470
 0.0000868 -0.0003751 -0.0009006 -0.0004871  0.0007919  0.0012151 -0.0000165 -0.0010468 -0.0005940  0.0002522

***************** ANNUAL  SUMMARY *****************

                         ENERGY DEMAND         LOAD FACTOR
                            (GWH)                  (%)
INTEGRATION     :         30353.4                 57.75
FOURIER SERIES :          30354.0                 57.75

* * * * * * * * * *  END OF DATA FOR YEAR  1997  * * * * * * * * * *
```

Figure 3.2 (page 2) LOADSY Printout for the Sample Problem. Load Description - 1997

```
PEAK LOAD FOR YEAR **** 1998 **** IS :     6333.0 MW

PERIOD PEAK LOADS AS FRACTION OF ANNUAL PEAK LOAD :
  0.9000  0.8700  0.9300  1.0000


* * * * * * * * * * *  PERIOD  1  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.60000   16.60000  -36.80000   36.00000  -12.80000

PEAK LOAD :  5699.7 MW    MINIMUM LOAD :  2279.9 MW

                          ENERGY DEMAND        LOAD FACTOR
                              (GWH)                (%)
INTEGRATION    :             7489.4              60.00
FOURIER SERIES :             7489.7              60.00


* * * * * * * * * * *  PERIOD  2  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.00000   13.85000  -31.20000   31.00000  -11.20000

PEAK LOAD :  5509.7 MW    MINIMUM LOAD :  2479.4 MW

                          ENERGY DEMAND        LOAD FACTOR
                              (GWH)                (%)
INTEGRATION    :             7843.1              65.00
FOURIER SERIES :             7843.0              65.00


* * * * * * * * * * *  PERIOD  3  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.00000   13.85000  -31.20000   31.00000  -11.20000

PEAK LOAD :  5889.7 MW    MINIMUM LOAD :  2650.4 MW

                          ENERGY DEMAND        LOAD FACTOR
                              (GWH)                (%)
INTEGRATION    :             8384.0              65.00
FOURIER SERIES :             8383.9              65.00


* * * * * * * * * * *  PERIOD  4  * * * * * * * * * * *
INPUT POLYNOMIAL COEFFICIENTS OF THE L.D.C ARE :
1.00000   -3.60000   16.60000  -36.80000   36.00000  -12.80000

PEAK LOAD :  6333.0 MW    MINIMUM LOAD :  2533.2 MW

                          ENERGY DEMAND        LOAD FACTOR
                              (GWH)                (%)
INTEGRATION    :             8321.6              60.00
FOURIER SERIES :             8321.9              60.00


***************** ANNUAL  SUMMARY *****************

                          ENERGY DEMAND        LOAD FACTOR
                              (GWH)                (%)
INTEGRATION    :            32038.0              57.75
FOURIER SERIES :            32038.6              57.75


* * * * * * * * * *  END OF DATA FOR YEAR  1998  * * * * * * * * * *
```

Figure 3.2 (page 3) LOADSY Printout for the Sample Problem. Load Description - 1998

PEAK LOAD FOR YEAR **** 2005 **** IS : 9120.6 MW

NUMBER OF PERIODS FOR WHICH DATA FOLLOW : 4
INDEX OF PERIODS TO BE CHANGED : 1 2 3 4

PERIOD 1 : 61 POINTS

LD	DUR
1.0000	0.0000
0.9964	0.0010
0.9929	0.0020
0.9893	0.0030
0.9824	0.0050
0.9656	0.0100
0.9496	0.0150
0.9344	0.0200
0.9060	0.0300
0.8803	0.0400
0.8571	0.0500
0.8363	0.0600
0.8176	0.0700
0.8008	0.0800
.	.
.	.
.	.
.	.
.	.
.	.
0.4628	0.7600
0.4578	0.7800
0.4537	0.8000
0.4504	0.8200
0.4477	0.8400
0.4453	0.8600
0.4429	0.8800
0.4401	0.9000
0.4364	0.9200
0.4313	0.9400
0.4240	0.9600
0.4138	0.9800
0.4000	1.0000

PERIOD 2 : 60 POINTS

LD	DUR
1.0000	0.0000
0.9970	0.0010
0.9941	0.0020
0.9853	0.0050
0.9714	0.0100
0.9580	0.0150
0.9453	0.0200
0.9216	0.0300
0.9002	0.0400
0.8809	0.0500
0.8635	0.0600
0.8479	0.0700
0.8339	0.0800
0.8214	0.0900
.	.
.	.
.	.
.	.
.	.
.	.
0.5262	0.7600
0.5213	0.7800
0.5172	0.8000
0.5135	0.8200
0.5102	0.8400
0.5070	0.8600
0.5035	0.8800
0.4993	0.9000
0.4940	0.9200
0.4871	0.9400
0.4780	0.9600
0.4658	0.9800
0.4500	1.0000

Figure 3.2 (page 4) LOADSY Printout for the Sample Problem. Input Information for 2005

```
          PERIOD PEAK LOADS AS FRACTION OF ANNUAL PEAK LOAD :
            0.9000  0.8700  0.9300  1.0000

          * * * * * * * * * * *  PERIOD  1  * * * * * * * * * * *

          PEAK LOAD :  8208.5 MW    MINIMUM LOAD :  3283.4 MW

                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
          INTEGRATION    :        10786.6               60.00
          FOURIER SERIES :        10787.0               60.01

      FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
          CONSTANT TERM -AOO- IS : 0.8571885
          COEFFICIENTS OF COSINE TERMS ARE :
 0.5914137  0.1189862 -0.1001288 -0.0637293  0.0009174  0.0119343  0.0061207  0.0109987  0.0129295 -0.0059423
-0.0213123 -0.0075242  0.0125015  0.0120916 -0.0000009 -0.0059314 -0.0036237 -0.0015402 -0.0012469  0.0026469
 0.0059729  0.0014753 -0.0050470 -0.0047250  0.0007132  0.0037323  0.0017968 -0.0005231 -0.0006472 -0.0011112
-0.0016963  0.0000239  0.0022995  0.0018330 -0.0009031 -0.0022460 -0.0006314  0.0010540  0.0008270  0.0002342
 0.0000808 -0.0003706 -0.0008781 -0.0004681  0.0007793  0.0011855 -0.0000226 -0.0010265 -0.0005828  0.0002464

          * * * * * * * * * * *  PERIOD  2  * * * * * * * * * * *

          PEAK LOAD :  7934.9 MW    MINIMUM LOAD :  3570.7 MW

                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
          INTEGRATION    :        11295.6               65.00
          FOURIER SERIES :        11295.5               65.00

      FOURIER COEFFICIENTS FOR INVERTED L.D.C. OF THE PERIOD :
          CONSTANT TERM -AOO- IS : 0.8965703
          COEFFICIENTS OF COSINE TERMS ARE :
 0.6047779  0.0903512 -0.1288676 -0.0576992  0.0219827  0.0210080  0.0058650  0.0047489 -0.0005119 -0.0133049
-0.0115872  0.0086774  0.0161539 -0.0001879 -0.0115338 -0.0045395  0.0037465  0.0035445  0.0009966  0.0003562
-0.0009289 -0.0032921 -0.0016218  0.0034553  0.0034920 -0.0016482 -0.0033272 -0.0002189  0.0018321  0.0008634
-0.0003862 -0.0002780 -0.0002240 -0.0007338  0.0000483  0.0013639  0.0004716 -0.0012876 -0.0009169  0.0006919
 0.0010199 -0.0000355 -0.0006973 -0.0002586  0.0001185  0.0000518  0.0003336  0.0004331 -0.0003306 -0.0007798

          * * * * * * * * * * *  PERIOD  3  * * * * * * * * * * *

          PEAK LOAD :  8482.1 MW    MINIMUM LOAD :  3817.0 MW

                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
          INTEGRATION    :        12074.6               65.00
          FOURIER SERIES :        12074.5               65.00

          * * * * * * * * * * *  PERIOD  4  * * * * * * * * * * *

          PEAK LOAD :  9120.6 MW    MINIMUM LOAD :  3648.2 MW

                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
          INTEGRATION    :        11985.1               60.00
          FOURIER SERIES :        11985.6               60.01

          ***************** ANNUAL  SUMMARY *****************

                                ENERGY DEMAND        LOAD FACTOR
                                    (GWH)                (%)
          INTEGRATION    :        46141.7               57.75
          FOURIER SERIES :        46142.7               57.75

      * * * * * * * * *  END OF DATA FOR YEAR  2005  * * * * * * * * *
```

Figure 3.2 (page 5)   LOADSY Printout for the Sample Problem. Load Description - 2005

CHAPTER 4

EXECUTION OF FIXSYS

4.1 Control Cards

The second group of cards in Fig. 2.3 are the FIXSYS job control cards. They are the same as for LOADSY except that the program module name (PGM=) is different and the file created is numbered FT10 and named FIXPLANT.CASE93.

As already explained in Section 3.1 "CASE93" is the label assigned to the particular fixed system description file created for this sample problem.

A FIXSYS run using a file name that has been used before will replace the old information filed under that name with new information (the old information is lost).

4.2 Data Cards

FIXSYS uses up to 9 types of data cards depending on the complexity of the system being described. A system containing only thermal plants uses only up to 7 types of data cards. Table 4.1 lists the 9 types of cards and tells what data they contain (in sequence for cards containing more than one piece of information).

The data cards are arranged in the deck in the following sequence:

a) For the first year:

- First line: One type-X card with the title of the study and the number of type-Y cards to be read next.

- Second and following lines: As many type-Y cards (equal to the value of NID on card type-X) as fuel types are to be used by the thermal plants of FIXSYS and VARSYS. (see Table 4.1 for explanation of information to be given in each card)[1].

- Following lines: Two type-Z cards, one for each hydro plant type. (see Table 4.1 for information to be given in each card.)

- Next line: One type-A card with the general information for the study (see Table 4.1).

- Following lines: A group of type-B cards describing the thermal plants (one card for each thermal plant; total number of cards equal to NTHPL on card type-A).

---

[1] If a given fuel type is subject to limitations in supply, NENGL=1 and NGENCO is a valid number of a FIXSYS plant to be used for substitution of the generation of plants using the given fuel type, if the specified I imitations are exceeded.

Table 4.1 (page 1) Types of data cards used in FIXSYS

Card type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of study (centered to columns 30-31).
	61-64	I	NID	Number of type-Y cards to be read next (maximum 10).
Y[2]	1-4	I	IDNUM	Thermal plant fuel type number (0 to 9).
	6-9	A	IDNAM	Code name for this fuel type.
	11-30	A	IDTXT[3]	Short description of this fuel type.
	31-34	I	NENGL	Index to define if this fuel type is limited in amount. If = 1 (Yes); if = 0 (No, default)
	35-38	I	NGENCO	If NENGL = 0 in the previous field (i.e. no fuel limitation) leave this field blank; otherwise specify the sequence number of the thermal power plant in FIXSYS that should be used to substitute for fuel limitations[4, 5, 6].
	41-50	F	ENGLIM	Fuel limitation for fuel type IDNUM in energy terms (in thousand 10^6 kcal/day).
Z[7]	6-9	A	IDNAM	Code name of the hydroelectric plant type (must be equal to NAMH on card type-A of FIXSYS and VARSYS).
	11-30	A	IDTXT[3]	Description of the hydroelectric plant type, or `NOT APPLICABLE' if it is the case.
A	1-4	I	JAHR	First year of study.
	5-8	I	NPER	Number of periods per year (maximum 12).
	9-12	I	NTHPL	Number of thermal plants in FIXSYS; maximum 58 less the number of expansion candidates in VARSYS (NTHPL must be equal to the number of type-B cards to be read).
	13-16	I	IHYDIS	Number of hydroconditions (maximum 5). <u>This field and rest of the card must be blank if hydro is not used in FIXSYS</u>.
	19-22	A	NAMH(1)	Code name of hydroelectric plant type A (must be blank if not used in FIXSYS).
	23-28	F	HOM(1)	Fixed operating and maintenance costs of hydroelectric plant type A ($/kW-month).
	31-34	A	NAMH(2)	Code name of hydroelectric plant type B (must be blank if not used in FIXSYS).
	35-40	F	HOM(2)	Fixed operating and maintenance costs of hydroelectric plant type B ($/kW-month).

Table 4.1 (page 2) Types of data cards used in FIXSYS

Card type	Columns	Format[1]	Fortran name	Information
A (cont.)	41-46 47-52 53-58 59-64 65-70	F F F F F	PROBH	Probability of hydroconditions 1 to 5 (in the same order used in type-2b cards). (The sum of these probabilities must be equal to 1.0.)
	1-4	A	NAME	Code name for the thermal power station.
	5-7	I	NSETS	Number of identical units in the power station at start of study.
	8-12	F	MWB	Minimum operating level of each unit (MW).
	13-17	F	MWC	Maximum unit generating capacity (MW).
	18-24	F	BHRT	Heat rate at minimum operating level (kcal/kWh).
	25-31	F	CRMHRT	Average incremental heat rate between minimum and maximum operating levels (kcal/kWh).
B[4,8]	32-36	F	FCST	Domestic fuel costs (c/10^6 kcal).
	37-41	F	FCSTF	Foreign fuel costs (c/10^6 kcal).
	42-44	I	NTYPE	Plant type number (0, 1, 2, ... 9) (This must be consistent with the values of IDNUM specified in type-Y card and the substitution definition for limited fuel types).
	45-46	I	ISPIN[9]	Unit spinning reserve as % of MWC.
	47-51	F	FOR	Unit forced outage rate (%).
	52-54	I	MAINT	Number of days per year required for scheduled maintenance of each unit.
	55-59	F	MAINCL	Maintenance class size (MW).
	60-61	I	IFS	Index for fuel substitution plant type. If = 0 (No, default); if = 1 (Yes) this plant can be used for making up excess generation by some limited fuel types.[4]
	66-70	F	OMA	Fixed component of non-fuel operation and maintenance cost ($/kW-month) of each unit; it is assumed to be a domestic cost.
	71-75	F	OMB	Variable component of non-fuel operation and maintenance cost ($/MWh) of each unit; it is assumed to be a domestic cost.

Table 4.1 (page 3) Types of data cards used in FIXSYS

Card type	Columns	Format[1]	Fortran name	Information
1	1-4	I	INDEX	An "index number" telling the computer what to do next; 1 means process current year data and proceed to read data for next year; 2 means hydro project data follow (type-2a and type-2b cards); and 3 means one type-3 card follows.
2a[10]	3-6	A	PNAME	Name of the hydroelectric project (must be equal to NOMHY in type-2a card of DYNPRO).
	9-12	A	TNAME	Code name of the hydroelectric plant type for the hydro project; must be equal to NAMH(1) or NAMH(2) of type-A card.
	13-18	F	HMW	Installed capacity (MW) of the hydro project; a negative value is used for retirements.
	19-24	F	PV	Energy storage capacity (GWh) of hydro project.
2b[11]				Hydrocondition 1:
	1-5	F	EA	Period inflow energy (GWh) of the hydro project.
	6-10	F	EMIN	Minimum generation in base in the period (GWh).
	11-15	F	HMWC	Available capacity in period (MW) of the project.
				Hydrocondition 2:
	16-20	F	EA	Period inflow energy (GWh) of the hydro project.
	21-25	F	EMIN	Minimum generation in base in the period (GWh).
	26-30	F	HMWC	Available capacity in period (MW) of the project.
	.	.	.	Continue up to last hydrocondition defined
	.	.	.	(maximum 5).
3	1-4	I	NS (NS=IP+2)	Number of the thermal plant in which one or more units are to be added or retired[5,6] .
	5-8	I	NA	Number of units to be either added (+) or retired (-) in plant IP.

Notes to Table 4.1

1 See Section 2.5 for Format description
2 One card for each thermal plant (fuel) type in ascending order (0 to 9).
3 If IDTXT starts with 4 blanks, the program replaces it by 'NOT APPLICABLE.'
4 Thermal plants that can be used to substitute for energy (fuel) limitations of some types of fuel must be specified in FIXSYS. These plants are defined each as a dummy thermal power plant with NSET=1, MWB=MWC=1, IFS=1, MAINT=0., and must be associated with a different unlimited fuel type IDNUM. In any case, if IFS=1 for this plant MWC is set to 1 regardless of the value specified in the type-B card.
5 The sequence number of thermal plants in FIXSYS starts with the first thermal plant as No. 3, since 1 and 2 are reserved for hydro. The last FIXSYS thermal plant is numbered NTHPL+2.
6 Plants defined for substitution of fuel limitation of a given fuel type cannot be retired in FIXSYS.
7 One card for each hydroelectric plant type; first hydro type A, second hydro type B.
8 One card for each thermal plant.
9 ISPIN should be defined consistently with the definitions of plant capacity blocks if the loading order is to be calculated by MERSIM (see Table 7.1).
10 One card for each hydroelectric project.
11 One card per period for each hydroelectric project.

- Next lines: Groups of type-2a and type-2b cards, preceded by one type-1 INDEX = 2 card, for each hydroelectric plant in operation (if any) for the first year of study. Each group is composed of one type-2a card and as many type-2b cards as periods have been defined for the study (NPER on card type-A). Each type-2b card should contain the energy and capacity data (see Table 4.1 (page 3)) for each hydrocondition used (total equal to IHYDIS on card type-A).

- Following lines: Groups of one type-1 INDEX = 3 and one type-3 cards for each change in the number of units (if any) of the thermal plant (additions or retirements).

- Last card: One type-1 INDEX = 1 card (end of the year card).

b) For the second and subsequent years:

- Groups of one type-1 INDEX = 2 card, followed by one type-2 card and the corresponding type-2b cards for each change to be made to the hydroelectric plant types (additions or retirements).

- Groups of one type-1 INDEX = 3 and one type-3 cards for changes (additions or retirements) to be made to the number of units in the thermal plants.

- One type-1 INDEX = 1 cards (end of the year).

4.3 Input Data for the Sample Problem

Figure 4.1 shows the complete listing of the input data used for executing the FIXSYS run of the sample problem. The contents of these data are described in the following paragraphs, taking one line at a time.

The first input data line on page 1 of Fig. 4.1 is a type-X card containing in columns 1-60 the title of the study and in column 64 a number telling the computer how many type-Y cards must be read next (7 in this case). The same comments made in Section 3.3 for the title of the study to be included in type-X card of LOADSY are valid for FIXSYS.

Lines 2 to 8 are the group of type-Y cards necessary to describe the fuel types used by the thermal plants of FIXSYS and/or VARSYS (one card for each fuel type must be given as input even if one or more of the fuel types are not used in FIXSYS but are associated to plants that will be described in VARSYS). In each type-Y card the respective fuel is assigned a *code number*, a *code name* and a *description*, together with the specification whether the given fuel type is subject to fuel limitations *(NENGL = 1)*, and if so the *daily limit*, and , optionally, the number of a FIXSYS thermal plant that can make up any excess generation over the specified limit.

Regarding the *code numbers*, only values 0, 1, 2, ..., 9 can be assigned in sequence to any type of fuel (ten in total) used by the thermal plants of FIXSYS and/or VARSYS. Modules 5, 6, and 7 of WASP-III Plus can handle up to twelve "fuel" types, with the additional two being the composite hydro plant types. The code number of the composite hydro plants are assigned automatically by the program so that it is not necessary to give these code numbers in FIXSYS or VARSYS (see description of input data lines 10 and 11 below).

In the sample problem the *code number*, *code name* and *description* of thermal fuel types are as follows:

Code Number	Code name	Description
0	NUCL	Nuclear Plants
1	CO-1	Coal Plants Dom-fuel
2	CO-2	Coal Plants Imp-fuel
3	FOIL	Oil Plants Imp-fuel
4	GTGO	Gas Turbines Gas-oil
5	LIGN	Lignite Plant (Lim.)
6	IMPO	Imports (Fuel Subs.)

It can be noticed in Fig. 4.1 that in the sample problem, *fuel limitations* apply to fuel type LIGN (a "1" appears in the fourth field of the respective type-Y card) and that a limit of up to 13 thousand 10^6 kcal in total can be made available to the thermal plants using this fuel. The last column in this card indicates that the FIXSYS thermal plant number 8 is to be used to substitute the generation of the plants burning LIGN, if their total generation exceeds the limit specified. This fuel limitation feature of WASP-III Plus is very convenient to represent practical operational problems faced by the planner (e.g. when confronted with limitations in the amount of fuel that can be made available for certain thermal power plants of FIXSYS and/or VARSYS[2]). Since these limitations can vary from year to year, the user is allowed to specify new limits in the input data to the MERSIM module.

Lines 9 and 10 in Fig. 4.1 are two type-Z cards giving a code name and a description of each composite hydroelectric plant used in FIXSYS and/or VARSYS (in our sample problem the two composite hydro plants are used in both modules). The same code name must be given in the type-A card of FIXSYS and when describing the hydro projects (if any) of VARSYS. The two type-Z cards must be always included in the FIXSYS input data even if no hydroelectric plants are considered in the study (in this case these cards will be blank). If one type of composite hydro plant is to be used in FIXSYS and/or VARSYS, the corresponding type-Z card must contain the plant code name and description, as this information is required by module 7 (REPROBAT) for writing the report of the study.

The *code name* and *description* of the two composite hydro plants used for our sample problem are as follows:

Code Name	Description
HYD1	Hydro Plants Group 1
HYD2	Hydro Plants Group 2

Apart from the restrictions mentioned above, the code number, code name and description of the fuel types and code name and description of composite hydro plants to be used for a case study may be assigned by the user at his/her own convenience while respecting the corresponding fields and formats.

---

[2] Although WASP-III Plus allows definition of fuel limitations for any fuel type associated with thermal plants in FIXSYS and/or VARSYS, this feature is believed to be more related to FIXSYS plants, since any expected fuel limitations of VARSYS thermal plants can be taken into account while generating the system configurations to be considered in CONGEN-MERSIM-DYNPRO.

```
   CASE93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL       7
   0 NUCL NUCLEAR PLANTS
   1 CO-1 COAL PLANTS DOM-FUEL
   2 CO-2 COAL PLANTS IMP-FUEL
   3 FOIL OIL  PLANTS IMP-FUEL
   4 GTGO GAS TURBINES GAS-OIL
   5 LIGN LIGNITE PLANT (LIM.)   1   8        13.0
   6 IMPO IMPORTS (FUEL SUBS.)
     HYD1 HYDRO PLANTS GROUP 1
     HYD2 HYDRO PLANTS GROUP 2
1997   4   6   3  HYD1   0.7  HYD2  0.55  0.75  0.15  0.10
FCO1  6  67. 200.  2490.  2190. 665.   0.  110  6.0 35  200        3.85 0.00
FCO2  3 133. 400.  2470.  2170.  80. 730.  210  9.0 42  400        2.95 0.00
FOIL  4 133. 400.  2450.  2150.  60.1190.  310  7.0 42  400        1.95 0.00
F-GT  8 100. 100.  3480.  3480.  50.1750.  4 0  1.2 14  100        0.75 0.00
FLIG  1 120. 294.  2560.  2250. 635.   0.  510  8.0 42  400        3.05 0.00
IMPT  1   1.   1.  2560.  2560.   0.3000.  6 0  3.0  0  100 1      3.10 1.55
   2
  FHY1  HYD1   75. 0.001
  85.  50.  50.  95.  40.  55.  65.  60.  40.
  95.  50.  55. 135.  40.  65.  75.  60.  40.
 110.  50.  55. 145.  40.  75.  85.  60.  40.
  75.  70.  50.  85.  65.  55.  65.  60.  40.
   2
  FHY2  HYD1   75.  0.16
  84.   0.  50. 100.   0.  55.  65.   0.  40.
  86.   0.  55. 110.   0.  65.  72.   0.  45.
 102.   0.  60. 144.   0.  75.  86.   0.  50.
  88.   0.  55. 134.   0.  65.  75.   0.  45.
   2
  FHY3  HYD1  350.  1.14
 445. 350. 290. 500. 350. 310. 355. 350. 250.
 455. 350. 300. 525. 350. 320. 360. 350. 250.
 465. 350. 310. 555. 350. 330. 385. 350. 260.
 485. 350. 310. 570. 350. 350. 395. 350. 260.
   2
  FHY4  HYD2 1000.   65.
1200. 460. 850.1450. 440. 900. 950. 470. 700.
1250. 460. 860.1500. 440. 950.1000. 470. 720.
1350. 460. 890.1600. 440. 970.1100. 470. 740.
1400. 460. 920.1700. 440.1000.1200. 470. 780.
   2
  FHY5  HYD2  600.   45.
 600.   0. 600. 750.   0. 600. 380.   0. 600.
 650.   0. 600. 800.   0. 600. 450.   0. 600.
 750.   0. 600. 950.   0. 600. 550.   0. 600.
 800.   0. 600.1000.   0. 600. 600.   0. 600.
   1          (END OF 1997)
   3
   3  -1
   3
   4   1
   1          (END OF 1998)
   3
   4   1
   3
   6  -2
   1          (END OF 1999)
   3
   3  -1
   3
   7   1
   1          (END OF 2000)
```

Figure 4.1 (page 1) WASP-III - FIXSYS Input Data for the Sample Problem (CASE93)

```
  1           (END OF 2001)
  3
  3  -1
  3
  6  -1
  3
  7   1
  1           (END OF 2002)
  2
 FH-1  HYD1 -75.0 0.001
 85.  50.  50.  95.  40.  55.  65.  60.  40.
 95.  50.  55. 135.  40.  65.  75.  60.  40.
110.  50.  55. 145.  40.  75.  85.  60.  40.
 75.  70.  50.  85.  65.  55.  65.  60.  40.
  1           (END OF 2003)
  3
  4  -1
  3
  6  -1
  3
  7   1
  1           (END OF 2004)
  3
  5  -1
  1           (END OF 2005)
  3
  3  -1
  3
  4  -1
  1           (END OF 2006)
  3
  5  -1
  3
  6  -1
  1           (END OF 2007)
  2
 FH-2  HYD1 -75.0  0.16
 84.   0.  50. 100.   0.  55.  65.   0.  40.
 86.   0.  55. 110.   0.  65.  72.   0.  45.
102.   0.  60. 144.   0.  75.  86.   0.  50.
 88.   0.  55. 134.   0.  65.  75.   0.  45.
  1           (END OF 2008)
  3
  5  -1
  1           (END OF 2009)
  3
  3  -2
  3
  6  -1
  1           (END OF 2010)
  3
  5  -1
  1           (END OF 2011)
  3
  6  -1
  1           (END OF 2012)
  1           (END OF 2013)
  3
  6  -1
  1           (END OF 2014)
  1           (END OF 2015)
  1           (END OF 2016)
```

Figure 4.1 (page 2) WASP-III - FIXSYS Input Data for the Sample Problem (cont.)

The next input line in Fig. 4.1 is a type-A card specifying the *first year of study* (1997 in this case); the *number of periods* in each year (4); the *number of thermal plants* in FIXSYS (i.e. the number of type-B cards to be read next, 6 in this case); the *number of hydrological conditions* (3); the *code names of the two composite hydroelectric* plants (HYD1 and HYD2, respectively) and their associated *operation and maintenance costs* (0.7 and 0.55 $/kW-month); and finally, the *probabilities of the hydrological conditions* (0.75, 0.15 and 0.10). (see Table 4.1 (page 1) to fill in the data on the type-A card).

The following lines are six type-B cards describing each thermal plant by its code name and 16 parameters (see Table 4.1 (page 2) to fill in the type-B cards and for explanation of each piece of information required). The last thermal power plant, identified with the short name IMPT, is the one that should be used (in MERSIM) to substitute for fuel limitations for fuel type number 5 (LIGN). Note the specifications for this plant (number of sets =1; MWB=1; MWC=1, IFS=1, and MAINT=0.0)[3]. Also note that this plant is associated with fuel type number 6 (i.e. a non-limited fuel type)[4].

After the last type-B card, a type-1 card must follow to tell the computer what to do next. In general these cards would be interpreted as follows: a type-1 INDEX=1 card means that no more data for current year follows and that the program should proceed to execute the calculations for the year; an INDEX=2 means that type-2a and type-2b cards follow containing the parameters of a hydroelectric project to be added (or retired) in the system; and INDEX=3 means that one type-3 card follows indicating an addition (or retirement) of units to (or from) a thermal station. For the first year of study, however, it is not recommended to use the retirement option for thermal or hydro plants.

In Fig. 4.1 the last thermal plant is followed by a type-1 INDEX=2 card and the next line is a type-2a card. This corresponds to hydroelectric project FHY1 of plant type code name HYD1, installed capacity 75. (MW) and energy storage capacity 0.001 (GWh). The code name on this line tells the computer that this project is of the hydro plants group 1. The subsequent lines are four type-2b cards containing information for hydro project FHY1 applicable in each of the four periods of the year and the three hydrological conditions specified; there is one type-2b card for each period and each card gives information for all hydrological conditions considered. Consult Table 4.1 (page 3) to fill in correctly the type-2a and type-2b data cards.

For example, the first line in this group corresponds to period 1 and contains in columns 1 to 15 the data for the first hydrological condition (85. GWh of inflow energy; 50. GWh required as base load generation; and 50. MW available capacity); in cols. 16-30 the data for the second hydrological condition (95. GWh inflow energy, 40. GWh base load generation requirements and 55. MW available capacity); and in cols. 31-45 the data for the last hydrocondition (65. GWh inflow energy, 60. GWh base load generation requirements and 40. MW available capacity). Columns 46-75 (reserved in this card type for hydrological conditions 4 and 5) are blank since only 3 hydroconditions are defined for the study.

---

[3] MAINT of substitution plants is set to 0.0 in order to avoid wrong calculations in the MERSIM program, and also to avoid confusion in the interpretation of the Plant Operational Summary which is part of the detailed output of MERSIM (see Chapter 7).

[4] The thermal plant to be used for substitution of generation of other thermal plants burning a limited-fuel type must be associated with a fuel type that has no limitation. In the sample problem this was specified by assigning to this substitution plant a separate fuel type (IMPO) in order to facilitate the description.

In a similar way, the next three lines specify the data applicable to hydro project FHY1 in period 2, 3, and 4, respectively, and for each of the hydroconditions used.

The next groups of input lines consist of one type-1 INDEX = 2 card followed by one type-2a and four type-2b cards. The first two groups provide the data for hydro projects FHY2 and FHY3, respectively, of plant code name HYD1. Similarly, the next two groups are used to specify the data for projects FHY4 and FHY5 of plant code name HYD2. Each group of type-2a and type-2b cards contain similar information as previously described for hydro project FHY1[5].

The next line is the first type-1 INDEX = 1 card meaning end of the year, in other words, that all information for the current year, 1997 in this case, has been completed. As can be seen in Fig. 4.1, this card (and all type-1 INDEX = 1 cards) have been identified with the corresponding year. As stated in Section 3.3 this information is not necessary but has been introduced for convenience.

The input data for the next year of study follows. These consist of two groups of one type-1 INDEX = 3 card followed by one type-3 card, indicating that changes are to be made to the number of units of the thermal plants in FIXSYS in this year (1998). Each type-3 card indicates on column 4 of the card, the thermal plant number for which an addition (+) or a retirement (-) (as specified on column 7) of the number of units on column 8 is to be made. For example, the first group specifies that one unit is to be retired from the FIXSYS thermal plant number 3 (FCO1) while the second group corresponds to addition of one unit to thermal plant number 4 (FCO2). These groups are followed by one line with a type-1 INDEX = 1 card indicating end of data for current year (1998).

The subsequent lines are also groups of type-3 and type-1 INDEX = 1 cards indicating that changes are to be made to the number of units of the thermal plants in FIXSYS in years 1999, 2000 and 2002; no change is made to FIXSYS in year 2001. In this case one unit is added to the thermal plant number 4 (FCO2) and two units are retired from plant number 6 (F-GT) in year 1999. Similarly, in year 2000 one unit is retired from plant 3 (FCO1) and one unit added to plant 7 (FLIG). Finally, in year 2002, one unit is retired from plant 3 (FCO1) and plant 6 (F-GT) while one unit is added to plant 7 (FLIG). The end of year card appears at the end of each group.

The input data for the next year (2003) includes a type-1 INDEX = 2 card meaning that a change is to be made to the characteristics of the hydro system in this year. This is followed by a type-2a card to specify the basic characteristics of hydro project FH-1 which is of the composite hydroelectric plant type HYD1 as shown on columns 9 to 12 of the card. In this case, the negative number in the field for the installed capacity (columns 13-18) of the card indicates that this project corresponds to a retirement from the composite plant HYD1. The next four lines specify the parameters of the hydro project to be retired (for each period and each hydro condition). After the last period data, a next line (a type-1 INDEX = 1 card) indicates the end of input data for the current year.

The input data for the subsequent years (2004 to 2007) correspond to modifications of the number of sets of the FIXSYS thermal plants (retirements of the units) using

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[5] It should be emphasized that the ordering of period and hydrocondition data must be consistent from project to project; otherwise it will lead to wrong calculations of the characteristics of the composite hydro plants. Also, as mentioned in Section 3.1, the ordering of the periods must be consistent with the order used in Modules 1 and 3.

combinations of the required type-1 INDEX=3 card followed by one type-3 card specifying these changes. A line with a type-1 INDEX=1 card is included at the end of each year.

In year 2008, a hydro project (FH-2 in this case) is also retired from the composite hydroelectric plant type HYD1 as specified by the negative value of the installed capacity (-75. MW) on columns 13-18 of the respective type-2a card. The characteristics of this hydro project are given in the subsequent input lines for each period and hydro condition used. These are followed by the usual end of the year card.

The input data for years 2009 through 2012 also show a sequence of type-1 INDEX=3 cards, followed by a type-3 card indicating changes to be made to the number of units of the corresponding thermal plants of FIXSYS in these years. In year 2009, 1 unit is retired from thermal plant number 5. In 2010, 2 units are retired from thermal plant number 3 and 1 unit from thermal plant number 6, and finally 1 unit is retired from thermal plant 5 in year 2011 and another one from plant 6 in year 2012. Each of these changes is followed by a card type-1 INDEX=1 indicating end of input data for the respective year.

The rest of the input data for the remaining years follows a similar pattern with no changes made in the composition of the Fixed System in these last years of study (2013 through 2016) with the exception of year 2014 in which a unit is retired from plant 6.

4.4 Printout of the Sample Problem

Figure 4.2 illustrates parts of the printout resulting from execution of the FIXSYS for the sample problem. Page 1 is the cover page printed by FIXSYS to identify the run. This contains: the *title of the study* and a list of the different "fuel" types used in the study, starting with the thermal plants fuel types followed by the two composite hydroelectric plants. Each list shows the *fuel type*, *code number*, and *description*. For thermal fuel types which are subject to energy (fuel) limitations, the list of thermal plant fuel types shows the amount of the daily limitation and the FIXSYS thermal power plant (if any) that can be used for substitution of energy generation above the limit specified. At the end of the composite hydroelectric plants, the output lists the hydro plant cases (mode of operation) considered by the program. These modes of operation are identified by a KEY (number 1 to 7) and the description of each case.

Each time input data for a hydroelectric project (addition or retirement) are read in, the program calls a special subroutine (HYRUN) to calculate the mode of operation of the project for each period and hydrocondition defined. This is determined by HYRUN using the given input data and according to a set of main assumptions (see Appendix C for description of HYRUN). Using this information, HYRUN distributes the available energy for the hydro project in "base" and "peak" portions as required for simulation purposes. The resulting base and peak capacities of the hydro project are included in the FIXSYS printout for the corresponding year, identifying with the corresponding KEY the mode of operation of the project. This should be checked by the user to make sure that the project "operates" in the intended mode and that no errors exist in the input data (particularly for KEY=5 and KEY=6).

The printout continues with a list of the card image of the input data information for the first year of study (1997), including: *general information* for the run; *thermal plant characteristics*; and the *changes made to the composite hydroelectric plants* for this year. Page 2 of Fig. 4.2 illustrates this portion of the output for the case example.

The next piece of information produced as output corresponds to the FIXSYS results for the year. Pages 3 and 4 of Fig. 4.2 show these results and the Fixed System description for year 1997.

This part of the output starts with the number of periods and hydroconditions; followed by the input characteristics and calculated parameters of the thermal plants which are displayed in a table. **Column 1** of the table gives the plant number (starting with 3 and finishing with NTHPL+2, in this case 8; plant NTHPL+3 will be the first of the plants in VARSYS). **Column 2** gives the code name of the thermal plants and **Column 3** the number of sets in this year. **Columns 4 to 16** are a repetition of the characteristics of the respective units. Finally, the **six right-hand columns** of the table are output values which are actually calculated by FIXSYS; they give the full load heat rate and the domestic and foreign components of unit generation costs at base load and full load; the last column (**Col. 22**) gives the total, domestic plus foreign, unit generation costs at full load. This value is used by the program to define the economic loading order also included in the printout.

Thermal plants that are specified for substitution of the excess generation of the plants using a fuel limited type are identified in this table by showing their code names between brackets (see plant number 8 in page 3). Note that this plant uses a fuel type (code number = 6, i.e. IMPO) that is not limited in amount.

Following the table of thermal plants, a summary of thermal capacity by fuel type is included in the printout (see page 3). In this case, no nuclear plants are included in FIXSYS[6], thus a 0 is given for the nuclear fuel; 1200 MW for fuel type 1 (CO-1), 1200 MW of fuel type 2 (CO-2), 1600 MW of type 3 (FOIL), 800 MW of gas turbines fuel type 4 (GTGO), and 2 MW for fuel type 6 (IMPO). The fuel types associated with energy limitations are listed below. In this case the total capacity for fuel type 5 (LIM.) is 294 MW. The total thermal capacity in this year is of 5096 MW.

Next, the program reports the economic loading order of the thermal plants used, in ascending order of total full load generation cost (col. 22 of thermal plant table). This information, together with the similar one from VARSYS will be used by CONGEN to calculate the basic economic loading order of the combined FIXSYS and VARSYS plants that is required by MERSIM.

Following the thermal plant information are the characteristics of the hydro projects (if any) of each plant type. In this case hydro type A (code name HYD1) with operation and maintenance costs 0.70 $/kW-month includes 3 projects. For each project, the printout shows the base and peak capacities (MW), peaking energy GWh), hours per day (during working days) in which the plant can provide peaking energy and finally the mode of operation calculated by HYRUN. This information is given for each period and hydro condition defined by the user. For example, project 1 of HYD1 type is incapable of supplying any peaking energy in all periods and hydroconditions (KEY = 1: run-of-river).

For hydro project 2, also of HYD1 type, the mode of operation corresponds to daily regulating cycle (KEY = 2) for all hydroconditions and periods except for hydrocondition 2 period 4. For example in hydrocondition 1, period 1, the base capacity is 30. MW, peak capacity 20. MW, energy available for peaking 18. GWh, and the plant operates in peak 13.7 hours/working day.

---

[6] The thermal fuel type NUCL, needs to be defined in FIXSYS since it is expected to be used in VARSYS.

Hydro project 3 (type HYD1) is mainly of weekly regulating cycle (KEY=3) except in periods 1,2 and 3 for hydrocondition 3 in which the project has been assigned KEY=4 (seasonal regulating reservoir).

Once the calculated information for the individual characteristics of all projects of a hydro plant type has been reported, the program prints the characteristics (capacities and energies per period and hydrocondition) of the composite hydro plant. This is shown on page 4 of Fig. 4.2 where 3 projects are composed in hydro plant type A (HYD1) with total installed capacity 500. MW. The base and peak capacity, available energy for peaking and total available capacity of the composite hydro plant are also printed for each period and hydrocondition. The above values are calculated as the algebraic sum of the individual values for the hydro projects composed; retirements being handled as negative capacities and energies. For the composite hydro plant no KEY of operation type is given since this only applies for individual projects.

Next information on page 4 corresponds to the characteristics of those individual projects composed in the hydro plant type B (HYD2), followed by the parameters of the composite hydro plant.

A similar output to the one described for year 1997 and shown in pages 2 to 4 of Fig. 4.2 is produced for each year of the study, starting with the listing of the card image of the input data for the respective year. If no change is to be made to the FIXSYS for the year, the program simply prints INDEX=1 and then proceeds to print the Fixed System description for the year, but without repeating the individual characteristics of the hydro projects composed in each plant type. If a change is made to FIXSYS in the year, the program prints the card image of input data and then proceeds with the report for the year as above. If the change concerns only thermal additions or retirements, the new number of sets of the corresponding plant will be printed in column 3 of the table of thermal plants and the summary of thermal capacity is revised accordingly.

For example, in year 1998 one unit has been retired from plant 3 and one unit added to plant 4 (page 5 of Fig. 4.2) and the new number of sets for these plants has been modified accordingly in the table of thermal plants (for FCO1 reduced to 5 and for FCO2 increased to 4). Similarly, the total capacity of fuel type 1 (CO-1) has been also reduced to 1000 MW and that of fuel type 2 (CO-2) increased to 1600. MW. The characteristics of the composite hydro plants in the printout for the same year are repeated without change (compare pages 3 and 5).

If any change is made to the composite hydro plants (additions or retirements), the program will print first the corresponding card images along with any other input data and then the report with the description of the fixed system for the year. The latter will include the characteristics calculated by the program for the hydro project being added or retired, followed by the resulting parameters for the composite hydro plant affected.

Pages 6 and 7 of Fig. 4.2 illustrate the FIXSYS output for year 2003 in which one hydro project, FH-1 of hydro type A (HYD1) has been retired. Page 6 shows (at the top) the corresponding card images of the input data, followed by the description of the Fixed System for the year. Page 7 shows the results of the calculations performed by subroutine HYRUN for the hydro project being retired and the new characteristics of the composite hydro plant HYD1. It should be noted that the number of projects composed in each hydro plant type keeps increasing each time the corresponding hydro plant has been affected by additions or retirements of projects. Thus, in page 7 the number of hydro projects of plant HYD1 has been increased to 4 to consider the project which has been retired this year.

The FIXSYS printout should be checked with great care to make sure that all reported numbers are those intended by the user. Each number is to be checked carefully as some errors will not be identified as such by the WASP code until the CONGEN or MERSIM modules are run (e.g. inconsistencies between LOADSY and FIXSYS input data), and some other errors will never be identified by the computer (e.g. the addition or retirement of some units from the "wrong" plant). At least some internal inconsistencies in FIXSYS input data will result in interruption of program execution and the printing of an error message in the output. Some other inconsistencies will result in an error message being printed (without stopping program execution) to warn the user about the potential sources of errors in his/her input data. Error and warning messages applicable to FIXSYS are described in Section B.2 of Appendix B.

```
                    WASP  COMPUTER  PROGRAM  PACKAGE

                             FIXSYS  MODULE

                               CASE  STUDY

          CASE93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL


*************************************************************
*                                                           *
*                     THERMAL    PLANTS                     *
*                                                           *
*     TYPE    NAME    DESCRIPTION            ENERGY LIMIT   *
*                                            MILLION  PL#   *
*                                            KCAL/DAY       *
*       0     NUCL    NUCLEAR PLANTS                        *
*       1     CO-1    COAL PLANTS DOM-FUEL                  *
*       2     CO-2    COAL PLANTS IMP-FUEL                  *
*       3     FOIL    OIL  PLANTS IMP-FUEL                  *
*       4     GTGO    GAS TURBINES GAS-OIL                  *
*       5     LIGN    LIGNITE PLANT (LIM.)     13000.   8   *
*       6     IMPO    IMPORTS (FUEL SUBS.)                  *
*       7     ****    NOT APPLICABLE                        *
*       8     ****    NOT APPLICABLE                        *
*       9     ****    NOT APPLICABLE                        *
*                                                           *
*************************************************************
*                                                           *
*                  HYDROELECTRIC PLANTS                     *
*                                                           *
*     TYPE    NAME    DESCRIPTION                           *
*                                                           *
*       A     HYD1    HYDRO PLANTS GROUP 1                  *
*       B     HYD2    HYDRO PLANTS GROUP 2                  *
*                                                           *
*                                                           *
*  IDENTIFICATION  OF  HYDROPLANT  CASES:                   *
*                                                           *
*  KEY                DESCRIPTION                           *
*   1   RUN OF RIVER-RESERVOIR EMPTY IN LESS THAN 2 HRS     *
*   2   DAILY REGULATING RESERVOIR                          *
*   3   WEEKLY REGULATING RESERVOIR                         *
*   4   SEASONAL REGULATING RESERVOIR                       *
*   5   INFLOW ENERGY EXCEEDS PLANT GENER. CAPABILITY       *
*   6   MINIMUM REQUIRED ENERGY EXCEEDS INFLOW ENERGY       *
*   7   PLANT OPERATES IN PEAK MORE THAN 5 DAYS/WEEK        *
*                                                           *
*************************************************************
```

Figure 4.2 (page 1) FIXSYS Printout for CASE93. Cover Page

FIXED SYSTEM INPUT DATA INFORMATION OF YEAR 1997

INIT. YEAR	NO. OF PERIODS	N.THERMAL PLANTS	HYDRO COND.	****** HYDRO PLANT TYPES ****** NAME	O&M	NAME	O&M	PROBABILITY OF HYDROCONDITIONS 1	2	3	4	5
1997	4	6	3	HYD1	0.70	HYD2	0.55	0.750	0.150	0.100	0.000	0.000

NAME	NO. OF SETS	MIN. LOAD MW	CAP-CITY MW	BASE LOAD HEAT RATE	AVGE INCR HEAT RATE	FUEL COSTS CENTS/MILLION DMSTC	FORGN	FUEL TYPE	S P I N	FRCD OUT-AGE RATE	DAYS SCHL MAIN	MAIN CLAS	FUEL SUBST. PLANT	O&M (FIX)	O&M (VAR)
FCO1	6	67.	200.	2490.	2190.	665.0	0.0	1	10	6.0	35	200.	0	3.85	0.00
FCO2	3	133.	400.	2470.	2170.	80.0	730.0	2	10	9.0	42	400.	0	2.95	0.00
FOIL	4	133.	400.	2450.	2150.	60.0	1190.0	3	10	7.0	42	400.	0	1.95	0.00
F-GT	8	100.	100.	3480.	3480.	50.0	1750.0	4	0	1.2	14	100.	0	0.75	0.00
FLIG	1	120.	294.	2560.	2250.	635.0	0.0	5	10	8.0	42	400.	0	3.05	0.00
IMPT	1	1.	1.	2560.	2560.	0.0	3000.0	6	0	3.0	0	100.	1	3.10	1.55

INDEX 2

PROJECT 1 (NAME: FHY1) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 75. MW REG. ENERGY: 0.00 GWH

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
85.	50.	50.	95.	40.	55.	65.	60.	40.
95.	50.	55.	135.	40.	65.	75.	60.	40.
110.	50.	55.	145.	40.	75.	85.	60.	40.
75.	70.	50.	85.	65.	55.	65.	60.	40.

INDEX 2

PROJECT 2 (NAME: FHY2) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 75. MW REG. ENERGY: 0.16 GWH

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
84.	0.	50.	100.	0.	55.	65.	0.	40.
86.	0.	55.	110.	0.	65.	72.	0.	45.
102.	0.	60.	144.	0.	75.	86.	0.	50.
88.	0.	55.	134.	0.	65.	75.	0.	45.

INDEX 2

PROJECT 3 (NAME: FHY3) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 350. MW REG. ENERGY: 1.14 GWH

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
445.	350.	290.	500.	350.	310.	355.	350.	250.
455.	350.	300.	525.	350.	320.	360.	350.	250.
465.	350.	310.	555.	350.	330.	385.	350.	260.
485.	350.	310.	570.	350.	350.	395.	350.	260.

INDEX 2

PROJECT 1 (NAME: FHY4) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 1000. MW REG. ENERGY: 65.00 GWH

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
1200.	460.	850.	1450.	440.	900.	950.	470.	700.
1250.	460.	860.	1500.	440.	950.	1000.	470.	720.
1350.	460.	890.	1600.	440.	970.	1100.	470.	740.
1400.	460.	920.	1700.	440.	1000.	1200.	470.	780.

INDEX 2

PROJECT 2 (NAME: FHY5) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 600. MW REG. ENERGY: 45.00 GWH

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
600.	0.	600.	750.	0.	600.	380.	0.	600.
650.	0.	600.	800.	0.	600.	450.	0.	600.
750.	0.	600.	950.	0.	600.	550.	0.	600.
800.	0.	600.	1000.	0.	600.	600.	0.	600.

INDEX 1

Figure 4.2 (page 2) FIXSYS Printout for CASE93. Input Data Information for Year 1997

FIXED SYSTEM OF YEAR 1997 (YEAR NUMBER 1 OF THE STUDY)
4 PERIODS
3 HYDRO CONDITIONS

	NAME	NO. OF SETS	MIN. LOAD MW	CAP-CITY MW	BASE LOAD HEAT RATE	AVGE INCR HEAT RATE	FUEL COSTS CENTS/MILLION DMSTC	FUEL COSTS CENTS/MILLION FORGN	FUEL TYPE	SPIN	FRCD OUT-AGE RATE	DAYS SCHL MAIN	MAIN CLAS	O&M (FIX)	O&M (VAR)	FULL LOAD HEAT RATE	UNIT GENERATION COSTS ($/MWH) BASE DOM	BASE FRGN	FLD DOM	FLD FRGN	FLD TOT
3	FCO1	6	67.	200.	2490.	2190.	665.0	0.0	1	10	6.0	35	200.	3.85	0.00	2291.	16.6	0.0	15.2	0.0	15.2
4	FCO2	3	133.	400.	2470.	2170.	80.0	730.0	2	10	9.0	42	400.	2.95	0.00	2270.	2.0	18.0	1.8	16.6	18.4
5	FOIL	4	133.	400.	2450.	2150.	60.0	1190.0	3	10	7.0	42	400.	1.95	0.00	2250.	1.5	29.2	1.3	26.8	28.1
6	F-GT	8	100.	100.	3480.	3480.	50.0	1750.0	4	0	1.2	14	100.	0.75	0.00	3480.	1.7	60.9	1.7	60.9	62.6
7	FLIG	1	120.	294.	2560.	2250.	635.0	0.0	5	10	8.0	42	400.	3.05	0.00	2377.	16.3	0.0	15.1	0.0	15.1
(8)	IMPT	1	1.	1.	2560.	2560.	0.0	3000.0	6	0	3.0	0	100.	3.10	1.55	2560.	1.6	76.8	1.6	76.8	78.3

THERMAL CAPACITY SUMMARY:

FUEL TYPE	DESCRIPTION	MW
0	NUCLEAR PLANTS	0.
1	COAL PLANTS DOM-FUEL	1200.
2	COAL PLANTS IMP-FUEL	1200.
3	OIL PLANTS IMP-FUEL	1600.
4	GAS TURBINES GAS-OIL	800.
6	IMPORTS (FUEL SUBS.)	1.
7	NOT APPLICABLE	0.
8	NOT APPLICABLE	0.
9	NOT APPLICABLE	0.

FUEL TYPES WITH LIMITATION:

5	LIGNITE PLANT (LIM.)	294.
	TOTAL	5095.

ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS

7 3 4 5 6 8

FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD1 *** O&M (FIX) = 0.70 $/KW-MONTH
****

PROJECT 1 INSTALLED CAP.: 75. MW REG. ENERGY: 0.00 GWH

HYDROCONDITION 1 BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	HYDROCONDITION 2 BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	HYDROCONDITION 3 BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY
39.	0.	0.	0.0	1	43.	0.	0.	0.0	1	30.	0.	0.	0.0	1
43.	0.	0.	0.0	1	62.	0.	0.	0.0	1	34.	0.	0.	0.0	1
50.	0.	0.	0.0	1	66.	0.	0.	0.0	1	39.	0.	0.	0.0	1
34.	0.	0.	0.0	1	39.	0.	0.	0.0	1	30.	0.	0.	0.0	1

Figure 4.2 (page 3) FIXSYS Printout for CASE93. Fixed System Description for Year 1997

```
PROJECT   2      INSTALLED CAP.:   75. MW    REG. ENERGY:    0.16 GWH

     HYDROCONDITION  1    *     HYDROCONDITION  2    *     HYDROCONDITION  3    *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR       MW    MW   GWH   HR       MW    MW   GWH   HR

   30.   20.   18. 13.7  2  36.   19.   21. 17.1  2  21.   19.   19. 15.5  2
   32.   23.   15. 10.2  2  43.   22.   15. 10.8  2  25.   20.   17. 13.2  2
   39.   21.   16. 11.9  2  56.   19.   22. 17.3  2  31.   19.   19. 14.9  2
   33.   22.   15. 10.8  2  53.   12.   18. 22.9  3  26.   19.   19. 14.9  2

PROJECT   3      INSTALLED CAP.:  350. MW    REG. ENERGY:    1.14 GWH

     HYDROCONDITION  1    *     HYDROCONDITION  2    *     HYDROCONDITION  3    *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR       MW    MW   GWH   HR       MW    MW   GWH   HR

  173.  117.   67.  8.7  3 187.  123.   91. 11.3  3 160.   90.    5.  0.9  4
  175.  125.   72.  8.8  3 194.  126.  100. 12.2  3 160.   90.   10.  1.7  4
  177.  133.   76.  8.9  3 203.  127.  111. 13.4  3 160.  100.   35.  5.4  4
  183.  127.   85. 10.2  3 206.  144.  119. 12.7  3 161.   99.   42.  6.5  3

 3 PROJECTS  COMPOSED IN  HYDRO TYPE *** HYD1 ***      INSTALLED CAP.:  500. MW
*****************************************************      ************************

     HYDROCONDITION  1    *     HYDROCONDITION  2    *     HYDROCONDITION  3    *
  BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL     BASE  PEAK P-ENG AVAIL
   MW    MW   GWH   MW         MW    MW   GWH   MW        MW    MW   GWH   MW

  242.  137.   84.  379.      266.  142.  112.  408.     210.  109.   24.  320.
  251.  148.   87.  398.      299.  148.  116.  447.     219.  110.   27.  329.
  267.  153.   93.  420.      325.  146.  132.  471.     229.  119.   54.  349.
  250.  149.  100.  399.      298.  156.  137.  454.     217.  118.   60.  335.

FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD2 ***    O&M (FIX) =   0.55 $/KW-MONTH
******************************************************************************************************************


PROJECT   1      INSTALLED CAP.: 1000. MW    REG. ENERGY:   65.00 GWH

     HYDROCONDITION  1    *     HYDROCONDITION  2    *     HYDROCONDITION  3    *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR       MW    MW   GWH   HR       MW    MW   GWH   HR

  210.  640.  740. 17.7  4 201.  699. 1010. 22.2  4 215.  485.  480. 15.2  4
  210.  650.  790. 18.6  4 201.  749. 1060. 21.7  4 215.  505.  530. 16.1  4
  210.  680.  890. 20.1  4 201.  769. 1160. 23.1  4 215.  525.  630. 18.4  4
  210.  710.  940. 20.3  4 201.  799. 1260. 17.3  7 215.  565.  730. 19.8  4

PROJECT   2      INSTALLED CAP.:  600. MW    REG. ENERGY:   45.00 GWH

     HYDROCONDITION  1    *     HYDROCONDITION  2    *     HYDROCONDITION  3    *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR       MW    MW   GWH   HR       MW    MW   GWH   HR

    0.  600.  600. 15.3  4    0.  600.  750. 19.2  4    0.  600.  380.  9.7  4
    0.  600.  650. 16.6  4    0.  600.  800. 20.5  4    0.  600.  450. 11.5  4
    0.  600.  750. 19.2  4    0.  600.  950. 17.4  7    0.  600.  550. 14.1  4
    0.  600.  800. 20.5  4    0.  600. 1000. 18.3  7    0.  600.  600. 15.3  4

 2 PROJECTS  COMPOSED IN  HYDRO TYPE *** HYD2 ***      INSTALLED CAP.: 1600. MW
*****************************************************      ************************

     HYDROCONDITION  1    *     HYDROCONDITION  2    *     HYDROCONDITION  3    *
  BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL     BASE  PEAK P-ENG AVAIL
   MW    MW   GWH   MW         MW    MW   GWH   MW        MW    MW   GWH   MW

  210. 1240. 1340. 1450.      201. 1299. 1760. 1500.     215. 1085.  860. 1300.
  210. 1250. 1440. 1460.      201. 1349. 1860. 1550.     215. 1105.  980. 1320.
  210. 1280. 1640. 1490.      201. 1369. 2110. 1570.     215. 1125. 1180. 1340.
  210. 1310. 1740. 1520.      201. 1399. 2260. 1600.     215. 1165. 1330. 1380.

* * * * * * * * * * * * END OF DATA FOR YEAR 1997 * * * * * * * * * * * *
```

Figure 4.2 (page 4) FIXSYS Printout for CASE93. Fixed System Description for 1997 (cont.)

INDEX 3

PLANT 3: -1 SET(S) RETIRED

INDEX 3

PLANT 4: 1 SET(S) ADDED

INDEX 1

∞

FIXED SYSTEM OF YEAR 1998 (YEAR NUMBER 2 OF THE STUDY)
4 PERIODS
3 HYDRO CONDITIONS

	NAME	NO. OF SETS	MIN. LOAD MW	CAP-CITY MW	BASE LOAD HEAT RATE	AVGE INCR HEAT RATE	FUEL COSTS CENTS/MILLION DMSTC	FUEL COSTS CENTS/MILLION FORGN	FUEL TYPE	S P I N	FRCD OUT-AGE RATE	DAYS SCHL MAIN	MAIN CLAS	O&M (FIX)	O&M (VAR)	FULL LOAD HEAT RATE	UNIT GENERATION COSTS ($/MWH) BASE DOM	BASE FRGN	FLD DOM	FLD FRGN	FLD TOT
3	FCO1	5	67.	200.	2490.	2190.	665.0	0.0	1	10	6.0	35	200.	3.85	0.00	2291.	16.6	0.0	15.2	0.0	15.2
4	FCO2	4	133.	400.	2470.	2170.	80.0	730.0	2	10	9.0	42	400.	2.95	0.00	2270.	2.0	18.0	1.8	16.6	18.4
5	FOIL	4	133.	400.	2450.	2150.	60.0	1190.0	3	10	7.0	42	400.	1.95	0.00	2250.	1.5	29.2	1.3	26.8	28.1
6	F-GT	8	100.	100.	3480.	3480.	50.0	1750.0	4	0	1.2	14	100.	0.75	0.00	3480.	1.7	60.9	1.7	60.9	62.6
7	FLIG	1	120.	294.	2560.	2250.	635.0	0.0	5	10	8.0	42	400.	3.05	0.00	2377.	16.3	0.0	15.1	0.0	15.1
(8)	IMPT	1	1.	1.	2560.	2560.	0.0	3000.0	6	0	3.0	0	100.	3.10	1.55	2560.	1.6	76.8	1.6	76.8	78.3

THERMAL CAPACITY SUMMARY:

FUEL TYPE	DESCRIPTION	MW
0	NUCLEAR PLANTS	0.
1	COAL PLANTS DOM-FUEL	1000.
2	COAL PLANTS IMP-FUEL	1600.
3	OIL PLANTS IMP-FUEL	1600.
4	GAS TURBINES GAS-OIL	800.
6	IMPORTS (FUEL SUBS.)	1.
7	NOT APPLICABLE	0.
8	NOT APPLICABLE	0.
9	NOT APPLICABLE	0.

FUEL TYPES WITH LIMITATION:

5	LIGNITE PLANT (LIM.)	294.
	TOTAL	5295.

ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS

7 3 4 5 6 8

3 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 500. MW

HYDROCONDITION 1 BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	HYDROCONDITION 2 BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	HYDROCONDITION 3 BASE MW	PEAK MW	P-ENG GWH	AVAIL MW
242.	137.	84.	379.	266.	142.	112.	408.	210.	109.	24.	320.
251.	148.	87.	398.	299.	148.	116.	447.	219.	110.	27.	329.
267.	153.	93.	420.	325.	146.	132.	471.	229.	119.	54.	349.
250.	149.	100.	399.	298.	156.	137.	454.	217.	118.	60.	335.

2 PROJECTS COMPOSED IN HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 1600. MW

HYDROCONDITION 1 BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	HYDROCONDITION 2 BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	HYDROCONDITION 3 BASE MW	PEAK MW	P-ENG GWH	AVAIL MW
210.	1240.	1340.	1450.	201.	1299.	1760.	1500.	215.	1085.	860.	1300.
210.	1250.	1440.	1460.	201.	1349.	1860.	1550.	215.	1105.	980.	1320.
210.	1280.	1640.	1490.	201.	1369.	2110.	1570.	215.	1125.	1180.	1340.
210.	1310.	1740.	1520.	201.	1399.	2260.	1600.	215.	1165.	1330.	1380.

* * * * * * * * * * * * END OF DATA FOR YEAR 1998 * * * * * * * * * * * *

Figure 4.2 (page 5) FIXSYS Printout for CASE93. Input Data and Fixed System Description for Year 1998

INDEX 2

PROJECT 4 (NAME: FH-1) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: -75. MW REG. ENERGY: 0.00 GWH *** RETIREMENT ***

HYDROCONDITION 1			HYDROCONDITION 2			HYDROCONDITION 3		
EA	EMIN	MWC	EA	EMIN	MWC	EA	EMIN	MWC
85.	50.	50.	95.	40.	55.	65.	60.	40.
95.	50.	55.	135.	40.	65.	75.	60.	40.
110.	50.	55.	145.	40.	75.	85.	60.	40.
75.	70.	50.	85.	65.	55.	65.	60.	40.

INDEX 1

∞

FIXED SYSTEM OF YEAR 2003 (YEAR NUMBER 7 OF THE STUDY)
4 PERIODS
3 HYDRO CONDITIONS

	NAME	NO. OF SETS	MIN. LOAD MW	CAP-CITY MW	BASE LOAD HEAT RATE	AVGE INCR HEAT RATE	FUEL COSTS CENTS/MILLION DMSTC	FORGN	FUEL TYPE	S P I N	FRCD OUT-AGE RATE	DAYS SCHL MAIN	MAIN CLAS	O&M (FIX)	O&M (VAR)	FULL LOAD HEAT RATE	UNIT GENERATION COSTS ($/MWH) BASE DOM	BASE FRGN	FLD DOM	FLD FRGN	FLD TOT
3	FCO1	3	67.	200.	2490.	2190.	665.0	0.0	1	10	6.0	35	200.	3.85	0.00	2291.	16.6	0.0	15.2	0.0	15.2
4	FCO2	5	133.	400.	2470.	2170.	80.0	730.0	2	10	9.0	42	400.	2.95	0.00	2270.	2.0	18.0	1.8	16.6	18.4
5	FOIL	4	133.	400.	2450.	2150.	60.0	1190.0	3	10	7.0	42	400.	1.95	0.00	2250.	1.5	29.2	1.3	26.8	28.1
6	F-GT	5	100.	100.	3480.	3480.	50.0	1750.0	4	0	1.2	14	100.	0.75	0.00	3480.	1.7	60.9	1.7	60.9	62.6
7	FLIG	3	120.	294.	2560.	2250.	635.0	0.0	5	10	8.0	42	400.	3.05	0.00	2377.	16.3	0.0	15.1	0.0	15.1
(8)	IMPT	1	1.	1.	2560.	2560.	0.0	3000.0	6	0	3.0	0	100.	3.10	1.55	2560.	1.6	76.8	1.6	76.8	78.3

THERMAL CAPACITY SUMMARY:

FUEL TYPE	DESCRIPTION	MW
0	NUCLEAR PLANTS	0.
1	COAL PLANTS DOM-FUEL	600.
2	COAL PLANTS IMP-FUEL	2000.
3	OIL PLANTS IMP-FUEL	1600.
4	GAS TURBINES GAS-OIL	500.
6	IMPORTS (FUEL SUBS.)	1.
7	NOT APPLICABLE	0.
8	NOT APPLICABLE	0.
9	NOT APPLICABLE	0.

FUEL TYPES WITH LIMITATION:

FUEL TYPE	DESCRIPTION	MW
5	LIGNITE PLANT (LIM.)	882.
	TOTAL	5583.

ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS

7 3 4 5 6 8

FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD1 *** O&M (FIX) = 0.70 $/KW-MONTH
****

PROJECT 4 INSTALLED CAP.: -75. MW REG. ENERGY: 0.00 GWH *** RETIREMENT ***

HYDROCONDITION 1					HYDROCONDITION 2					HYDROCONDITION 3				
BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY
39.	0.	0.	0.0	1	43.	0.	0.	0.0	1	30.	0.	0.	0.0	1
43.	0.	0.	0.0	1	62.	0.	0.	0.0	1	34.	0.	0.	0.0	1
50.	0.	0.	0.0	1	66.	0.	0.	0.0	1	39.	0.	0.	0.0	1
34.	0.	0.	0.0	1	39.	0.	0.	0.0	1	30.	0.	0.	0.0	1

4 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 425. MW
*** ***********************

HYDROCONDITION 1				HYDROCONDITION 2				HYDROCONDITION 3			
BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW
203.	137.	84.	340.	223.	142.	112.	365.	181.	109.	24.	290.
207.	148.	87.	355.	237.	148.	116.	385.	185.	110.	27.	295.
217.	153.	93.	370.	259.	146.	132.	405.	191.	119.	54.	310.
216.	149.	100.	365.	259.	156.	137.	415.	187.	118.	60.	305.

2 PROJECTS COMPOSED IN HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 1600. MW
*** ***********************

HYDROCONDITION 1				HYDROCONDITION 2				HYDROCONDITION 3			
BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW
210.	1240.	1340.	1450.	201.	1299.	1760.	1500.	215.	1085.	860.	1300.
210.	1250.	1440.	1460.	201.	1349.	1860.	1550.	215.	1105.	980.	1320.
210.	1280.	1640.	1490.	201.	1369.	2110.	1570.	215.	1125.	1180.	1340.
210.	1310.	1740.	1520.	201.	1399.	2260.	1600.	215.	1165.	1330.	1380.

* * * * * * * * * * * * * * END OF DATA FOR YEAR 2003 * * * * * * * * * * * * * *

Figure 4.2 (page 6) FIXSYS Printout for CASE93. Input Data and Fixed System Description for Year 2003

CHAPTER 5

EXECUTION OF VARSYS

5.1 Control Cards

The third group of cards in Fig. 2.3 consists of the VARSYS job control cards. They are the same as for LOADSY and FIXSYS except for the differences in the name of the program module (on the first card), the input data file used in the run (on the 3rd card), and the output file number and name (on the 5th card). The file name VARPLANT ("variable" plant as opposed to "fixed" plant) applies to file FT11 created by a VARSYS run and CASE93 is the label assigned to the particular expansion candidate description file created by this run from the data for the sample problem. VARSYS runs using a file name that has been used before will replace the old information with the new information.

5.2 Data Cards

VARSYS uses up to 5 types of data cards, depending on the types of candidate plants to be considered. If only thermal candidate plants are used, 3 data cards types are only necessary (type-2a and type-2b cards are not used in this case). Table 5.1 lists the 5 card types used by VARSYS and tells what data they contain, in sequence.

The input data are arranged in the following sequence:

First line: One type-X card with the title of the study.

Second line: One type-A card with the general information for the study.

Next lines: As many type-B cards as thermal plants need to be described in VARSYS (total number of type-B cards equal to NTHPL on the type-A card).

Rest of the input lines: As many groups of type-2a and type-2b cards as hydroelectric projects are to be considered in VARSYS. The group of cards needed for each hydro project is composed of one type-2a card and as many type-2b cards as periods per year (NPER on card type-A); each type-2b car should contain the hydro project data on capacity and energy in the period for each hydro condition specified (total equal to IHYDIS on card type-A).

5.3 Input Data for the Sample Problem

Figure 5.1 shows the input data used for the VARSYS run of the sample problem (CASE93). The first data card in this figure is a type-X card with the title of study. The same comments made in Section 3.3 for the title of study to be used in the type-X data card of LOADSY are valid for VARSYS.

The second input line in Fig. 5.1 is a type-A card used to specify the general information for the VARSYS run.

Table 5.1 (page 1) Types of data cards used in VARSYS

Card type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of study (centered to columns 30-31).
A	5-8	I	NPER	Number of periods per year (maximum 12). [Must be equal to NPER in FIXSYS].
	9-12	I	NTHPL	Number of thermal plants used as system expansion candidates (maximum 12).
	13-16	I	IHYDIS	Number of hydroconditions (maximum 5). This field and the rest of the card must be blank if hydro is not used in VARSYS.
	19-22	A	NAMH(1)	Code name of hydroelectric plant type A (same as in FIXSYS); this field must be blank if not used in VARSYS.
	23-28	F	HOM(1)	Fixed operating and maintenance costs of hydro plant type A ($/kW-month).
	31-34	A	NAMH(2)	Code name of hydroelectric plant type B (same as in FIXSYS); this field must be blank if not used in VARSYS.
	35-40	F	HOM(2)	Fixed operating and maintenance costs of hydro plant type B ($/kW-month).
	41-46 47-52 53-58 59-64 65-70	F F F F F	PROBH	Probability of hydroconditions 1 to 5; same sequence and values as in FIXSYS (the sum of these probabilities must be equal to 1.0).
B[2]	1-4	A	NAME	Code name for the thermal plant used as expansion candidate.
	8-12	F	MWB	Minimum operating level (MW).
	13-17	F	MWC	Maximum operating level (MW).
	18-24	F	BHRT	Heat rate at minimum operating level (kcal/kWh).
	25-31	F	CRMHRT	Average incremental heat rate between minimum and maximum operating levels (kcal/kWh).
	32-36	F	FCST	Domestic fuel costs (c/10^6 kcal).
	37-41	F	FCSTF	Foreign fuel costs (c/10^6 kcal).
	42-44	I	NTYPE	Plant type number (0, 1, 2, ... 9).
	45-46	I	ISPIN[3]	Spinning reserve as % of MWC.

Table 5.1 (page 2) Types of data cards used in VARSYS

Card type	Columns	Format[1]	Fortran name	Information
B (cont.)	47-51	F	FOR	Forced outage rate (%).
	52-54	I	MAINT	Number of days per year required for scheduled maintenance.
	55-59	F	MAINCL	Maintenance class size (MW).
	66-70	F	OMA	Fixed component of non-fuel operation and maintenance cost ($/kW-month) (assumed to be a domestic cost).
	71-75	F	OMB	Variable component of non-fuel operation and maintenance cost ($/MWh) (assumed to be a domestic cost).
2a[4]	3-6	A	PNAME	Name of the hydroelectric project (must be equal to NOMHY in card 2a of DYNPRO).
	9-12	A	TNAME	Code name of the hydroelectric plant type for the hydro project; must be equal to NAMH(1) of NAMH(2) of card type-A.
	13-18	F	HMW	Installed capacity of hydro project (MW).
	19-24	F	PV	Energy storage capacity of project (GWh).
	25-30	I	JAV	First year the project is available to be considered as expansion candidate.
2b[5]				Hydrocondition 1:
	1-5	F	EA	Period inflow energy (GWh) of the hydro project.
	6-10	F	EMIN	Minimum generation in base in the period (GWh).
	11-15	F	HMWC	Available capacity in period (MW).
				Hydrocondition 2:
	16-20	F	EA	Period inflow energy (GWh) of the hydro project.
	21-25	F	EMIN	Minimum generation in base in the period (GWh).
	26-30	F	HMWC	Available capacity in period (MW).
	. .	. .	. .	Continue up to last hydrocondition (maximum 5).

Notes to Table 5.1

1 See Section 2.5 for Format description.

2 One card for each thermal plant.

3 ISPIN should be defined consistently with definitions of plant capacity blocks if the loading order is to be calculated by MERSIM (see Table 7.1).

4 One card for each hydroelectric project.

5 One card per period for each hydroelectric project.

The type-A card in this case specifies the *number of periods* per year (4 in this case); *number of thermal plants* in VARSYS (i.e. the number of type-B cards to be read next) which are to be used as expansion candidates (4); *number of hydrological conditions* (3); the *code names of the two composite hydroelectric plants* (HYD1 and HYD2) and their *fixed operation and maintenance* (O&M) costs (0.7 and 0.55 $/kW-month, respectively); and finally, the *probabilities of the hydroconditions* (0.75, 0.15 and 0.10) See Table 5.1 (page 1) to fill in the data of card type-A. This type-A card is similar to the type-A data card of FIXSYS except that in VARSYS columns 1-4 are left blank. Although FIXSYS and VARSYS are independent, the input information given in the respective type-A card must be consistent; otherwise it will lead to interruption of execution of any of the subsequent modules. For example, the number of periods per year must be the same in both modules and in the respective type-A data cards.

Concerning the use of hydro plant types, it must be emphasized that when a type of hydro plant is to be used in both, FIXSYS and VARSYS, its code name and corresponding fixed O&M costs must be equal in both modules. Also, if only one but different hydro plant type is used in each module, the number of hydroconditions and their respective probabilities given in the type-A cards must be consistent. Finally, the number and order of the periods must be consistent with the input data to LOADSY (see Section 3.2).

The next lines in Fig. 5.1 are four type-B cards describing each thermal plant candidate for system expansion by its code name and 13 parameters. This type-B card is similar to the type-B data card of FIXSYS, except for cols. 5-7 which are left blank in VARSYS (i.e. no number of sets is specified for the expansion candidates) and col. 60-61 which are not used in VARSYS, since only FIXSYS thermal plants can be specified for substitution of generation by fuel limited types. The thermal plant type-B data are included as a group after the type-A card. They can appear in any order, though it is convenient to group them by fuel type and order them by unit size (e.g. if coal plants of 200 MW, 400 MW and 600 MW are to be considered as expansion candidates, they would constitute a group of three type-B cards starting with the 200 MW plant and finishing with the 600 MW plant).

The thermal expansion candidates considered for the sample problem are: 600 MW coal-fired plants (VCOA); 600 MW oil-fired plants (VFOL); 900 MW nuclear plants (VNUC); and 200 MW gas turbine plants (V-GT). These gas turbines, actually a composite pseudo unit equivalent to four 50 MW units, are used in order to reduce the number of configurations to be generated in Module 4.

After the group of type-B cards, the subsequent lines in Fig. 5.1 form the group required to define one hydroelectric project used as expansion candidate. The first line in this group is a type-2a card giving the *name* (VHY1), *plant code name* (HYD2), *installed capacity* (300.MW), the *energy regulation capacity* (15.GWh) and the *first year the hydro project* VHY1 is available to be considered as expansion candidate (1997 in this case). This type-2a card is similar to type-2a of FIXSYS, except that in VARSYS the year from which the hydro project can be considered as candidate plant must be specified. The next lines of input are four type-2b cards which contain the information for project VHY1 applicable for each period in each hydrological condition.

There is one card type-2b per period and each one gives the data for all hydro conditions: Columns 1 to 15 for hydro condition 1; 16 to 30 for hydro condition 2; and 31 to 45 for hydro condition 3. No information is given for hydro conditions 4 and 5 (cols. 46-60 and 61-75) since only 3 hydro conditions were specified in card type-A of VARSYS. See Table 5.1 (page 2) to correctly fill in the data of type-2a and type-2b cards.

```
CASE93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL
      4    4    3  HYD1     0.7  HYD2   0.55   0.75   0.15   0.10
VCOA     200. 600.  2460.   2160.   80. 730.   210 12.0 42  600        3.85 0.00
VFOL     200. 600.  2440.   2140.   60.1190.   310 10.0 42  600        1.95 0.00
VNUC     600. 900.  2566.   2361.    0. 246.   010  8.0 42  900        3.05 0.00
V-GT     200. 200.  3470.   3470.   50.1750.   4 0  1.2 14  200        0.70 0.00
  VHY1  HYD1  180.   0.13   1999
 200. 100. 160. 240. 100. 170. 140. 100. 155.
 220. 100. 170. 260. 100. 180. 160. 100. 160.
 240. 100. 170. 300. 100. 180. 175. 100. 160.
 200. 100. 160. 240. 100. 170. 140. 100. 155.
  VHY2  HYD2  300.   15.0   2001
 350. 200. 240. 400. 150. 280. 300. 250. 200.
 380. 150. 260. 420. 100. 300. 310. 200. 230.
 400. 100. 280. 450.  80. 300. 340. 150. 240.
 380. 150. 260. 420. 100. 300. 300. 200. 230.
  VHY3  HYD1  200.    3.7   2002
 235.   0. 150. 240.   0. 170. 155.   0. 140.
 245.   0. 170. 270.   0. 190. 160.   0. 140.
 255.   0. 190. 300.   0. 200. 170.   0. 140.
 235.   0. 150. 250.   0. 170. 155.   0. 140.
  VHY4  HYD2  600.   35.0   2003
 620. 300. 490. 700. 200. 550. 560. 400. 490.
 720. 200. 520. 790. 100. 560. 600. 300. 515.
 820. 150. 550. 950.  50. 600. 660. 100. 530.
 760. 200. 540. 850. 100. 570. 620. 300. 525.
  VHY5  HYD1  210.   0.45   2004
 200. 100. 210. 240. 100. 210. 155. 100. 210.
 200. 100. 210. 240. 100. 210. 155. 100. 210.
 200. 100. 210. 240. 100. 210. 155. 100. 210.
 200. 100. 210. 240. 100. 210. 155. 100. 210.
  VHY6  HYD2  300.   15.0   2005
 310.   0. 280. 360.   0. 300. 265.   0. 250.
 330.   0. 280. 380.   0. 300. 275.   0. 250.
 350.   0. 280. 400.   0. 300. 290.   0. 250.
 320.   0. 280. 380.   0. 300. 275.   0. 250.
  VHY7  HYD2  600.   40.0   2006
 500.   0. 550. 600.   0. 600. 420.   0. 540.
 600.   0. 550. 700.   0. 600. 470.   0. 540.
 700.   0. 550. 900.   0. 600. 520.   0. 540.
 640.   0. 550. 750.   0. 600. 490.   0. 540.
```

Figure 5.1 WASP-III Plus - VARSYS Input Data for the Sample Problem

In the sample problem, the data for hydro project VHY1 in period 1 are as follows:

Data	Hydro condition		
	1 (Cols. 1-15)	2 (Cols. 16-30)	3 (Cols. 31-45)
Inflow energy (GWh)	200.	240.	140.
Minimum generation in base (GWh)	100.	100.	100.
Available capacity (MW)	160.	170.	155.

The rest of the input data consists of six groups of one type-2a and four type-2b cards giving information for hydroelectric projects VHY2, VHY3, VHY4, VHY5, VHY6 and VHY7. Of these projects, VHY2, VHY4 and VHY6 are of the HYD1 type (Hydro Plants Group 1), while the remaining projects (VHY3, VHY5 and VHY7) are of the HYD2 type (Hydro Plants Group 2).

5.4 Printout of the Sample Problem

Figure 5.2 shows the printed output resulting from execution of the VARSYS module for the sample problem.

Page 1 of Fig. 5.2 is the cover page printed by VARSYS giving the title of the study. This is followed by the list of the card images of the input data used in the run. Page 2 of the figure shows this part of the printout for the sample problem. This include in sequence: the *general information* for the case study; the *thermal plant characteristics* and the *parameters describing the hydro projects* used as expansion candidates.

The next pages of the output list the description of the Variable System which will be used by Modules 3 to 6 of WASP. Pages 3 to 5 of Fig. 5.2 show the VARSYS description for the case example. It contains first, the *number of periods* per year (4) and *number of hydroconditions* (3); then the *characteristics of the candidate thermal plants* are displayed following a similar format to the one used by FIXSYS (see page 4 of Figure 4.2), except that in VARSYS column 2 of the list of thermal plants includes zeroes for the number of sets. Similar to the case in FIXSYS, the values calculated by the program for full load total (domestic + foreign) generation costs (last column to the right of the thermal plant list) are used to define the economic loading order of these plants. This loading order is also printed below the list of thermal plants (as stated in Section 4.4, this information will be used by CONGEN for calculating the basic economic loading order of the combined FIXSYS and VARSYS plants).

Following the basic economic loading order of the thermal plants are the calculated characteristics of the hydroelectric projects, if any, of each plant type, first for hydro type A and then hydro type B. For each group, the individual hydro projects are listed separately. These are printed in a similar fashion as in FIXSYS with the difference that in VARSYS the year of availability of the project is added[1]. For example, hydro project 1 (VHY2) of the HYD1 type is available for expansion from 1998 onward while the second hydro project of the same type (VHY4) is available in year 2000 (see page 4 of Fig. 5.2).

Additionally, the VARSYS printout contains the characteristics of the composite hydroelectric plant types resulting from the combination of the individual characteristics of the projects of the respective type considering all projects up to the current project; in other words they are given: for the first project, for the first and the second, for the first, second and third, and so on, up to the last project of the type. This information is printed immediately after the individual characteristics of each hydro project have been reported in the output (see pages 4 and 5 of Fig. 5.2). These characteristics of composite hydro plants are also reported in a similar fashion as in FIXSYS (see Section 4.4).

---

[1] For each hydro plant type the individual hydro projects are listed in ascending order of year of availability of the projects.

The printout of VARSYS for the user's case study should be checked with great care to make sure that the reported numbers are those intended by the user. Each number should be verified carefully as some errors will not be identified by the WASP code until the subsequent modules are run (e.g. inconsistencies between FIXSYS and VARSYS input data), and some will never be identified by the computer (e.g. a "wrong" data for the year of availability of one hydro project).

At least some internal inconsistencies in the input data are checked by the program and in case of incompatibility with the capabilities of calculation, they will cause interruption of program execution and an error message is printed. Some other inconsistencies will simply produce an error (or warning) message being printed, in order to warn the user of the potential sources of error for the subsequent WASP modules due to the input data used in VARSYS. The error and warning messages applicable to VARSYS are treated in Section B.3 of Appendix B.

```
                    WASP   COMPUTER   PROGRAM   PACKAGE

                               VARSYS  MODULE

                                CASE  STUDY

          CASE93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL
```

Figure 5.2 (page 1)   VARSYS Printout for the Sample Problem. Cover Page

VARIABLE SYSTEM INPUT DATA INFORMATION

INIT. YEAR	NO. OF PERIODS	N.THERMAL PLANTS	HYDRO COND.	****** HYDRO PLANT TYPES ****** NAME	O&M	NAME	O&M	PROBABILITY OF HYDROCONDITIONS 1	2	3	4	5
0	4	4	3	HYD1	.70	HYD2	.55	.750	.150	.100	.000	.000

NAME	NO. OF SETS	MIN. LOAD MW	CAP-CITY MW	BASE LOAD HEAT RATE	AVGE INCR HEAT RATE	FUEL COSTS CENTS/MILLION DMSTC	FORGN	TYPE	SPIN	FRCD OUT-AGE RATE	DAYS SCHL MAIN	MAIN CLAS	O&M (FIX)	O&M (VAR)
VCOA	0	200.	600.	2460.	2160.	80.0	730.0	2	10	12.0	42	600.	3.85	.00
VFOL	0	200.	600.	2440.	2140.	60.0	1190.0	3	10	10.0	42	600.	1.95	.00
VNUC	0	600.	900.	2566.	2361.	.0	246.0	0	10	8.0	42	900.	3.05	.00
V-GT	0	200.	200.	3470.	3470.	50.0	1750.0	4	0	1.2	14	200.	.70	.00

PROJECT 1 (NAME: VHY1) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 180. MW REG. ENERGY: .13 GWH AVAILABLE YEAR: 1999

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
200.	100.	160.	240.	100.	170.	140.	100.	155.
220.	100.	170.	260.	100.	180.	160.	100.	160.
240.	100.	170.	300.	100.	180.	175.	100.	160.
200.	100.	160.	240.	100.	170.	140.	100.	155.

PROJECT 1 (NAME: VHY2) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 300. MW REG. ENERGY: 15.00 GWH AVAILABLE YEAR: 2001

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
350.	200.	240.	400.	150.	280.	300.	250.	200.
380.	150.	260.	420.	100.	300.	310.	200.	230.
400.	100.	280.	450.	80.	300.	340.	150.	240.
380.	150.	260.	420.	100.	300.	300.	200.	230.

PROJECT 2 (NAME: VHY3) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 200. MW REG. ENERGY: 3.70 GWH AVAILABLE YEAR: 2002

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
235.	0.	150.	240.	0.	170.	155.	0.	140.
245.	0.	170.	270.	0.	190.	160.	0.	140.
255.	0.	190.	300.	0.	200.	170.	0.	140.
235.	0.	150.	250.	0.	170.	155.	0.	140.

PROJECT 2 (NAME: VHY4) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 600. MW REG. ENERGY: 35.00 GWH AVAILABLE YEAR: 2003

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
620.	300.	490.	700.	200.	550.	560.	400.	490.
720.	200.	520.	790.	100.	560.	600.	300.	515.
820.	150.	550.	950.	50.	600.	660.	100.	530.
760.	200.	540.	850.	100.	570.	620.	300.	525.

PROJECT 3 (NAME: VHY5) OF HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 210. MW REG. ENERGY: .45 GWH AVAILABLE YEAR: 2004

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
200.	100.	210.	240.	100.	210.	155.	100.	210.
200.	100.	210.	240.	100.	210.	155.	100.	210.
200.	100.	210.	240.	100.	210.	155.	100.	210.
200.	100.	210.	240.	100.	210.	155.	100.	210.

PROJECT 3 (NAME: VHY6) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 300. MW REG. ENERGY: 15.00 GWH AVAILABLE YEAR: 2005

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
310.	0.	280.	360.	0.	300.	265.	0.	250.
330.	0.	280.	380.	0.	300.	275.	0.	250.
350.	0.	280.	400.	0.	300.	290.	0.	250.
320.	0.	280.	380.	0.	300.	275.	0.	250.

PROJECT 4 (NAME: VHY7) OF HYDRO TYPE *** HYD2 *** INSTALLED CAP.: 600. MW REG. ENERGY: 40.00 GWH AVAILABLE YEAR: 2006

HYDROCONDITION 1 EA	EMIN	MWC	HYDROCONDITION 2 EA	EMIN	MWC	HYDROCONDITION 3 EA	EMIN	MWC
500.	0.	550.	600.	0.	600.	420.	0.	540.
600.	0.	550.	700.	0.	600.	470.	0.	540.
700.	0.	550.	900.	0.	600.	520.	0.	540.
640.	0.	550.	750.	0.	600.	490.	0.	540.

Figure 5.2 (page 2) VARSYS Printout for the Sample Problem. Card Image of Input Data

VARIABLE SYSTEM, RESULT OF THE STUDY
4 PERIODS
3 HYDRO CONDITIONS

	NAME	NO. OF SETS	MIN. LOAD MW	CAP-CITY MW	BASE LOAD HEAT RATE	AVGE INCR HEAT RATE	FUEL COSTS CENTS/MILLION DMSTC	FUEL COSTS CENTS/MILLION FORGN	TYPE	SPIN	FRCD OUT-AGE RATE	DAYS SCHL MAIN	MAIN CLAS	O&M (FIX)	O&M (VAR)	FULL LOAD HEAT RATE	UNIT GENERATION COSTS ($/MWH) BASE DOM	BASE FRGN	FLD DOM	FLD FRGN	FLD TOT
1	VCOA	0	200.	600.	2460.	2160.	80.0	730.0	2	10	12.0	42	600.	3.85	0.00	2260.	2.0	18.0	1.8	16.5	18.3
2	VFOL	0	200.	600.	2440.	2140.	60.0	1190.0	3	10	10.0	42	600.	1.95	0.00	2240.	1.5	29.0	1.3	26.7	28.0
3	VNUC	0	600.	900.	2566.	2361.	0.0	246.0	0	10	8.0	42	900.	3.05	0.00	2498.	0.0	6.3	0.0	6.1	6.1
4	V-GT	0	200.	200.	3470.	3470.	50.0	1750.0	4	0	1.2	14	200.	0.70	0.00	3470.	1.7	60.7	1.7	60.7	62.5

ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS

3 1 2 4

FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD1 *** O&M (FIX) = 0.70 $/KW-MONTH
****

PROJECT 1 INSTALLED CAP.: 180. MW REG. ENERGY: 0.13 GWH AVAILABLE YEAR: 1999

HYDROCONDITION 1 *					HYDROCONDITION 2 *					HYDROCONDITION 3 *				
BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY
91.	0.	0.	0.0	1	105.	65.	9.	2.2	2	64.	0.	0.	0.0	1
100.	0.	0.	0.0	1	115.	65.	9.	2.1	2	73.	0.	0.	0.0	1
105.	65.	9.	2.2	2	133.	47.	9.	3.0	2	80.	0.	0.	0.0	1
91.	0.	0.	0.0	1	105.	65.	9.	2.2	2	64.	0.	0.	0.0	1

1 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 180. MW
*** ************************

HYDROCONDITION 1 *				HYDROCONDITION 2 *				HYDROCONDITION 3 *			
BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW
91.	0.	0.	91.	105.	65.	9.	170.	64.	0.	0.	64.
100.	0.	0.	100.	115.	65.	9.	180.	73.	0.	0.	73.
105.	65.	9.	170.	133.	47.	9.	180.	80.	0.	0.	80.
91.	0.	0.	91.	105.	65.	9.	170.	64.	0.	0.	64.

PROJECT 2 INSTALLED CAP.: 200. MW REG. ENERGY: 3.70 GWH AVAILABLE YEAR: 2002

HYDROCONDITION 1 *					HYDROCONDITION 2 *					HYDROCONDITION 3 *				
BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY
29.	121.	172.	21.8	3	29.	141.	177.	19.2	3	3.	137.	149.	16.7	3
31.	139.	177.	19.6	3	39.	151.	185.	18.8	3	4.	136.	152.	17.1	3
33.	157.	183.	17.8	3	50.	150.	191.	19.5	3	6.	134.	156.	17.9	3
29.	121.	172.	21.8	3	33.	137.	178.	19.9	3	3.	137.	149.	16.7	3

2 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 380. MW
*** ************************

HYDROCONDITION 1 *				HYDROCONDITION 2 *				HYDROCONDITION 3 *			
BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW
120.	121.	172.	241.	134.	206.	186.	340.	66.	137.	149.	204.
131.	139.	177.	270.	153.	217.	194.	370.	77.	136.	152.	213.
139.	221.	192.	360.	182.	198.	201.	380.	86.	134.	156.	220.
120.	121.	172.	241.	138.	202.	187.	340.	66.	137.	149.	204.

PROJECT 3 INSTALLED CAP.: 210. MW REG. ENERGY: 0.45 GWH AVAILABLE YEAR: 2004

HYDROCONDITION 1 *					HYDROCONDITION 2 *					HYDROCONDITION 3 *				
BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY	BASE MW	PEAK MW	P-ENG GWH	P-HR HR	KEY
76.	134.	33.	3.8	2	94.	116.	34.	4.5	2	56.	154.	32.	3.2	2
76.	134.	33.	3.8	2	94.	116.	34.	4.5	2	56.	154.	32.	3.2	2
76.	134.	33.	3.8	2	94.	116.	34.	4.5	2	56.	154.	32.	3.2	2
76.	134.	33.	3.8	2	94.	116.	34.	4.5	2	56.	154.	32.	3.2	2

3 PROJECTS COMPOSED IN HYDRO TYPE *** HYD1 *** INSTALLED CAP.: 590. MW
*** ************************

HYDROCONDITION 1 *				HYDROCONDITION 2 *				HYDROCONDITION 3 *			
BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW	BASE MW	PEAK MW	P-ENG GWH	AVAIL MW
196.	255.	205.	451.	229.	321.	219.	550.	122.	291.	182.	414.
208.	273.	210.	480.	247.	333.	228.	580.	133.	290.	184.	423.
215.	355.	225.	570.	276.	314.	235.	590.	142.	288.	189.	430.
196.	255.	205.	451.	232.	318.	221.	550.	122.	291.	182.	414.

Figure 5.2 (page 3) VARSYS Printout for the Sample Problem. Description of the Variable System.

```
FOLLOWING HYDRO PROJECTS ARE OF TYPE *** HYD2 ***    O&M (FIX) =   0.55 $/KW-MONTH
*****************************************************************************************************************

PROJECT   1     INSTALLED CAP.:  300. MW     REG. ENERGY:    15.00 GWH    AVAILABLE YEAR: 2001

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR         MW    MW   GWH   HR         MW    MW   GWH   HR

   91.  149.  150. 15.5  4   68.  212.  250. 18.1  4  114.   86.   50.  8.9  4
   68.  192.  230. 18.4  4   46.  254.  320. 19.3  4   91.  139.  110. 12.2  4
   46.  234.  300. 19.6  4   37.  263.  370. 21.5  4   68.  172.  190. 17.0  4
   68.  192.  230. 18.4  4   46.  254.  320. 19.3  4   91.  139.  100. 11.1  4

 1 PROJECTS  COMPOSED IN  HYDRO TYPE *** HYD2 ***        INSTALLED CAP.:  300. MW
 ***********************************************        ***********************

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
   BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL
    MW    MW   GWH   MW         MW    MW   GWH   MW         MW    MW   GWH   MW

    91.  149.  150.  240.       68.  212.  250.  280.      114.   86.   50.  200.
    68.  192.  230.  260.       46.  254.  320.  300.       91.  139.  110.  230.
    46.  234.  300.  280.       37.  263.  370.  300.       68.  172.  190.  240.
    68.  192.  230.  260.       46.  254.  320.  300.       91.  139.  100.  230.

PROJECT   2     INSTALLED CAP.:  600. MW     REG. ENERGY:    35.00 GWH    AVAILABLE YEAR: 2003

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR         MW    MW   GWH   HR         MW    MW   GWH   HR

  137.  353.  320. 13.9  4   91.  459.  500. 16.7  4  183.  307.  160.  8.0  4
   91.  429.  520. 18.6  4   46.  514.  690. 20.6  4  137.  378.  300. 12.2  4
   68.  482.  670. 21.3  4   23.  577.  900. 23.9  4   46.  484.  560. 17.7  4
   91.  449.  560. 19.1  4   46.  524.  750. 21.9  4  137.  388.  320. 12.7  4

 2 PROJECTS  COMPOSED IN  HYDRO TYPE *** HYD2 ***        INSTALLED CAP.:  900. MW
 ***********************************************        ***********************

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
  BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL
   MW    MW   GWH   MW         MW    MW   GWH   MW         MW    MW   GWH   MW

  228.  502.  470.  730.      160.  670.  750.  830.      297.  393.  210.  690.
  160.  620.  750.  780.       91.  769. 1010.  860.      228.  517.  410.  745.
  114.  716.  970.  830.       59.  841. 1270.  900.      114.  656.  750.  770.
  160.  640.  790.  800.       91.  779. 1070.  870.      228.  527.  420.  755.

PROJECT   3     INSTALLED CAP.:  300. MW     REG. ENERGY:    15.00 GWH    AVAILABLE YEAR: 2005

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR         MW    MW   GWH   HR         MW    MW   GWH   HR

    0.  280.  310. 17.0  4    0.  300.  360. 18.4  4    0.  250.  265. 16.3  4
    0.  280.  330. 18.1  4    0.  300.  380. 19.4  4    0.  250.  275. 16.9  4
    0.  280.  350. 19.2  4    0.  300.  400. 20.5  4    0.  250.  290. 17.8  4
    0.  280.  320. 17.5  4    0.  300.  380. 19.4  4    0.  250.  275. 16.9  4

 3 PROJECTS  COMPOSED IN  HYDRO TYPE *** HYD2 ***        INSTALLED CAP.: 1200. MW
 ***********************************************        ***********************

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
  BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL
   MW    MW   GWH   MW         MW    MW   GWH   MW         MW    MW   GWH   MW

  228.  782.  780. 1010.      160.  970. 1110. 1130.      297.  643.  475.  940.
  160.  900. 1080. 1060.       91. 1069. 1390. 1160.      228.  767.  685.  995.
  114.  996. 1320. 1110.       59. 1141. 1670. 1200.      114.  906. 1040. 1020.
  160.  920. 1110. 1080.       91. 1079. 1450. 1170.      228.  777.  695. 1005.

PROJECT   4     INSTALLED CAP.:  600. MW     REG. ENERGY:    40.00 GWH    AVAILABLE YEAR: 2006

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
  BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY BASE  PEAK P-ENG P-HR KEY
   MW    MW   GWH   HR         MW    MW   GWH   HR         MW    MW   GWH   HR

    0.  550.  500. 13.9  4    0.  600.  600. 15.3  4    0.  540.  420. 11.9  4
    0.  550.  600. 16.7  4    0.  600.  700. 17.9  4    0.  540.  470. 13.4  4
    0.  550.  700. 19.5  4    0.  600.  900. 23.0  4    0.  540.  520. 14.8  4
    0.  550.  640. 17.9  4    0.  600.  750. 19.2  4    0.  540.  490. 13.9  4

 4 PROJECTS  COMPOSED IN  HYDRO TYPE *** HYD2 ***        INSTALLED CAP.: 1800. MW
 ***********************************************        ***********************

       HYDROCONDITION  1   *      HYDROCONDITION  2   *      HYDROCONDITION  3   *
  BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL      BASE  PEAK P-ENG AVAIL
   MW    MW   GWH   MW         MW    MW   GWH   MW         MW    MW   GWH   MW

  228. 1332. 1280. 1560.      160. 1570. 1710. 1730.      297. 1183.  895. 1480.
  160. 1450. 1680. 1610.       91. 1669. 2090. 1760.      228. 1307. 1155. 1535.
  114. 1546. 2020. 1660.       59. 1741. 2570. 1800.      114. 1446. 1560. 1560.
  160. 1470. 1750. 1630.       91. 1679. 2200. 1770.      228. 1317. 1185. 1545.
```

Figure 5.2 (page 4) VARSYS Printout for the Sample Problem. Description of the Variable System (cont.)

CHAPTER 6

EXECUTION OF CONGEN

6.1 Control Cards

The fourth group of cards listed in Fig. 2.3 are the eleven CONGEN job control cards. The first four are similar to the respective control cards for Modules 1 to 3 except for the module name, and the input data file involved. Control cards 5 to 7 define which data files are called upon by CONGEN, i.e. the FIXPLANT, VARPLANT and LOADDUCU files created by earlier runs of modules 1 to 3; in this case the files labelled "CASE93" which were created by the runs of the sample problem.

Control card 8 defines the data file created by CONGEN, the EXPANALT file, which is used subsequently by MERSIM, DYNPRO, and REPROBAT. The first CONGEN run of the sample problem (see Section 6.3 and 6.4) creates the EXPANALT file labelled "CASE93"; for which file space has been previously allocated by the WASP analyst. Any subsequent CONGEN run using this label will replace the old information with the new information.

Control card 9 specifies the simulation file (SIMULOLD) containing the results of the simulations performed so far by the MERSIM Module. This is used by CONGEN to verify whether a configuration generated in the current run has already been simulated and if not, to mark it as a "new" configuration in the printed output[1]. This feature allows the user to estimate the execution time of the subsequent MERSIM run, based on the total number of "new" configurations expected to be simulated.

Finally, the last control cards define a working file used by CONGEN to temporarily handle information during execution of the program (notice that the comma in card 10 means that the next one is a continuation card).

6.2 Data Cards

CONGEN uses up to 8 types of data cards, depending on the constraint options selected by the user to generate system configurations in each year of study. Table 6.1 lists the 8 types of data cards of CONGEN, showing also what data they contain and the corresponding field, formats and Fortran names of the variables.

The type-X card is required once at the beginning of the input data. A type-1 INDEX=1 card is the end of year card indicating that all data for current year have been completed and that the calculations for the year must be done next. Cards type-1 with INDEX=2, 3, 4, 6, 7 or 8 are used to tell the computer that the next input line to be read is a card of type equal to the INDEX number (e.g. one card type-1 INDEX=4 must be followed by one type-4 card). Therefore, it is important to check that the proper sequence of data cards is used; otherwise it will lead to wrong calculations or interruption of the CONGEN execution and the printing of an error message (see Section B.4 of Appendix B).

---

[1] For the first run of CONGEN, the SIMULOLD file will obviously be empty so that all configurations are "new". However, they are not marked as such in the printout of the run (see Section 6.3).

Table 6.1 (page 1) Types of data cards used in CONGEN

Card type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of study (centered to colums 30-31).
	61-64	I	IOFILE	File printing option; equal 1 to print files from FIXSYS and VARSYS (default value = 0, i.e. no printing of files).
1	1-4	I	INDEX	Index number; 1 indicates end of data for the current year; 2, 3, 4, 6, 7 or 8 indicates that a card follows of type equal to the index number[2].
2	1-4 5-8 9-12 etc.	I	MINST(j)	Each number is the minimum number of sets of variable system expansion candidate type j required to be in service during current year ($j \leq 14$)[3] (default values =0).
3	1-4 5-8 9-12 etc.	I	ITWTH(j)	Maximum number of sets of the expansion candidate type j permitted for expansion in addition to MINST(j)[3]. It is also called the tunnel width (default values = 0).
4	1-10	F	RSVMN	Minimum permissible reserve margin (% of the peak load) in critical period[4].
	11-20	F	RSVMX	Maximum permissible reserve margin (% of the peak load) in critical period[4].
6	1-4	I	IOPTN	LOLP option; 0 (zero), default value, calls for no calculation of LOLP in CONGEN: 1 calls for calculation of LOLP (ignoring maintenance requirements of the thermal power plants) in CONGEN and rejection of configurations for which LOLP exceeds one of the critical values specified on card type-7 (see below); 2 is like 1, except that, in addition no over-expansion will be permitted[5]; once the 0 option is chosen it must remain 0; however, the 1 and 2 options can be changed by year. [Note: It is strongly recommended to use the default value (0) and in this case the cards type-1 INDEX=6 and INDEX=7 and the related type-6 and type-7 cards are not required.]

Table 6.1 (page 2) Types of data cards used in CONGEN

Card type	Columns	Format[1]	Fortran name	Information
7	1-10	F	CLOLP	Critical (maximum acceptable) value of LOLP in each period (%) [the default value is equal to 100 x (NPER/365)].
	11-20	F	ALOLP	Critical (maximum acceptable) average annual value of LOLP (%) [the default value is equal to 100/365)].
8	1-4	I	IHCRIT	Number of the hydro condition for which critical period and reserve margins are to be calculated. [default value equals 1]

Notes to Table 6.1:

1 See Section 2.5 for format description.

2 INDEX=5 is not available in CONGEN.

3 The order of the expansion candidates is: first, the thermal plants in the same order they were read in VARSYS (from 1 to NTHPL); followed by hydro projects type A (if they exist in VARSYS) and finally hydro projects type B (if they exist in VARSYS).

4 Critical period: The period of the year in which the difference between the corresponding available generating capacity and the peak load is the smallest.

5 No over-expansion means that each configuration retained by CONGEN satisfies the constraints on LOLP and reserve margins, but the number of units of each candidate plant is the smallest compatible with the minimum number of sets required [MINST(j)] and tunnel widths [ITWTH(j)].

Each type-1 INDEX=2 (3, 4, 6, 7 or 8) card, followed by a card type-2 (3, 4, 6, 7 or 8) will constitute a group. Although these groups may appear in the input data in any order, each group will be examined in ascending order of the INDEX number. Moreover, some of these groups of data cards must be always provided as input, at least for the first year of study, unless the user does not want to change the default values for the respective variables in CONGEN. For example, if the user wants to define MINST and ITWTH greater than the default values ("0"), type-2 and type-3 cards must be used (at least for the first year). In this case, one type-1 INDEX=2 card followed by a type-2 card are included to define the minimum number of sets (or projects for hydro candidates) for each Variable System expansion candidate that can be contained in any acceptable configuration for the year. Similarly, a type-1 INDEX=3 and a type-3 cards are used to define the maximum acceptable number (in addition to the minimum required) of sets or projects of each expansion candidate. If no type-2 or type-3 cards are used in a particular CONGEN run, the only configuration which can be examined for each year is the one containing zeroes for all expansion candidates (i.e. no expansion of the system is permitted).

A type-1 INDEX=4 and a type-4 cards must be included in the input data (at least for the first year) to tell the computer what are the values for the minimum and maximum reserve margins to be respected by each configuration of the system. If no card type-4 is used in a particular CONGEN run, the only configuration which can be examined by CONGEN in each year is the one having zero reserve margin since the default values for RSVMN and RSVMX are both zero. This is not mentioned in Table 6.1 in order to emphasize the need to use the type-4 card as input for the run.

A type-1 INDEX = 6 card and a type-6 card may be used if it is desired to change the option for calculating LOLP from the default value ("0") in the CONGEN module. This can be changed to "1" or "2" with the only restrictions indicated in Table 6.1.

Similarly, a type-1 INDEX = 7 and a type-7 cards may be used to change the default values for the critical period LOLP and annual average LOLP. Obviously, this group of cards is to be used only if the option for LOLP calculation is equal to 1 or 2 is used for the run. Finally, a type-1 INDEX = 8 and a type-8 cards may be used to change the number of the hydrocondition for which the critical period and reserve margins of the system configurations are to be calculated.

The input data of CONGEN are arranged in the following sequence:

a) For the first year:

- First line: One type-X card with the title of the study and the file printing option chosen for the run.

- Next lines: Groups of cards type-1 INDEX = 2, 3 or 4, each one followed by a card of type-2, -3 or -4, respectively, defining the constraints for the number of sets or projects of each expansion candidate and for the reserve margins. Groups of cards type-1 INDEX = 6, 7 or 8, each one followed by a card type-6, -7 or -8, respectively, if the user wants to modify the default values in the program for the corresponding variables (IOPTN, CLOLP, ALOLP and IHCRIT).

  As mentioned earlier, the above groups of cards may appear in any order.

- Last line: One type-1 INDEX = 1 card (end of the year).

b) For the second and subsequent years:

- Groups of cards type-1 INDEX = 2, 3, 4 or 7, each one followed by the corresponding card of type equal to the INDEX number for each change to be introduced to the respective values applicable in the preceding year.

  The user may also include changes to the option for LOLP calculation (a type-1 INDEX = 6 and a type-6 cards) with the only restriction stated in Table 6.1.

  In principle, a card type-1 INDEX = 8 (followed by a type-8 card) may be included each year to change the number of the hydrocondition for which LOLP and reserve margins are to be calculated. For planning purposes, however, it is advisable to maintain the same hydrocondition throughout all years of study in a single CONGEN run (and throughout the WASP study).

- Last line: One type-1 INDEX = 1 card (end of the year).

6.3 Input Data for a Fixed Expansion Plan (CONGEN Run-1)

Sometimes, it is convenient to carry out a WASP run with a predetermined expansion plan (i.e. one single configuration per year) in order to examine such aspects as cash flows, value of the objective function as a function of varying economic parameters, and comparison of a limited number of expansion policies. For the purposes of the discussion that follows, this type of run is called a 'fixed expansion plan'. This usually involves execution in sequential order of modules 4 to 6 (and sometimes Module 7).

Carrying out a WASP run for a fixed expansion plan has also the advantage of permitting to check up the accuracy of control cards and data cards used by Modules 4 to 6 (and 7), as well as the files created by each preceding module which are called upon during program execution. This is particularly valid for the first runs of CONGEN (MERSIM and DYNPRO) under the user's case name. The following paragraphs describe how a fixed expansion plan is carried out with the CONGEN module and presents the sample data for the first CONGEN run of CASE93. The corresponding printout for this run is presented in Section 6.4, while the subsequent MERSIM and DYNPRO runs for this fixed expansion plan are presented in Sections 7.3 and 7.4 for MERSIM, and in Sections 8.3 and 8.4 for DYNPRO. The use of CONGEN to generate alternative configurations each year (called a dynamic or variable expansion run) which are to be, first, simulated by MERSIM, and then compared by the dynamic programming algorithm of DYNPRO is discussed in Sections 6.5 and 6.6.

Figure 6.1 represents the input data prepared for a fixed expansion plan of the sample problem, corresponding to the first CONGEN run for CASE93, therefore identified as CONGEN Run-1.

The first input line in Fig. 6.1 is a type-X card containing in columns 1-60 the title of study and in column 64 the selected option for printing of the FIXSYS and VARSYS files (in this case a 1 asks for printing of this information). In principle all comments made in Section 3.3 for the title of study to be used in the type-X card of LOADSY are also valid for CONGEN. Also, as stated in that section, the same title of the study is used along all runs of our sample problem. However, since this title is only used by CONGEN to print the cover page of the output for the run, the user may change the title for subsequent runs in order to identify the sequence followed, for quick reference. This is particularly useful in the search for the optimal solution when many sequential variable expansion runs of modules CONGEN-MERSIM-DYNPRO are executed. During such process, the user may identify each sequential run of these three modules (called an iteration) by a corresponding number to be included in the title of study data for these modules.

The second line of data is a type-1 INDEX=4 card and is followed by a type-4 card, which is used to specify the minimum and maximum reserve margins in the critical period, in percent (%) of peak load. For a predetermined expansion plan it is recommended that the minimum and maximum reserve margins are such that they permit a wide range of acceptable capacity for the configurations, so that the predetermined plan is not excluded in any year. In the example, a minimum reserve margin of -5% and a maximum of 50% have been specified[2].

[2] Although the capacity of the configurations considered in the present example are not below the period peak load, the use of a negative value for the minimum reserve margin and the large value of the maximum reserve margin guarantees that all configurations will be accepted. In some cases, the maximum reserve margin can have larger values.

```
CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL        1
4
   -5.0       50.0
6
0
8
1
2
0    0    0    0    0    0
3
0    0    0    0    0    0
1              (END OF 1997)
2
0    0    0    0    0    0
1              (END OF 1998)
2
0    0    0    0    1    0
1              (END OF 1999)
2
0    0    0    1    1    0
1              (END OF 2000)
2
1    0    0    1    1    1
1              (END OF 2001)
2
1    0    0    2    2    1
1              (END OF 2002)
2
1    0    0    2    2    2
1              (END OF 2003)
2
2    0    0    2    3    2
1              (END OF 2004)
2
2    0    0    3    3    3
1              (END OF 2005)
2
2    0    1    3    3    4
1              (END OF 2006)
2
3    0    1    4    3    4
1              (END OF 2007)
2
3    1    2    4    3    4
1              (END OF 2008)
2
4    1    2    4    3    4
1              (END OF 2009)
2
4    1    3    6    3    4
1              (END OF 2010)
2
5    1    3    6    3    4
1              (END OF 2011)
2
5    1    4    6    3    4
1              (END OF 2012)
2
6    1    4    8    3    4
1              (END OF 2013)
```

Figure 6.1 (Page 1)   WASP-III Plus - CONGEN Input Data for a Fixed Expansion for the Sample Problem. CONGEN Run-1

```
2
6   1   5   8   3   4
1           (END OF 2014)
2
7   1   5   8   3   4
1           (END OF 2015)
2
8   1   5   8   3   4
1           (END OF 2016)
```

Figure 6.1 (Page 1) WASP-III Plus - CONGEN Input Data for a Fixed Expansion for the Sample Problem. CONGEN Run-1

The next input lines are a type-1 INDEX=6 and a type-6 cards which specify the LOLP calculation option. In the case example, option 0 has been selected[3], asking for no calculation of LOLP of the configurations in the run[4].

The next data lines are a type-1 INDEX=8 card, followed by one type-8 card telling the computer that the critical LOLP and reserve margins of the configurations are to be calculated for hydro condition 1[3].

The following two lines are a type-1 INDEX=2 and a type-2 cards giving the minimum number of sets (or projects in the case of hydro plants) of each candidate plant that can be included in the yearly configurations. This set of numbers will normally determine the so-called "minimum configuration" required by the user in the given year; however, since this is a predetermined expansion plan, in this case they determine the system configuration for the year. The order of the expansion candidates is the same as in the VARSYS listing shown in Figures 5.1 and 5.2. Hence, column 4 applies to the VCOA plant; column 8 to the VFOL plant and so on, with the last two columns applying to the two composite hydro plants (HYD1 and HYD2). In the sample problem all columns are shown as zeroes meaning that no addition of VARSYS candidates is considered this year[3].

The next group of input lines are a type-1 INDEX=3 and a type-3 cards giving the *maximum number of sets (or projects)* of each expansion candidate permitted for addition to the system, *above the minimum number of sets (or projects)* specified in the type-2 card. The set of numbers in the type-3 card will normally determine the so-called "tunnel-width"; however, since this is a predetermined expansion plan, the minimum and maximum number of units or projects permitted are the same (e.g. tunnel width is zero for all candidates). Therefore, the type-3 card shows a zero for each expansion candidate being considered[3].

---

[3] Note that the specified value(s) is(are) equal to the default value(s) contained in the program (see Table 6.1); therefore, these two cards may have been omitted altogether, but they have been included here for demonstration purposes.

[4] If a different value is used for the LOLP option (1 or 2) the LOLP (without maintenance) for each period and for the annual average would be calculated for each configuration and the critical period LOLP and annual average LOLP would be compared against the respective LOLP limits, CLOLP and ALOLP (using either the default value or any values specified by the user in the corresponding type-7 data cards). For fixed expansion runs of CONGEN it is recommended to use the default values for CLOLP and ALOLP so as to avoid rejection by CONGEN of any configuration contained in the predetermined expansion plan.

This tunnel width will remain the same until a new group of one type-1 INDEX = 3 and one type-3 cards showing a change are used. For a predetermined expansion plan, the tunnel width for each expansion candidate remains zero, so that no further cards type-3 are required.

The last line of input for this year (1997) is a card type-1 INDEX = 1 (end of the year card). Similarly as explained for the previous WASP modules, CONGEN will read the "1" in column 4 and will proceed to execute the calculations for the year. For the convenience of the user, however, the year is shown in this card (columns 16 to 28) to indicate the end of input information for the year being considered.

The input data for the second year (1998) includes a type-1 INDEX = 2 card to indicate that another type-2 card follows. This card shows a 0 in all columns[3] (again no addition of VARSYS candidates is made in this year). These are followed by a type-1 INDEX = 1 card to tell the computer that the data for 1998 have been completed.

The first addition of VARSYS candidates is made in year 1999. This is shown in the subsequent type-2 card which includes a 1 in the fifth column, corresponding to addition of the first project of hydro plant A (HYD1) .

The same sequence of cards (one type-1 INDEX = 2, a type-2 and a type-1 INDEX = 1 cards) follows up to the end of the study describing each year's configurations and giving the data for that year. For example the configuration in the last year of study (2016) includes 8 x 600 MW coal-fired units (plant VCOA of VARSYS); 1 x 600 MW oil-fired units (plant VFOL); 5 x 900 MW nuclear units (plant VNUC); 8 x 200 MW gas turbines sets (plant V-GT); 3 hydro projects of the HYD1 type and 4 of the HYD2 type.

6.4 Printout for a Fixed Expansion Plan (CONGEN Run-1)

Figure 6.2 shows a sample of the printed output of the CONGEN run using the data of Fig. 6.1. Since the file printing option has been set to "1" for this run, the output begins with a listing of the information read by CONGEN from the FIXSYS and VARSYS files. Pages 1 to 2 of Fig. 6.2 show these listings for the CONGEN Run-1 of the sample case.

Page 1 contains the description of the Fixed System for year 1997, as it was written by the latest run of FIXSYS on the FIXPLANT file labelled "CASE93". The same information is used by CONGEN while generating the configurations of the system for this year[5]. The top part starts with the title of the study as given in FIXSYS, followed by a listing of the "fuel" types used in the study (first the thermal plant fuel types and then the two composite hydro plants). The two fields to the right hand side of each thermal fuel type identify fuel types associated with energy (fuel) limitations. Consequently, for the sample printout, fuel type code 5 shows the FIXSYS plant to be used for substitution (plant 8) and the actual amount of limitation imposed to this fuel type (13,000 10^6 kcal/day).

The lower part in page 1 lists the actual description of the Fixed System for the year, starting with the number of the year (1 for first year of study), followed by the number of records read in (35 in this case), the corresponding year (1997), and the general information which was given on card type-A of FIXSYS (see Figure 4.2). Lines 2 to 7 show the state

---

[5] The information shown in this page actually spreads over two separate pages of the printout. These have been compressed into a single page to reduce the size of the manual.

of the FIXSYS thermal plants in this year. Line 8 corresponds to the summary of thermal capacity by type of fuel; line 9 is the basic economic loading order of the FIXSYS thermal plants; and line 10 lists the full load total operating costs of these plants. The last part of the listing shows the characteristics of the two composite hydro plants. This information is the same one shown in pages 3 and 4 of Fig. 4.2, except that for hydroelectric plants, only the characteristics of each composite hydro plant are included (the individual characteristics of the hydro projects of each type are indeed not required for the calculations carried out by CONGEN, MERSIM or DYNPRO).

Consequently, lines 11 to 22 of the lower part of Fig. 6.2 correspond to composite hydro plant type A (HYD1) and 23-34 to the composite hydro plant type B (HYD2). Each line lists the information applicable to one period and one hydrocondition starting with period 1 hydrocondition 1, followed by period 1 hydrocondition 2 and so on until period 4 hydrocondition 3. The sequence of the data included in each line is as follows: *name* of the hydro plant type name; *number of projects* composed; *year* of this information; total *installed capacity*; the *base, peak, and total available capacity*; and the *base, peak, and total available energy*. The names of these variables are listed in the last line of the printout in order to facilitate the identification of each piece of information.

The printout continues with the Variable System description as it will be used by CONGEN. Page 2 of Fig. 6.1 shows this part of the printout for CONGEN Run-1 of the sample problem[5]. Comparing this information with the one shown in pages 4-6 of Fig. 5.2, it can be seen that they are basically the same, except that in the CONGEN printout only the characteristics of each composite hydro plant are included (combining up to the first, up to the second, ... , and up to the last project of the corresponding type). It should also be noticed that the information listed in this page follows the same sequence described for the state of the Fixed System discussed above, except that in VARSYS the year shown in the listing of hydro plant characteristics corresponds to the year of availability of the projects combined in this plant type.

Page 3 of Fig. 6.2 is the cover page printed by CONGEN (which serves to identify the run) showing the title of the study and the list of the Variable System expansion candidates which is read from the VARSYS file. This list starts with the thermal plants, followed by the two hydro plants defined for the sample problem. Each expansion candidate is identified by its code name and a number corresponding to the sequential number in which the candidates were defined in VARSYS. The same sequential order is used throughout the printout to define the system configurations.

The next piece of output produced by CONGEN in this particular run consists of the basic economic loading order calculations using the combined list of FIXSYS and VARSYS thermal plants and contains all the information read from these two modules for the associated plants. This is shown in the upper part of page 4 of Fig. 6.1[5]. The last two lines of this part list, in sequence, the resulting basic economic loading order and the full load total generation costs for the combined FIXSYS and VARSYS systems. This information will be passed by CONGEN onto MERSIM where it can be used for calculation of the actual loading order of the blocks of capacity of thermal and hydro plants, if the user so desires.

The bottom part of page 4[5] shows the results of the CONGEN analysis for the first year of study (1997). It starts with the number of Fourier coefficients (read from the LOADSY file), followed by the INDEX number of the data cards type-1 read for the year along with the constraints used to generate the configurations. These include the constraints on the minimum required number of sets (or projects) and the maximum additional number of sets (or projects) of each expansion candidate, followed by the minimum and maximum acceptable values for reserve margins, and the option selected for LOLP calculations (0 in this case)[6]. Next, the output reports the hydrocondition (1 in this case) for which the critical period and reserve margin of the configurations are to be calculated. This is followed by a summary of the Fixed System capacity by period, also broken down into thermal plants and the two composite hydro plants, together with the information on the period peak loads (as read from the LOADSY file). The critical period (4 in this case) is next identified in the printout, and the minimum and maximum acceptable capacities (based on the reserve margins specified) in this period are listed. This is followed by the total capacity of the "minimum configuration" of the year (i.e. capacity of all plants in FIXSYS plus the capacity of all units or projects defined as minimum required shown above) in the critical period. The next output line is the minimum number of Fourier coefficients required for accurate LOLP calculation for the maximum reserve margin capacity (5 in this case). This value is an indication of how far is the maximum reserve margin capacity from the limit of validity of the Fourier Series approximation to the inverted load duration curve (this limit is equal to Peak load + 2*Min. load). A too-high value of this required number of Fourier coefficients will indicate the user that the maximum reserve margin should be lowered if accurate calculation of LOLP is required for all configurations.

The printout proceeds with the actual list of configurations generated by CONGEN for this year while respecting all above mentioned constraints. The information for each configuration (state) is reported in one line of the output as follows (with reference to the state on page 4 of Fig. 6.1): The first column (STATE) is the *number of the configuration throughout the run* (1); the second column (IC) the *state number of the year* (1); the third column (CAP) the *capacity of the state* (7014. MW) in the critical period[7]. The right-hand columns list the accepted configurations for the year. Since this is a predetermined expansion plan, only one configuration has been accepted. This is identified with "0" for all expansion candidates. The remaining information consists of the number of configurations for the year and the total number of accepted configurations accumulated through the current run (both 1 in this case).

A similar output is produced for each year of the study with the only difference that the information read by CONGEN from the VARSYS file will not be repeated. However, the Fixed System description for the year will be listed. As an example, page 5 of Fig. 6.2 shows the output for year 2003. Since a change was made to hydro plant type HYD1 of FIXSYS in this year (see Fig. 4.2 page 8), the characteristics of this composite hydro plant report this change. (see modification of number of projects composed into this plant).

At the end of the printout, a list of the number of configurations generated within the constraints for each year is included. For a predetermined expansion plan run, there must be one and only one accepted configuration per year as shown in page 6 of Fig. 6.2. Other features of the CONGEN printout are described in the discussion of the variable expansion runs for the sample problem (see Section 6.6).

---

6 If other values of the option for LOLP calculation are used (e.g., 1 or 2) they must be associated with some limits for the LOLP values in the critical period and annual average. In this case, these limits will also be included in the printout.

7 If the option for LOLP calculation is set to 1 or 2, LOLP values will be calculated for each period (*%SEASONAL LOLP*) and for the annual average (*%LOLP*) and will be reported in the output immediately after the column CAP. In addition, a slightly different printout is produced if more than 4 periods per year are used for the case study. In this case, the period LOLP's are reported in a second line, below all other characteristics of the respective configuration.

```
CASE93:  CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL
  0   NUCL   NUCLEAR PLANTS
  1   CO-1   COAL PLANTS DOM-FUEL
  2   CO-2   COAL PLANTS IMP-FUEL
  3   FOIL   OIL  PLANTS IMP-FUEL
  4   GTGO   GAS TURBINES GAS-OIL
  5   LIGN   LIGNITE PLANT (LIM.)      8    13000.
  6   IMPO   IMPORTS (FUEL SUBS.)
  7   ****   NOT APPLICABLE
  8   ****   NOT APPLICABLE
  9   ****   NOT APPLICABLE
 10   HYD1   HYDRO PLANTS GROUP 1
 11   HYD2   HYDRO PLANTS GROUP 2
```

```
     1    35 1997     4     6     3 HYD1 HYD2     0.70      0.55  0.7500  0.1500  0.1000  0.0000  0.0000
 FCO1     6   67.   200. 2490. 2190.  665.     0.     1    10    6.0   35  200.     3.85     0.00
 FCO2     3  133.   400. 2470. 2170.   80.   730.     2    10    9.0   42  400.     2.95     0.00
 FOIL     4  133.   400. 2450. 2150.   60.  1190.     3    10    7.0   42  400.     1.95     0.00
 F-GT     8  100.   100. 3480. 3480.   50.  1750.     4     0    1.2   14  100.     0.75     0.00
 FLIG     1  120.   294. 2560. 2250.  635.     0.     5    10    8.0   42  400.     3.05     0.00
 IMPT     1    1.     1. 2560. 2560.    0.  3000.     6     0    3.0    0  100.     3.10     1.55
  5095.     0. 1200. 1200. 1600.  800.  294.     1.     0.     0.     0.     3      2
     7      3     4     5     6     8
  15.09 15.23 18.38 28.12 62.64 78.35
  HYD1     3 1997    500.0     241.8     137.0     378.8     529.6      84.4     614.0
  HYD1     3 1997    500.0     266.2     142.2     408.4     583.0     112.0     695.0
  HYD1     3 1997    500.0     210.3     109.3     319.7     460.6      24.4     485.0
  HYD1     3 1997    500.0     250.9     147.5     398.4     549.4      86.6     636.0
  HYD1     3 1997    500.0     298.7     148.0     446.6     654.1     115.9     770.0
  HYD1     3 1997    500.0     219.1     110.1     329.2     479.8      27.2     507.0
  HYD1     3 1997    500.0     266.8     153.4     420.2     584.3      92.7     677.0
  HYD1     3 1997    500.0     325.0     146.3     471.2     711.6     132.4     844.0
  HYD1     3 1997    500.0     229.3     119.5     348.8     502.3      53.7     556.0
  HYD1     3 1997    500.0     250.1     149.2     399.2     547.6     100.4     648.0
  HYD1     3 1997    500.0     297.8     156.1     453.8     652.1     136.9     789.0
  HYD1     3 1997    500.0     216.7     118.0     334.7     474.6      60.4     535.0
  HYD2     2 1997   1600.0     210.0    1240.0    1450.0     460.0    1340.0    1800.0
  HYD2     2 1997   1600.0     200.9    1299.1    1500.0     440.0    1760.0    2200.0
  HYD2     2 1997   1600.0     214.6    1085.4    1300.0     470.0     860.0    1330.0
  HYD2     2 1997   1600.0     210.0    1250.0    1460.0     460.0    1440.0    1900.0
  HYD2     2 1997   1600.0     200.9    1349.1    1550.0     440.0    1860.0    2300.0
  HYD2     2 1997   1600.0     214.6    1105.4    1320.0     470.0     980.0    1450.0
  HYD2     2 1997   1600.0     210.0    1280.0    1490.0     460.0    1640.0    2100.0
  HYD2     2 1997   1600.0     200.9    1369.1    1570.0     440.0    2110.0    2550.0
  HYD2     2 1997   1600.0     214.6    1125.4    1340.0     470.0    1180.0    1650.0
  HYD2     2 1997   1600.0     210.0    1310.0    1520.0     460.0    1740.0    2200.0
  HYD2     2 1997   1600.0     200.9    1399.1    1600.0     440.0    2260.0    2700.0
  HYD2     2 1997   1600.0     214.6    1165.4    1380.0     470.0    1330.0    1800.0
  1997
  NAMH   NCH  JAV      CMWI      CMWB      CMWP      CMWC       CEM       CEP       CEA
```

Figure 6.2 (page 1) CONGEN Printout for a Fixed Expansion Plan of the Sample Problem. Thermal Fuel Types and Fixed System Description for 1997 (from FIXSYS File)

```
CASE93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL
  0    93    0     4     4     3 HYD1 HYD2     0.70      0.55   0.7500   0.1500   0.1000   0.0000   0.0000
VCOA     0  200.    600. 2460. 2160.     80.   730.     2    10   12.0    42   600.     3.85     0.00
VFOL     0  200.    600. 2440. 2140.     60.  1190.     3    10   10.0    42   600.     1.95     0.00
VNUC     0  600.    900. 2566. 2361.      0.   246.     0    10    8.0    42   900.     3.05     0.00
V-GT     0  200.    200. 3470. 3470.     50.  1750.     4     0    1.2    14   200.     0.70     0.00
  0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     3     4
   3      1      2      4      0      0
 6.14 18.31 28.00 62.46   0.00   0.00
HYD1     1 1999    180.0     91.3      0.0     91.3    200.0      0.0    200.0
HYD1     1 1999    180.0    105.5     64.5    170.0    230.9      9.1    240.0
HYD1     1 1999    180.0     63.9      0.0     63.9    140.0      0.0    140.0
HYD1     1 1999    180.0    100.5      0.0    100.5    220.0      0.0    220.0
HYD1     1 1999    180.0    114.6     65.4    180.0    251.0      9.0    260.0
HYD1     1 1999    180.0     73.1      0.0     73.1    160.0      0.0    160.0
HYD1     1 1999    180.0    105.5     64.5    170.0    230.9      9.1    240.0
HYD1     1 1999    180.0    132.7     47.3    180.0    290.7      9.3    300.0
HYD1     1 1999    180.0     79.9      0.0     79.9    175.0      0.0    175.0
HYD1     1 1999    180.0     91.3      0.0     91.3    200.0      0.0    200.0
HYD1     1 1999    180.0    105.5     64.5    170.0    230.9      9.1    240.0
HYD1     1 1999    180.0     63.9      0.0     63.9    140.0      0.0    140.0
HYD1     2 2002    380.0    119.9    121.4    241.3    262.6    172.4    435.0

 .       .  .      .        .        .        .        .        .        .
 .       .  .      .        .        .        .        .        .        .

HYD1     3 2004    590.0    232.4    317.6    550.0    509.0    221.0    730.0
HYD1     3 2004    590.0    122.4    291.5    413.9    268.1    181.9    450.0
HYD2     1 2001    300.0     91.3    148.7    240.0    200.0    150.0    350.0
HYD2     1 2001    300.0     68.5    211.5    280.0    150.0    250.0    400.0
HYD2     1 2001    300.0    114.2     85.8    200.0    250.0     50.0    300.0
HYD2     1 2001    300.0     68.5    191.5    260.0    150.0    230.0    380.0
HYD2     1 2001    300.0     45.7    254.3    300.0    100.0    320.0    420.0
HYD2     1 2001    300.0     91.3    138.7    230.0    200.0    110.0    310.0
HYD2     1 2001    300.0     45.7    234.3    280.0    100.0    300.0    400.0
HYD2     1 2001    300.0     36.5    263.5    300.0     80.0    370.0    450.0
HYD2     1 2001    300.0     68.5    171.5    240.0    150.0    190.0    340.0
HYD2     1 2001    300.0     68.5    191.5    260.0    150.0    230.0    380.0
HYD2     1 2001    300.0     45.7    254.3    300.0    100.0    320.0    420.0
HYD2     1 2001    300.0     91.3    138.7    230.0    200.0    100.0    300.0
HYD2     2 2003    900.0    228.3    501.7    730.0    500.0    470.0    970.0
HYD2     2 2003    900.0    159.8    670.2    830.0    350.0    750.0   1100.0
HYD2     2 2003    900.0    296.8    393.2    690.0    650.0    210.0    860.0
HYD2     2 2003    900.0    159.8    620.2    780.0    350.0    750.0   1100.0
HYD2     2 2003    900.0     91.3    768.7    860.0    200.0   1010.0   1210.0
HYD2     2 2003    900.0    228.3    516.7    745.0    500.0    410.0    910.0
HYD2     2 2003    900.0    114.2    715.8    830.0    250.0    970.0   1220.0
HYD2     2 2003    900.0     59.4    840.6    900.0    130.0   1270.0   1400.0
HYD2     2 2003    900.0    114.2    655.8    770.0    250.0    750.0   1000.0
HYD2     2 2003    900.0    159.8    640.2    800.0    350.0    790.0   1140.0
HYD2     2 2003    900.0     91.3    778.7    870.0    200.0   1070.0   1270.0
HYD2     2 2003    900.0    228.3    526.7    755.0    500.0    420.0    920.0
HYD2     3 2005   1200.0    228.3    781.7   1010.0    500.0    780.0   1280.0
HYD2     3 2005   1200.0    159.8    970.2   1130.0    350.0   1110.0   1460.0
HYD2     3 2005   1200.0    296.8    643.2    940.0    650.0    475.0   1125.0
HYD2     3 2005   1200.0    159.8    900.2   1060.0    350.0   1080.0   1430.0
HYD2     3 2005   1200.0     91.3   1068.7   1160.0    200.0   1390.0   1590.0
HYD2     3 2005   1200.0    228.3    766.7    995.0    500.0    685.0   1185.0
HYD2     3 2005   1200.0    114.2    995.8   1110.0    250.0   1320.0   1570.0
HYD2     3 2005   1200.0     59.4   1140.6   1200.0    130.0   1670.0   1800.0
HYD2     3 2005   1200.0    114.2    905.8   1020.0    250.0   1040.0   1290.0
HYD2     3 2005   1200.0    159.8    920.2   1080.0    350.0   1110.0   1460.0
HYD2     3 2005   1200.0     91.3   1078.7   1170.0    200.0   1450.0   1650.0
HYD2     3 2005   1200.0    228.3    776.7   1005.0    500.0    695.0   1195.0
HYD2     4 2006   1800.0    228.3   1331.7   1560.0    500.0   1280.0   1780.0
HYD2     4 2006   1800.0    159.8   1570.2   1730.0    350.0   1710.0   2060.0
HYD2     4 2006   1800.0    296.8   1183.2   1480.0    650.0    895.0   1545.0
HYD2     4 2006   1800.0    159.8   1450.2   1610.0    350.0   1680.0   2030.0
HYD2     4 2006   1800.0     91.3   1668.7   1760.0    200.0   2090.0   2290.0
HYD2     4 2006   1800.0    228.3   1306.7   1535.0    500.0   1155.0   1655.0
HYD2     4 2006   1800.0    114.2   1545.8   1660.0    250.0   2020.0   2270.0
HYD2     4 2006   1800.0     59.4   1740.6   1800.0    130.0   2570.0   2700.0
HYD2     4 2006   1800.0    114.2   1445.8   1560.0    250.0   1560.0   1810.0
HYD2     4 2006   1800.0    159.8   1470.2   1630.0    350.0   1750.0   2100.0
HYD2     4 2006   1800.0     91.3   1678.7   1770.0    200.0   2200.0   2400.0
HYD2     4 2006   1800.0    228.3   1316.7   1545.0    500.0   1185.0   1685.0
 0
NAME   NCH  JAV    CMWI     CMWB     CMWP     CMWC     CEM      CEP      CEA
```

Figure 6.2 (page 2) CONGEN Printout for a Fixed Expansion Plan of the Sample Problem. Variable System Description (from VARSYS File)

```
                    WASP   COMPUTER   PROGRAM   PACKAGE

                              CONGEN  MODULE

                                CASE  STUDY

          CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL




            ***************************************
            *                                     *
            *   LIST OF VAR. EXPAN. CANDIDATES    *
            *                                     *
            ***************************************
            *                                     *
            *          THERMAL    PLANTS          *
            *                                     *
            *                                     *
            *      SEQU.NUMBER          NAME      *
            *                                     *
            *           1               VCOA      *
            *           2               VFOL      *
            *           3               VNUC      *
            *           4               V-GT      *
            *                                     *
            ***************************************
            *                                     *
            *       HYDROELECTRIC PLANTS          *
            *                                     *
            *                                     *
            *      SEQU.NUMBER          NAME      *
            *                                     *
            *           5               HYD1      *
            *           6               HYD2      *
            *                                     *
            ***************************************
```

Figure 6.2 (page 3) CONGEN Printout for a Fixed Expansion Plan of the Sample Problem. Cover Page

```
ECONOMIC LOADING ORDER DEFINED IN ASCENDING ORDER OF TOTAL FULL LOAD UNIT GENERATION COSTS :

TOTAL FULL LOAD UNIT GENERATION COSTS :

FIXED    SYSTEM :

     7      3      4      5      6      8

 15.09  15.23  18.38  28.12  62.64  78.35

VARIABLE SYSTEM :

    11      9     10     12

  6.14  18.31  28.00  62.46

COMBINED SYSTEM :

    11      7      3      9      4     10      5     12      6      8

  6.14  15.09  15.23  18.31  18.38  28.00  28.12  62.46  62.64  78.35
```

```
NUMBER OF FOURIER COEFF. IS    50
INDEX READ    4
INDEX READ    6
INDEX READ    8
INDEX READ    2
INDEX READ    3
INDEX READ    1
CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 1997  *  *  *  *  *  *  *  *  *  *  *  *
*
MINIMUM REQUIRED OF EACH ALTERNATIVE      0    0    0    0    0    0
MAXIMUM ADDITIONAL EACH  ALTERNATIVE      0    0    0    0    0    0
RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)     -5.00   50.00
OPTION FOR MODE OF GENERATION (IOPTN) :    0
CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

      TOTAL CAPAC.                                           PERIOD
PER     IN FIXSYS      --- THERMAL  HYDRO 1  HYDRO 2 ---    PEAK LOAD
 1         6923.8          5095.0    378.8   1450.0          5400.0
 2         6953.4          5095.0    398.4   1460.0          5220.0
 3         7005.2          5095.0    420.2   1490.0          5580.0
 4         7014.2          5095.0    399.2   1520.0          6000.0
CRITICAL PERIOD IS    4
CAPACITY RANGE IN CRITICAL PERIOD IS        5700.0           9000.0
COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD         7014.2

MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    5


STATE IC   CAP     ACCEPTED CONFIGURATION

   1   1   7014.   0    0    0    0    0    0
CONFIGURATIONS THIS YEAR              1
CONFIGURATIONS THROUGH THIS YEAR      1
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 1997  *  *  *  *  *  *  *  *  *  *  *  *
```

Figure 6.2 (page 4) CONGEN Printout for a Fixed Expansion Plan of the Sample Problem. Basic Economic Loading Order for FIXSYS /VARSYS Thermal Plants & Output for Year 1997

```
      7    33 2003     4     6     3 HYD1 HYD2      0.70      0.55  0.7500  0.1500  0.1000  0.0000  0.0000
  FCO1     3    67.   200. 2490. 2190.  665.     0.     1    10     6.0   35  200.     3.85     0.00
  FCO2     5   133.   400. 2470. 2170.   80.   730.     2    10     9.0   42  400.     2.95     0.00
  FOIL     4   133.   400. 2450. 2150.   60.  1190.     3    10     7.0   42  400.     1.95     0.00
  F-GT     5   100.   100. 3480. 3480.   50.  1750.     4     0     1.2   14  100.     0.75     0.00
  FLIG     3   120.   294. 2560. 2250.  635.     0.     5    10     8.0   42  400.     3.05     0.00
  IMPT     1     1.     1. 2560. 2560.    0.  3000.     6     0     3.0    0  100.     3.10     1.55
   5583.     0.   600. 2000. 1600.   500.   882.     1.      0.      0.      0.      4      2
   HYD1     4 2003     425.0     203.0     137.0     340.0     444.6     84.4     529.0
   HYD1     4 2003     425.0     222.8     142.2     365.0     488.0    112.0     600.0
   HYD1     4 2003     425.0     180.7     109.3     290.0     395.6     24.4     420.0
   HYD1     4 2003     425.0     207.5     147.5     355.0     454.4     86.6     541.0
   HYD1     4 2003     425.0     237.0     148.0     385.0     519.1    115.9     635.0
   HYD1     4 2003     425.0     184.9     110.1     295.0     404.8     27.2     432.0
   HYD1     4 2003     425.0     216.6     153.4     370.0     474.3     92.7     567.0
   HYD1     4 2003     425.0     258.7     146.3     405.0     566.6    132.4     699.0
   HYD1     4 2003     425.0     190.5     119.5     310.0     417.3     53.7     471.0
   HYD1     4 2003     425.0     215.8     149.2     365.0     472.6    100.4     573.0
   HYD1     4 2003     425.0     258.9     156.1     415.0     567.1    136.9     704.0
   HYD1     4 2003     425.0     187.0     118.0     305.0     409.6     60.4     470.0
   HYD2     2 2003    1600.0     210.0    1240.0    1450.0     460.0   1340.0    1800.0
   HYD2     2 2003    1600.0     200.9    1299.1    1500.0     440.0   1760.0    2200.0
   HYD2     2 2003    1600.0     214.6    1085.4    1300.0     470.0    860.0    1330.0
   HYD2     2 2003    1600.0     210.0    1250.0    1460.0     460.0   1440.0    1900.0
   HYD2     2 2003    1600.0     200.9    1349.1    1550.0     440.0   1860.0    2300.0
   HYD2     2 2003    1600.0     214.6    1105.4    1320.0     470.0    980.0    1450.0
   HYD2     2 2003    1600.0     210.0    1280.0    1490.0     460.0   1640.0    2100.0
   HYD2     2 2003    1600.0     200.9    1369.1    1570.0     440.0   2110.0    2550.0
   HYD2     2 2003    1600.0     214.6    1125.4    1340.0     470.0   1180.0    1650.0
   HYD2     2 2003    1600.0     210.0    1310.0    1520.0     460.0   1740.0    2200.0
   HYD2     2 2003    1600.0     200.9    1399.1    1600.0     440.0   2260.0    2700.0
   HYD2     2 2003    1600.0     214.6    1165.4    1380.0     470.0   1330.0    1800.0
   2003
   NAME   NCH   JAV       CMWI      CMWB      CMWP      CMWC       CEM      CEP       CEA
```

```
INDEX READ     2
INDEX READ     1
CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 2003  *  *  *  *  *  *  *  *  *  *  *  *
*
MINIMUM REQUIRED OF EACH ALTERNATIVE     1    0    0    2    2    2
MAXIMUM ADDITIONAL EACH  ALTERNATIVE     0    0    0    0    0    0
RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)     -5.00    50.00
OPTION FOR MODE OF GENERATION (IOPTN) :    0
CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

      TOTAL CAPAC.                                          PERIOD
PER     IN FIXSYS      --- THERMAL  HYDRO 1  HYDRO 2 ---     PEAK LOAD
 1        7373.0           5583.0    340.0   1450.0          7473.8
 2        7398.0           5583.0    355.0   1460.0          7224.7
 3        7443.0           5583.0    370.0   1490.0          7722.9
 4        7468.0           5583.0    365.0   1520.0          8304.2
CRITICAL PERIOD IS    4
CAPACITY RANGE IN CRITICAL PERIOD IS         7889.0          12456.3
COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD          9509.3

MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    5


STATE IC   CAP     ACCEPTED CONFIGURATION

   7   1   9509.   1   0   0   2   2   2
CONFIGURATIONS THIS YEAR              1
CONFIGURATIONS THROUGH THIS YEAR      7
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 2003  *  *  *  *  *  *  *  *  *  *  *  *
```

Figure 6.2 (page 5) CONGEN Printout for a Fixed Expansion Plan of the Sample Problem. Fixed System Description and Output for Year 2003

LIST OF # OF CONFIGURATIONS PER YEAR

YEAR	#C	#CCUM
1997	1	1
1998	1	2
1999	1	3
2000	1	4
2001	1	5
2002	1	6
2003	1	7
2004	1	8
2005	1	9
2006	1	10
2007	1	11
2008	1	12
2009	1	13
2010	1	14
2011	1	15
2012	1	16
2013	1	17
2014	1	18
2015	1	19
2016	1	20
TOTAL	20	

Figure 6.2 (page 6) CONGEN Printout for a Fixed Expansion Plan of the Sample Problem. List of Number of Configurations generated by CONGEN Run-1

6.5 Input Data for Dynamic Expansion Plans

Sections 6.3 and 6.4 describe the first CONGEN run for the sample problem which corresponds to a fixed expansion plan of CASE93 for which CONGEN was not actually used as an alternative configuration generator but, rather, to set up the EXPANALT file to be used by MERSIM (and DYNPRO), and to evaluate a predetermined expansion plan generated by the user. In addition, such a run (or runs) permitted to verify that the files created by Modules 1 to 3 include the intended information and that the control and data cards used in CONGEN are correct. This section concentrates on a discussion of the input data required for dynamic expansion plans (or variable expansion plans) in which CONGEN is used to generate all alternative configurations which will satisfy the user-imposed constraints on reserve margins, limits for the period and annual LOLP's (if any), and the number of units (or projects) of each expansion candidate.

Section 6.5.1 discusses the input data for the first of such dynamic expansion plans, and Section 6.5.2 the input data for the last of a series of runs made while searching for the optimal solution for the expansion of the hypothetical system represented by CASE93. The corresponding printouts for these two CONGEN runs are discussed in Section 6.6 and illustrated in Figures 6.5 and 6.6.

6.5.1 Input Data for the First Dynamic Expansion Plan (CONGEN Run-2)

Figure 6.3 shows the input data prepared for the first variable expansion CONGEN run of the sample problem. The first data card is a type-X card specifying the title of the study (kept the same along all runs as stated in Section 6.3), and the printing option for the FIXSYS and VARSYS files read by CONGEN, which in this case has been set to 0 so as to reduce the printout for the run. (Note that the FIXPLANT and VARPLANT files have already been checked while executing the fixed expansion CONGEN run or runs).

The second input line in Fig. 6.3 is a type-1 INDEX=4 card followed by a type-4 card specifying the minimum and maximum reserve margins (in % of peak load) in the critical period. The minimum and maximum reserve margin requirements should be set so that those configurations with a capacity outside this range will not be "accepted" by CONGEN. This will allow saving computer time in the execution of Modules 4 to 6, and eliminating from the economic comparison those system configurations considered to be not competitive[8]. In the sample problem, since this is the first variable expansion CONGEN run, the minimum and maximum reserve margins have been set to 15% and 40% respectively, for all years of study in order not to eliminate too many configurations[9] (The number of accepted configurations is kept reduced in the sample run by means of the constraints on the number of sets or projects of the expansion candidates).

The next input line is a type-1 INDEX=2 card. This is followed by a type-2 card which indicates the minimum number of sets (or projects) of each VARSYS plant that can be contained in the configurations for this year. In the sample problem, no set or project from the VARSYS candidates is required beyond those in FIXSYS in 1997. Thus, the type-2 card gives a zero for all expansion candidates. It should be noted that these are equal to the respective default values so that these two input lines could have been omitted.

The subsequent two lines in Fig. 6.3 are a type-1 INDEX=3 card and a type-3 card, which are used to specify the maximum number of expansion candidates units (or projects) permitted in addition to the minimum number required (given on the type-2 card above). The type-3 card, in other words, shows the "tunnel width" for the year. This is usually a number between 0 and 2; otherwise there would be too many configurations (possible combinations of all alternatives allowed) generated. This, in turn, will increase the computer time required for execution of modules 5 and 6. In the sample problem, the tunnel width in 1997 is held to zero for all VARSYS candidates except for the candidate number 4 (V-GT) which is opened to "1". The next line is a type-1 INDEX=1 card (the information in cols. 16-28 of the card is not read by the computer) instructing the computer to carry out the calculations for this year.

---

[8] Too-low reserve margins will lead to system configurations with LOLP considerably greater than the maximum allowed (i.e. not technically acceptable) whereas too-high reserve margins will lead to system configurations having excessive installed capacity (i.e. not economically competitive).

[9] The reserve margins to be used for variable expansion CONGEN runs of a WASP study must be carefully selected by the user after having executed several fixed expansion CONGEN runs, and applying past experience on "acceptable" reserve margins for the power system under study, in order not to reject those configurations which might represent the optimal solution for the expansion planning study. By looking at the output of the first variable expansion run, one can usually estimate what the reserve range for a case study should be. As the plant sizes in the system become larger, the reserve margin necessary for an acceptable LOLP also increases; thus, the reserve margin requirements should be future-oriented.

```
CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL       0
4
   15.0      40.0
2
0   0   0   0   0   0
3
0   0   0   1   0   0
1           (END OF 1997)
3
0   0   0   2   0   0
1           (END OF 1998)
2
0   0   0   1   0   0
3
0   1   0   2   1   0
1           (END OF 1999)
3
1   2   0   2   1   0
1           (END OF 2000)
3
2   2   0   2   1   1
1           (END OF 2001)
3
2   2   0   2   2   1
1           (END OF 2002)
2
0   0   0   2   1   0
3
2   2   0   2   1   2
1           (END OF 2003)
2
0   0   0   2   1   1
3
2   2   0   2   2   1
1           (END OF 2004)
2
0   1   0   2   2   2
3
2   2   1   2   1   1
1           (END OF 2005)
2
0   1   0   3   2   2
3
2   2   1   2   1   2
1           (END OF 2006)
2
1   1   0   3   2   3
3
2   2   1   2   1   1
1           (END OF 2007)
2
2   1   0   3   3   3
3
2   2   2   2   0   1
1           (END OF 2008)
2
3   2   0   4   3   4
3
2   2   2   2   0   0
1           (END OF 2009)
2
3   2   0   5   3   4
1           (END OF 2010)
2
4   2   0   6   3   4
1           (END OF 2011)
2
4   3   0   7   3   4
1           (END OF 2012)
2
5   3   0   8   3   4
1           (END OF 2013)
2
5   3   1   9   3   4
1           (END OF 2014)
2
6   3   1  10   3   4
1           (END OF 2015)
2
6   3   1  11   3   4
1           (END OF 2016)
```

Figure 6.3 (page 1) CONGEN (Run-2) Input Data for the First Variable Expansion for the Sample Problem (CASE93)

The data for the next year of study (1998) begin with a type-1 INDEX=3 card followed by a type-3 card. This opens the tunnel width to "2" for the VARSYS plant number 4 (V-GT), while that for all the remaining candidates is kept constant to "0". The subsequent line is a type-1 INDEX=1 card, indicating end of input data for the year. Since no other type of data card was used for this year, all other constraints which were specified for the preceding year are still applicable for this year.

In 1999 a change is introduced to the minimum required number of sets or projects and the corresponding tunnel widths of the expansion candidates. Thus, the corresponding type-2 card specifies a "1" for the number of sets of plant number 4 (V-GT) required to be installed in this year. Similarly, the type-3 card for this year opens the tunnel width to "1" for VARSYS candidate number 2 (VFOL) and number 5 (hydroplant HYD1), while that of all other candidates is maintained constant (including the "2" for V-GT). The next input line is the usual end of input data for the year.

The remaining input data in Fig. 6.3 define constraints in the expansion schedule up to the last year of the study (2016) by means of the corresponding cards type-1 INDEX=2 (and/or INDEX=3), each one followed by the respective card type-2 (and/or type-3), introducing changes to the minimum required number of sets or projects (and/or to the tunnel width) for each expansion candidate in the applicable year. In each case, a card type-1 INDEX=1 is used to indicate end of input information for the year.

As illustrated in this CONGEN run, groups of a type-1 INDEX=2 and a type-2 cards and a type-1 INDEX=3 and a type-3 cards may be used for any year in order to direct the area of optimization. However, the changes made by these cards must be introduced with care in order to allow the possibility of transition from one year to the next. In this respect, the following rules should be kept in mind:

- Each number included in the new type-2 should be greater than, or equal to the respective number on the last type-2 card previously used for the preceding years.

- The sum of the numbers given in the type-2 and type-3 cards for each expansion candidate should always be greater than, or equal to, the sum of the respective numbers applicable for the preceding year.

To illustrate these points, let us take the values specified for years 2003 and 2004 (see Fig. 3.6) which clearly satisfy the two conditions listed above:

	Year 2003						Year 2004					
	VCOA	VFOL	VNUC	V-GT	HYD1	HYD2	VCOA	VFOL	VNUC	V-GT	HYD1	HYD2
Card 2	0	0	0	2	1	0	0	0	0	2	1	1
Card 3	2	2	0	2	1	2	2	2	0	2	2	1
Sum	2	2	0	4	2	2	2	2	0	4	3	2

It should be mentioned here that the selection of adequate values to be used as minimum required number of sets (type-2 card) and tunnel widths (type-3 card) for the first variable expansion plan of a WASP case study usually involves execution of several CONGEN runs until a satisfactory number of configurations is obtained for each year, without exceeding the program capabilities (300 per year and 3000 in a single run).

For the first of such runs it is convenient to make some hand calculations of the capacity involved and required additions on a year-by-year basis. The screening curve approach (see Section 11.2) may also be useful in the determination of the first guess as to the preferred candidates and the total capacity of each plant to be accepted each year. Furthermore, the series of fixed expansion runs of CONGEN-MERSIM-DYNPRO may help the user in the selection of the first guess. In the case of the sample problem, the first variable expansion run of CONGEN was determined after three runs of the program for several changes in the definitions of type-2 and type-3 cards from year to year.

The use of constraints on the number of sets or projects of the expansion candidates that can be contained in system configurations for the year, permits the user to direct the area of study towards the range of configurations which are believed to be the most economical for the power system under study. Later, the report of the DYNPRO module will tell the user if any of the restrictions imposed in the current CONGEN acted as a constraint on the solution found. If this is the case, the user can simply redefine these restrictions and perform a new optimization iteration (a new variable expansion plan) involving sequential runs of Modules 4 to 6 in the same order (CONGEN - MERSIM - DYNPRO), with MERSIM working in the "merge" mode of operation. This procedure would continue until the user found a solution which was free of user-imposed constraints. Chapter 8 describes how to proceed in order to obtain the optimal solution free of user-imposed constraints.

6.5.2 Input Data for the Last Dynamic Expansion Plan (CONGEN Run-3)

Before discussing the last dynamic expansion plan for the case example, it is necessary to discuss the rules set up for the determination of the optimal solution. These take into account other issues rather than the pure economic ones, based on planning guidelines and regulations applicable to the hypothetical country and power system under study. They include the following:

- No more than 2 units of the expansion candidate based on fuel-oil (VFOL) are to be included in the reference optimal solution to reflect energy policies of the hypothetical country relating to oil imports.
- No more than 14 gas turbines sets of expansion candidate V-GT can be accepted in the reference optimal solution due to policies concerning the generation mix of the power system.

It should be noted that the above rules were not strictly followed for the first variable expansion runs of the sample problem (e.g. the first run accepted up to 5 units of VFOL from year 2011 to 2016). This was done as a means of analyzing wide open strategies of system expansion and identifying the preferences for expansion of the hypothetical system. A discussion of the consequences of the above rules is made in Chapter 8.

Finally, special care was taken in order not to allow competition of thermal expansion candidates or hydro projects before the year when they can be first put into operation in light of their construction time and year of availability[10].

---

[10] The year of availability of hydro projects is specified in VARSYS and is checked by CONGEN while generating the configurations. The construction period of thermal plants is specified in DYNPRO together with the capital cost information for the candidates. Consistency between the construction period and the first year when the thermal candidate can be used for expansion must be done by the user.

With these rules in mind, several variable expansion plans were performed for CASE93. Figure 6.4 illustrates the input data used for the last variable expansion CONGEN run (CONGEN Run-3). It can be seen in this figure that the first fifteen lines (up to year 1999) are all identical to the respective cards used for CONGEN Run-2. Thus, all constraints imposed for the years 1997-1999, in this run, are exactly the same as in CONGEN Run-2.

From year 2000 onwards, however, the constraints on reserve margins or on expansion schedule differ from the ones imposed in CONGEN Run-2. For example, the first two input lines for year 2000 are a type-1 INDEX=4 card and a type-4 card specifying new values for the reserve margins to be respected by the configurations of the system from this year. In this case, the maximum acceptable reserve margin has been decreased to 30% of the peak load in the critical period. This permits eliminating a considerable number of configurations with relatively large installed capacity which have never been included in the best solutions reported by DYNPRO for the previous variable expansion runs.

The next input lines specify the "minimum configuration" for year 2000. Comparing it to the same data of Fig. 6.3, it can be seen that they differ in the minimum number of units for plant numbers 1 (VCOA), 4 (V-GT) and 5 (HYD1). The tunnel width for all candidates in this year are identical in the two runs. Note that the tunnel width of candidate number 3 (VNUC)[11] is maintained to zero taken into consideration that this plant requires 7 years of construction time. Similarly, the tunnel width of candidate number 6 (HYD2) is also zero since the first hydro project of this type (VHY2) is available for expansion in year 2001. The usual type-1 INDEX = 1 card is used to indicate end of input information for the year.

The remaining cards in Figure 6.4 define constraints on the expansion schedule up to the last year of study. All changes introduced in the constraints for expansion schedule and reserve margins are the result of interpreting the messages given in the printout of Module 6, after several dynamic expansion plans (10 in the case of the sample problem CASE93) had been executed. Chapter 8 describes how to interpret the messages in the DYNPRO printout and to proceed to a new dynamic optimization iteration of WASP Modules 4 to 6. As explained earlier, the use of reserve margin constraints helps reducing the number of configurations which have not been included in the best solutions found through the dynamic optimization process; thus reducing considerably the computer time required for execution of these modules as explained in Chapters 7 and 8.

On the other hand, the values of the minimum and maximum reserve margins to be used in any variable expansion CONGEN run must be carefully selected by the user in order not to reject any configuration which has been found economically competitive during the optimization process. By moving the reserve margins in one direction or another, the user is able to focus the area of interest for the next optimization run. Nevertheless, such moves have to be made with great care and the results of CONGEN be revised accordingly. In this revision, it is important to ensure that sufficient competition exists between the alternative expansion candidates and that no short cuts are being imposed by the user. For example, too narrow gaps between the minimum and maximum reserve margins may lead to a DYNPRO solution free of messages that is far from the optimum even if the tunnel widths in CONGEN are wide open. This can be found out by reviewing the CONGEN output, where most probably the number of configurations in one or several years is too low or the possible expansion paths can follow one single configuration in a given year.

---

[11] Candidate number 4 (VNUC) cannot be considered for expansion until year 2005 owing to its relatively large size compared to the annual peak load of the system in previous years.

```
CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL        0
4
   15.0      40.0
2
0   0   0   0   0   0
3
0   0   0   1   0   0
1           (END OF 1997)
3
0   0   0   2   0   0
1           (END OF 1998)
2
0   0   0   1   0   0
3
0   1   0   2   1   0
1           (END OF 1999)
4
   15.0      30.0
2
0   0   0   2   0   0
3
1   2   0   2   1   0
1           (END OF 2000)
2
0   0   0   3   0   0
3
1   2   0   2   1   1
1           (END OF 2001)
3
2   2   0   2   2   1
1           (END OF 2002)
2
0   0   0   3   0   0
3
2   2   1   2   2   2
1           (END OF 2003)
2
0   0   0   5   1   1
3
2   2   1   2   2   1
1           (END OF 2004)
2
0   0   0   8   1   1
3
2   2   1   2   2   2
1           (END OF 2005)
2
0   0   0   9   2   2
3
2   2   1   2   1   2
1           (END OF 2006)
2
1   0   0   9   2   3
3
2   2   2   2   1   1
1           (END OF 2007)
2
2   0   0   9   2   3
1           (END OF 2008)
2
3   0   0  11   2   3
1           (END OF 2009)
2
4   0   0  11   2   3
1           (END OF 2010)
2
5   0   0  12   2   3
1           (END OF 2011)
2
6   0   0  12   2   3
1           (END OF 2012)
2
7   0   0  12   2   3
1           (END OF 2013)
1           (END OF 2014)
2
8   0   0  12   2   3
1           (END OF 2015)
2
8   0   1  12   2   3
1           (END OF 2016)
```

Figure 6.4 CONGEN (Run-3) Input Data for the Last Variable Expansion for the Sample Problem (CASE93)

6.6 Printouts for Dynamic Expansion Plans

The CONGEN printouts for the variable expansion runs, using the data listed in figures 6.3 and 6.4, are essentially the same as for fixed expansion runs (see Section 6.4) with some differences: Firstly, since the file printing option (IOFILE) chosen for variable expansion runs was "0," the printouts do not include the listing of the information on the FIXSYS and VARSYS files. Secondly, variable expansion runs usually include more than one configuration per year as can be seen in Figures 6.5 and 6.6. Lastly, if the "merge" mode of operation is being used in the MERSIM runs of previous iterations, the CONGEN printout will identify the "new" configurations for the run, i.e. those states generated by CONGEN not contained in the current SIMULOLD file and which are expected to be simulated in the subsequent MERSIM run.

Figure 6.5 shows a sample of the printout produced by CONGEN for the first variable expansion run (using the data of Fig. 6.3) and Figure 6.6 of the one produced for the last variable expansion run (using the data of Fig. 6.4) of our CASE93. The printout for some typical years (1997 and 2000) is shown in each figure.

As can be seen in both figures, the printout for the year reports the data on capacities and the conditions governing acceptance of the configurations, along with the number of the critical period, and the minimum number of Fourier coefficients corresponding to the maximum reserve capacity margin in the critical period.

The printout for the year continues with the list of accepted configurations in the year. Here again, *STATE* is the number of the configuration as counted from the first year of study; *IC* is the configuration number within the year; *CAP* is the installed capacity in the critical period; and finally under *ACCEPTED CONFIGURATION* each configuration is identified by the number of sets or projects of each expansion candidate considered[12]. As can be seen in both figures, an additional column is printed next to *IC* with a header *NEW*. Here the printout identifies which are the new configurations for this run. Configurations marked with asterisks under this column correspond to states already simulated in previous MERSIM runs (see page 1 of Fig. 6.5).

Both figures show also the total number of "accepted" configurations which were generated in the run (1166 for CONGEN Run-2, and 2157 for CONGEN Run-3). This listing appears immediately after the printout for the last year of study under a header *#OF CONFIGURATIONS* shown at the bottom of these figures. They summarize the number of total accepted and new configurations per year. Note that in the case of CONGEN Run-3 no new configuration was generated in the run.

Before proceeding to execute the runs for the subsequent WASP-III Plus modules, the user should revise very carefully the printout for the current CONGEN run in order to make sure that the intended configurations are included in the EXPANALT file created by this run, and that no ERROR (or WARNING) messages appear in the printout. Section B.4 of Appendix B discusses the error and warning messages applicable to CONGEN.

---

[12] See Footnote 7 for differences in the CONGEN printout when the option for LOLP calculation (IOPTN) is set to 1 or 2.

```
NUMBER OF FOURIER COEFF. IS     50
INDEX READ     4
INDEX READ     2
INDEX READ     3
INDEX READ     1
CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 1997  *  *  *  *  *  *  *  *  *  *  *  *  *  *
MINIMUM REQUIRED OF EACH ALTERNATIVE     0    0    0    0    0    0
MAXIMUM ADDITIONAL EACH  ALTERNATIVE     0    0    0    1    0    0
RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)      15.00    40.00
OPTION FOR MODE OF GENERATION (IOPTN) :    0
CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                              PERIOD
PER       IN FIXSYS      --- THERMAL  HYDRO 1  HYDRO 2 ---      PEAK LOAD
 1          6923.8            5095.0    378.8   1450.0             5400.0
 2          6953.4            5095.0    398.4   1460.0             5220.0
 3          7005.2            5095.0    420.2   1490.0             5580.0
 4          7014.2            5095.0    399.2   1520.0             6000.0
CRITICAL PERIOD IS    4
CAPACITY RANGE IN CRITICAL PERIOD IS              6900.0            8400.0
COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD              7014.2

MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS      4


STATE IC NEW     CAP      ACCEPTED CONFIGURATION

   1   1 ***   7014.    0    0    0    0    0    0
   2   2   1   7214.    0    0    0    1    0    0
CONFIGURATIONS THIS YEAR               2
CONFIGURATIONS THROUGH THIS YEAR       2
NEW CONFIG.(S) THROUGH THIS YEAR       1
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 1997  *  *  *  *  *  *  *  *  *  *  *  *  *
```

```
INDEX READ     3
INDEX READ     1
CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 2000  *  *  *  *  *  *  *  *  *  *  *  *  *  *
MINIMUM REQUIRED OF EACH ALTERNATIVE     0    0    0    1    0    0
MAXIMUM ADDITIONAL EACH  ALTERNATIVE     1    2    0    2    1    0
RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)      15.00    40.00
OPTION FOR MODE OF GENERATION (IOPTN) :    0
CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

       TOTAL CAPAC.                                              PERIOD
PER       IN FIXSYS      --- THERMAL  HYDRO 1  HYDRO 2 ---      PEAK LOAD
 1          7417.8            5589.0    378.8   1450.0             6398.1
 2          7447.4            5589.0    398.4   1460.0             6184.8
 3          7499.2            5589.0    420.2   1490.0             6611.4
 4          7508.2            5589.0    399.2   1520.0             7109.0
CRITICAL PERIOD IS    4
CAPACITY RANGE IN CRITICAL PERIOD IS              8175.4            9952.6
COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD              7708.2

MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS      4


STATE IC NEW     CAP      ACCEPTED CONFIGURATION

  15   1   1   8308.    0    1    0    1    0    0
  16   2   2   8908.    1    1    0    1    0    0
  17   3   3   8908.    0    2    0    1    0    0
  18   4   4   9508.    1    2    0    1    0    0
  19   5   5   8508.    1    0    0    2    0    0
  20   6   6   8508.    0    1    0    2    0    0
  21   7   7   9108.    1    1    0    2    0    0
  22   8   8   9108.    0    2    0    2    0    0
  23   9   9   9708.    1    2    0    2    0    0
  24  10  10   8708.    1    0    0    3    0    0
  25  11  11   8708.    0    1    0    3    0    0
  26  12  12   9308.    1    1    0    3    0    0
  27  13  13   9308.    0    2    0    3    0    0
  28  14  14   9908.    1    2    0    3    0    0
  29  15  15   8400.    0    1    0    1    1    0
  30  16  16   9000.    1    1    0    1    1    0
  31  17  17   9000.    0    2    0    1    1    0
  32  18  18   9600.    1    2    0    1    1    0
  33  19  19   8600.    1    0    0    2    1    0
  34  20  20   8600.    0    1    0    2    1    0
  35  21  21   9200.    1    1    0    2    1    0
  36  22  22   9200.    0    2    0    2    1    0
  37  23  23   9800.    1    2    0    2    1    0
  38  24  24   8200.    0    0    0    3    1    0
  39  25  25   8800.    1    0    0    3    1    0
  40  26  26   8800.    0    1    0    3    1    0
  41  27  27   9400.    1    1    0    3    1    0
  42  28  28   9400.    0    2    0    3    1    0
CONFIGURATIONS THIS YEAR              28
CONFIGURATIONS THROUGH THIS YEAR      42
NEW CONFIG.(S) THROUGH THIS YEAR      41
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 2000  *  *  *  *  *  *  *  *  *  *  *  *  *
```

Figure 6.5 (Page 1) Sample of the CONGEN Printout for the First Variable Expansion Run of the Sample Problem. CONGEN Run-2

```
LIST OF # OF CONFIGURATIONS PER YEAR

 YEAR        #C      #CNEW    #NEWCUM

 1997         2         1          1
 1998         2         2          3
 1999        10        10         13
 2000        28        28         41
 2001        75        75        116
 2002       100       100        216
 2003        96        96        312
 2004        68        67        379
 2005       146       146        525
 2006       142       142        667
 2007        74        74        741
 2008        83        82        823
 2009        60        60        883
 2010        39        39        922
 2011        33        33        955
 2012        35        35        990
 2013        39        39       1029
 2014        47        47       1076
 2015        51        51       1127
 2016        36        36       1163

TOTAL       1166
```

Figure 6.5 (Page 2) Sample of the CONGEN Printout for the First Variable Expansion Run of the Sample Problem. CONGEN Run-2. List of Configurations

---

```
NUMBER OF FOURIER COEFF. IS     50
INDEX READ     4
INDEX READ     2
INDEX READ     3
INDEX READ     1
CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 1997  *  *  *  *  *  *  *  *  *  *  *  *
MINIMUM REQUIRED OF EACH ALTERNATIVE     0    0    0    0    0    0
MAXIMUM ADDITIONAL EACH  ALTERNATIVE     0    0    0    1    0    0
RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)     15.00    40.00
OPTION FOR MODE OF GENERATION (IOPTN) :    0
CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

     TOTAL CAPAC.                                              PERIOD
PER     IN FIXSYS      --- THERMAL  HYDRO 1  HYDRO 2 ---      PEAK LOAD
 1         6923.8          5095.0    378.8   1450.0            5400.0
 2         6953.4          5095.0    398.4   1460.0            5220.0
 3         7005.2          5095.0    420.2   1490.0            5580.0
 4         7014.2          5095.0    399.2   1520.0            6000.0
CRITICAL PERIOD IS   4
CAPACITY RANGE IN CRITICAL PERIOD IS        6900.0             8400.0
COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD         7014.2

MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    4


STATE IC NEW    CAP     ACCEPTED CONFIGURATION

   1   1 ***    7014.   0    0    0    0    0    0
   2   2 ***    7214.   0    0    0    1    0    0
CONFIGURATIONS THIS YEAR          2
CONFIGURATIONS THROUGH THIS YEAR  2
NEW CONFIG.(S) THROUGH THIS YEAR  0
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 1997  *  *  *  *  *  *  *  *  *  *  *  *
```

Figure 6.6 (page 1) Sample of the CONGEN Printout for the Last Variable Expansion Run of the Sample Problem. CONGEN Run-3

```
INDEX READ    4
INDEX READ    2
INDEX READ    3
INDEX READ    1
CONDITIONS GOVERNING ALTERNATIVE GENERATION  *  *  *  *  *  *  YEAR 2000  *  *  *  *  *  *  *  *  *  *  *  *
MINIMUM REQUIRED OF EACH ALTERNATIVE      0    0    0    2    0    0
MAXIMUM ADDITIONAL EACH  ALTERNATIVE      1    2    0    2    1    0
RESERVE RANGE PERMITTED IN CRITICAL PERIOD (%)     15.00   30.00
OPTION FOR MODE OF GENERATION (IOPTN) :   0
CALCULATION OF CRITICAL PERIOD IS BASED ON HYDRO CONDITION  1

      TOTAL CAPAC.                                                  PERIOD
PER      IN FIXSYS       --- THERMAL  HYDRO 1  HYDRO 2 ---          PEAK LOAD
 1        7417.8            5589.0    378.8   1450.0               6398.1
 2        7447.4            5589.0    398.4   1460.0               6184.8
 3        7499.2            5589.0    420.2   1490.0               6611.4
 4        7508.2            5589.0    399.2   1520.0               7109.0
CRITICAL PERIOD IS   4
CAPACITY RANGE IN CRITICAL PERIOD IS        8175.4              9241.7
COMMITTED CAPACITY SPECIFIED IN CRIT PERIOD         7908.2

MINIMUM NUMBER OF FOURIER COEFF. CORRESPONDING TO MAXIMUM RESERVE MARGIN IN CRIT PER IS    3

STATE IC NEW    CAP      ACCEPTED CONFIGURATION

  15   1 ***   8508.   1    0    0    2    0    0
  16   2 ***   8508.   0    1    0    2    0    0
  17   3 ***   9108.   1    1    0    2    0    0
  18   4 ***   9108.   0    2    0    2    0    0
  19   5 ***   8708.   1    0    0    3    0    0
  20   6 ***   8708.   0    1    0    3    0    0
  21   7 ***   8308.   0    0    0    4    0    0
  22   8 ***   8908.   1    0    0    4    0    0
  23   9 ***   8908.   0    1    0    4    0    0
  24  10 ***   8600.   1    0    0    2    1    0
  25  11 ***   8600.   0    1    0    2    1    0
  26  12 ***   9200.   1    1    0    2    1    0
  27  13 ***   9200.   0    2    0    2    1    0
  28  14 ***   8200.   0    0    0    3    1    0
  29  15 ***   8800.   1    0    0    3    1    0
  30  16 ***   8800.   0    1    0    3    1    0
  31  17 ***   8400.   0    0    0    4    1    0
  32  18 ***   9000.   1    0    0    4    1    0
  33  19 ***   9000.   0    1    0    4    1    0
CONFIGURATIONS THIS YEAR             19
CONFIGURATIONS THROUGH THIS YEAR     33
NEW CONFIG.(S) THROUGH THIS YEAR      0
*  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  *  END OF YEAR 2000  *  *  *  *  *  *  *  *  *  *  *  *
```

YEAR	#C	#CNEW	#NEWCUM
1997	2	0	0
1998	2	0	0
1999	10	0	0
2000	19	0	0
2001	41	0	0
2002	90	0	0
2003	199	0	0
2004	154	0	0
2005	238	0	0
2006	165	0	0
2007	156	0	0
2008	164	0	0
2009	173	0	0
2010	161	0	0
2011	145	0	0
2012	136	0	0
2013	132	0	0
2014	60	0	0
2015	52	0	0
2016	58	0	0
TOTAL	2157		

Figure 6.6 (page 2) Sample of the CONGEN Printout for the Last Variable Expansion Run of the Sample Problem. CONGEN Run-3

CHAPTER 7

EXECUTION OF MERSIM

The following sections discuss the execution of WASP module 5 MERSIM for the various expansion plans of the sample problem (CASE93) which have been presented in the preceding sections. The control cards and data cards for executing the program are explained in Sections 7.1 and 7.2, respectively. Sections 7.3 and 7.4 describe the execution of MERSIM for a pre-determined expansion plan (i.e. one configuration per year). The use of MERSIM when there are many alternative configurations each year (dynamic or variable expansion plans) will be treated in Sections 7.5 and 7.6.

7.1 Control Cards

Figure 2.3 lists the MERSIM control cards in two groups. The 11 cards in the first group control a file renaming utility sub-program, "RENAME," which automatically renames the existing SIMULNEW file (created by the most recent MERSIM run) as SIMULOLD, and the old SIMULOLD file to SIMULNEW, to store the information from the current MERSIM run. The 15 cards in the second group control the current version of the MERSIM (merge/simulate program) which ***compares*** the configuration list on the EXPANALT file created by the most recent CONGEN run with the list of configurations already simulated in the SIMULOLD file, ***simulates*** system operation for any configuration not already simulated and ***merges*** the new results with the old ones, if any, to create a SIMULNEW file which is then used by DYNPRO. The RENAME/MERSIM combination makes it possible to execute a series of MERSIM-DYNPRO runs without having to change the control cards describing the SIMULOLD and SIMULNEW files.

MERSIM can be executed in the "initial" mode (i.e. for the fixed expansion plan or plans) without the 11 RENAME control cards[1], provided that the SIMULOLD file has been initialized (i.e. SIMULINL, an "empty" SIMULOLD file with the desired label, has been created) by arrangement with the WASP analyst. For the "initial" mode, in the 14th control card of MERSIM, the SIMULOLD file must be an empty file. In this case, there is nothing on this file to be merged into the SIMULNEW file, and until the RENAME control cards are added, each new run will replace the old information on the SIMULNEW file with the new information created by the current MERSIM run. One of the most useful features of the MERSIM program, however, is its ability to save the results of new simulations. This saves valuable computer time, not only when running the program for dynamic expansion plans, but also when simulating a series of alternative predetermined expansion plans since the alternative plans normally have at least some, and sometimes most, of the annual configurations in common. Thus, it is recommended that MERSIM be executed in the "initial" mode during the data debugging phase but, after getting the first successful run of a series, the "merge" mode be used. The changeover is accomplished simply by placing the 11 RENAME control cards in front of the 15 MERSIM control cards. If SIMULINL was used as an empty file, do not forget to replace it by SIMULOLD in the MERSIM control cards, after the first RENAME has been executed.

---

[1] It is shown in Fig. 2.3 that the RENAME control cards 5, 7, 8 and 10 have a "C" in column 72, indicating that the following card is a "continuation card" (i.e., in fact a continuation of the same card). This C must be on the card for the module to run.

The first three MERSIM control cards are similar to those of Modules 1 to 4 except for the program module name and the input data file involved. Cards 4, 5 and 7 control the desired printout capabilities from three separate files (note that control cards 6 and 8 are in fact a continuation card of cards 5 and 7, respectively). Cards 9 to 12 identify the files containing information from Modules 1-4 and used as input by MERSIM. Cards 13 and 14 identify the SIMULNEW and SIMULOLD files used for storing and reading simulation results, respectively. Finally, card 15 identifies the SIMGRAPH file basically needed to store information generated during resimulation runs. (see Section 9.6 and Section E.10 for more details about this file and comments about its use in a case study).

7.2 Data Cards

MERSIM uses up to eight types of data cards as shown in Table 7.1. Similar to other WASP modules, a type-X card is required as the first data card, and cards type-1 with INDEX=1, 2, 4, 5, 6 or 7 will tell the program what to do next.

A card type-1 INDEX=1 is the usual end of year card telling the computer that all data for current year have been completed and that the program can carry out the calculations for the year. A card type-1 with INDEX=2, 4, 5, 6 or 7 tells the computer that the next card to be read is a card of type equal to the INDEX number[2]. Similar to the other modules, it is important to check that the proper sequence of data cards is used in order to avoid wrong calculations or interruption of program execution and the printing of an error message (see Section B.5 of Appendix B). Each type-1 INDEX=2 (4, 5, 6, or 7) card and the corresponding type-2 (4, 5, 6 or 7) card will constitute a group. Although these groups may appear in any order, they will be examined in ascending order of the INDEX number.

A type-1 INDEX=2 card calls for a type-2 card, which is used to give the instructions for calculation of the loading order (SPNVAL) and, if applicable, the values of PEAKF, LBASE, and NOLO in the 1st to 4th fields of the card (each field spreads over 5 columns); the 5th (columns 21-25) and 6th (columns 26-30) fields of the card are reserved for the spinning reserve of the hydro plants type A and type B, respectively. This spinning reserve is expressed as the percentage of the total available capacity of each hydro plant type that can be used to replace outages of the other plants in the system. This information is required when the program is asked to calculate the loading order of the plants (cases (b) and (c) of SPNVAL in Table 7.1) and it must be always given each time a new type-2 card is used, regardless of the values assigned to the other variables in the card, even if the hydro spinning reserves (the percentages) are the same for all years of the study.

Three cases are possible for the loading order instructions (SPNVAL), as shown in Table 7.1 and they are combined with the value specified for NOLO:

If SPNVAL corresponds to case (a), the loading order of the plants is to be given as input data on card(s) type-2a which follow (in this case the NOLO option is not active).

Cases (b) and (c) for SPNVAL mean that the program has to calculate the loading order respecting the specified system spinning reserve requirements and following the basic economic loading order that is either given on cards type-2a (if NOLO = 0), or passed by CONGEN (if NOLO = -1).

---

[2] A type-1 INDEX=7 card should be followed by a sequence of as many type-7a, type-7b, type-7c and type-7d cards as needed.

Table 7.1 (page 1) Types of data cards used in MERSIM

Card type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of study (centered to columns 30-31).
	61-64	I	IOFILE	File printing option; equal 1 to print the FIXSYS and VARSYS files (default value = 0; i.e. no printing of files).
1	1-4	I	INDEX	Index number[2]; 1 indicates that all data for the current year have been completed; 2 indicates that one type-2 and one or more type-2a cards follow; 4 through 5 indicate that a card follows with a type number equal to the INDEX number; 6 and 7 indicate that one or more cards (as needed) with type number equal to the INDEX number will follow.
2	1-5	F	SPNVAL[3]	Loading order instructions, for which three cases are possible: (a) SPNVAL < 0, the loading order (L.O.) is given as input in type-2a cards. In this case, columns 6 to 20 are left blank. (b) $0 \le$ SPNVAL ≤ 5.0, L.O. is calculated by MERSIM rearranging the basic economic L.O. given in type-2a cards, or passed by CONGEN if so instructed (NOLO = -1), in such a way as to meet the spinning reserve (SPNRES) requirements of the system as follows: SPNRES = SPNVAL * CAP + PEAKF * PKMW where: CAP = largest unit capacity block already loaded PEAKF = multiplier of PKMW PKMW = period peak load (c) SPNVAL > 5.0. Same as case (b) above described but in this case: SPNRES = SPNVAL (constant value).
	6-10	F	PEAKF	Multiplier of period peak load (PKMW) for calculating the required spinning reserve. Leave blank for cases (a) and (c) described above.
	11-15	I	LBASE	If = 0, the loading order (L.O.) is calculated on a plant by plant basis. If = 1, the L.O. is calculated on a unit by unit basis. Leave blank for case (a) of SPNVAL described above.

Table 7.1 (page 2) Types of data cards used in MERSIM

Card type	Columns	Format[1]	Fortran name	Information
2 (cont.)	16-20	I	NOLO	If = -1, use the basic economic loading order (L.O.) passed from CONGEN (this option is only applicable in the first year and for SPNVAL ≥ 0, i.e. cases (b) and (c) of SPNVAL). If = 0, the L.O. is specified in the cards that follow. If = 1, no L.O. follow indicating to the program to use the L.O. from the previous year (this option is only allowed from the second year on, when other variables are altered but the L.O. may remain the same). Leave blank for case (a) of SPNVAL above described.
	21-25	I	ISPIN(1)	Part (%) of the total available hydro capacity of hydro plant type A that will be considered as spinning reserve (default = 0).
	26-30	I	ISPIN(2)	Part (%) of the total available hydro capacity of hydro plant type B that will be considered as spinning reserve (default = 0).
2a	1-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 41-45 46-50 51-55 56-60	I I I I I I I I I I I I	NORDER	Plant loading order from the combined FIXSYS plus VARSYS list of plants[4] (a) If SPNVAL < 0, base and peak blocks of thermal plants must be specified individually in the loading order: base blocks are specified by their plant order number in the combined FIXSYS plus VARSYS list of plants, whereas peak blocks are specified adding 1000 to that number. If a plant has only one block of capacity (MWB=MWC), only the base block must be specified. Hydro plants are not to be included in the loading order list since these plants are handled automatically by MERSIM. (b) If SPNVAL ≥ 0, the economic loading order must be specified for thermal plants giving their plant order number in the combined FIXSYS plus VARSYS list of plants. The program will automatically dispatch base and peak blocks of the thermal plants in order to meet the spinning reserve requirements.
4	1-4	I	IOPT	Output option: 0 (zero), default value, calls for minimum output (list of the configurations); 1 calls for intermediate output (summary of annual costs for each year); 2 calls for maximum output (detail of simulation for each configuration, per period and per hydrocondition). Note: Whichever option is used, the program prints out only the results for the new configurations simulated in the current run.

Table 7.1 (page 3) Types of data cards used in MERSIM

Card type	Columns	Format[1]	Fortran name	Information
5	1-4	I	NOCOF	Number of Fourier coefficients to be used in the simulation for the representation of the equivalent load duration curve (LDC), if it is desired to use fewer than in LOADSY (the default is the value specified in LOADSY). The original LDC is represented by the constant term (a_0) plus NOCOF cosine terms. The equivalent LDC is represented by the constant term plus NOCOF cosine and sine terms. The recommended value for NOCOF is between 20 and 50.
6	1-4	I	NFUEL	Thermal plant fuel type number subject to energy limitation (0 to 9).
	5-14	F	ENGLIM	New energy limit of fuel type NFUEL (in thousand 10^6 kcal/day).
7a[5]	1-8 9-16 65-72	F F F	C1CBL	Domestic fuel consumption by unit (TON/GWh) (starting with FIXSYS: first thermal power plant is plant no. 3, continued with VARSYS). 9 entries per card. Use as many 7a cards as required[6].
7b[5]	1-8 9-16 65-72	F F F	C1CBF	Foreign fuel consumption by unit (TON/GWh) (same notes as for card 7a above) Use as many 7b cards as required[6].
7c[5]	1-8 9-16 65-72	F F F	F1SL	Domestic fuel stock by unit (TON) (same notes as for card 7a above) Use as many 7c cards as required[6].
7d[5]	1-8 9-16 65-72	F F F	F1SF	Foreign fuel stock by unit (TON) (same notes as for card 7a above) Use as many 7d cards as required[6].

Notes to Table 7.1

[1] See Section 2.5 for Format description.

[2] Card type-1 INDEX=3 is not used.

[3] The options for calculation of the loading order (L.O.) by MERSIM, i.e. Cases (b) and (c) for SPNVAL, should be treated with great care because the resulting L.O. will be dependent on the data given by the user, not only for the involved variables, SPNVAL, CAP, PEAKF, PKMW, but also for the capacity blocks of the various FIXSYS and VARSYS plants and their respective ISPIN. Before deciding on all these data, it is strongly recommended to read Section D.8 of Appendix D which describes in detail the L.O. calculations carried out by MERSIM.

[4] Card type 2a is used only if NOLO = 0. The numbering of the plants for the simulation process is as follows: 1 and 2 are reserved for the hydro plants type A and type B (even if they do not exist). Then, the thermal plants of FIXSYS, beginning with 3 (this number appears to the left of the thermal plant table included in the FIXSYS output). Finally, the thermal plants of VARSYS in the same order in which they were read (beginning with the number of the last thermal plant in FIXSYS plus 1). Note: hydroelectric plants should not be included in the loading order.

[5] Card type-1 INDEX=7 and card types 7a, 7b, 7c and 7d used only for RESIMULATION.

[6] These cards permit separating unit fuel consumption and fuel stock into domestic and foreign components for the MERSIM and REPROBAT reports. For results on fuel consumption to be correct, the heat rates for the respective plants (in FIXSYS and VARSYS) must reflect the same distribution.

For the first year of the study and independently of the value of SPNVAL, it is necessary to specify either a *predetermined loading order* or the *basic economic loading order*, according to the case. This will require using one or more type-2a cards immediately after the type-2 card to provide this information, unless NOLO = -1 and SPNVAL corresponds to case (b) or (c). Cards type-2 may be used for subsequent years to change the instructions for calculation of the loading order (SPNVAL), the spinning reserve requirements of the system or the spinning reserve (%) of the hydro plants, or all of them. If the new type-2 card specifies a value of SPNVAL corresponding to case (a), additional type-2a card(s) must follow to give the predetermined loading order of the plants, even if this does not change the one applicable to preceding years. If SPNVAL corresponds to cases (b) or (c), type-2a card (or cards) are to be used if there is a change in the basic economic loading order specified for preceding years. In this case, NOLO = 0 (see Table 7.1 page 1). (Note that starting from the second year, NOLO can only take a value of 0 or 1).

The predetermined (or the basic economic) loading order is given in the order in which load is to be assigned. This is described on the subsequent type-2a card (or cards) by integer numbers right-adjusted (Format "I") in 5-columns fields using as many type-2a cards as required (12 fields per type-2a card). Each number on the card represents one of the thermal plants considered in the same order in which they appear in the combined listing of fixed-system plants and variable-system plants, with the fixed-system plants listed first. It should be remembered that the first thermal plant in the fixed-system listing will be always assigned number 3 since numbers 1 and 2 are reserved by the program for hydro type A and hydro type B, respectively, even if any of these two plant types is not actually used in the case under study. The hydro plants are not to be included in the loading order as they are automatically handled by the program. Inclusion of any hydro plant in the loading order will lead to interruption of program execution (see Appendix B Section B.5).

If type-2a cards are used to specify a *predetermined loading order* (**case (a) of SPNVAL**), base and peak portions of thermal plants are to be included in this loading order (L.O.), beginning with the first base loaded plant and ending with the last peaking plant. The base-load portion of plant capacity is indicated by the same number of the corresponding plant from the combined listing of fixed system and variable-system plants. The peak load portion of capacity of the plant is indicated by adding 1000 to the integer describing the base-load portion. Thermal plants for which MWB is equal to MWC appear only once in the loading order indicating only the base-load portion number, i.e. no peak-load portion is defined for these plants (Note that the plant can be operating in any portion of the load, i.e. as baseload, peaking or intermediate load plant).

If type-2a cards are used to give the *basic economic loading order* (**cases (b) and (c) of SPNVAL**), the thermal plants are not split into base and peak blocks and each plant is represented only once by the same number in which they appear in the combined listing of fixed-system and variable-system plants. The economic loading order calculated by FIXSYS and VARSYS (see page 4 of Figs. 4.2 and 5.2) are combined by CONGEN into a single one (see page 2 of Fig. 6.2) to help the user in preparing the loading order for MERSIM.

One type-1 INDEX=4 and one type-4 cards may be used to obtain different types of output. The default value ("0") calls for minimum output, and this can be changed to "1" (intermediate output) or "2" (maximum output). The use of this option will be explained when describing the MERSIM runs for the sample problem. A set of one type-1 INDEX=5 and one type-5 cards may be used to change the number of Fourier coefficients to be used in the simulation. The new number of coefficients to be given in card type-5 cannot be greater than the default value, which is set by MERSIM to the value specified in Module 1 (read by the program from the LOADDUCU file).

A type-1 INDEX = 6 card followed by a type-6 card is used to specify new limits for the thermal fuel types associated with fuel (energy) limitations. Finally, a type-1 INDEX = 7 card followed by as many type-7a through 7-d cards can be used to specify the unit fuel consumption and unit fuel stock for each thermal plant existing in the system. (Note that the type-7 cards are used only for resimulation runs.)

The data cards of MERSIM are arranged in the following sequence:

a) For the first year:

- First card: One type-X card with the title of the study and file printing option.

- Next cards: One type-1 INDEX = 2 card, followed by a type-2 card giving the loading order instructions. This must be followed by type-2a cards giving the predetermined loading order (L.O.) or the basic economic L.O. of the plants according to the value of SPNVAL. The card type-1 INDEX = 2 must also give the spinning reserve of the hydro plant types and, if applicable, the values for the other variables defined by this card type. (Note: If NOLO = -1 in the type-2 card, it is not permitted to specify the loading order in type-2a cards)

  One card type-1 INDEX = 4 (or 5) followed by a type-4 (or 5) card if a printout option (or NOCOF value) different from default is required.

  One type-1 INDEX = 7 card followed by as many type-7a through -7d cards, as necessary, to specify the unit fuel consumption and fuel stock of the thermal plants in the system, if the run corresponds to a resimulation of the current DYNPRO best solution (or ultimately the optimal solution).

- Last card: One card type-1 INDEX = 1 (end of the year).

b) For the second and subsequent years:

- Groups of a type-1 INDEX = 2 and a type-2 cards for each change to be made to the instructions for L.O. calculation, spinning reserve requirements of the system, or spinning reserve supplied by the hydro plants. If the value of SPNVAL in the new type-2 card corresponds to case (a), cards type-2a (as necessary) must follow to give the predetermined L.O. of the plants. For cases (b) and (c) of SPNVAL, new type-2a cards are only required if a change is to be made to the basic economic L.O. (NOLO = -1 is not permitted).

- One card type-1 INDEX = 4 and a type-4 card if the printout option for current year is different from the one applicable to the preceding year. Although additional type-1 INDEX = 5 and type-5 cards may be used for each year of the study to change the number of Fourier coefficients to be used in the simulations for this year, this is not recommended for planning purposes.

- One card type-1 INDEX = 6 and one type-6 cards if changes are to be made to the limits on some thermal fuel types associated with fuel limitations.

- One card type-1 INDEX = 7 and as many type-7 cards as needed to give any changes in specific fuel consumption and fuel stock of the thermal plants.

- Last card: One card type-1 INDEX = 1 (end of the year).

7.3 Input Data for a Fixed Expansion Plan (MERSIM Run-1)

Figure 7.1 lists the input data prepared for a fixed expansion plan of CASE93, for which MERSIM is used in the "initial" mode (see Sec. 7.1). In effect, this was the first run of module MERSIM for the sample problem, corresponding to the predetermined expansion plan presented in Sections 6.3 and 6.4 (CONGEN Run-1). The first input data in Fig. 7.1 is the type-X card with the title of study (columns 1-60) and the printout option for FIXPLANT and VARPLANT files (column 64). The same remarks made in Section 6.3 for the title of study to be used in the type-X card of CONGEN are also valid for MERSIM. Since we are in the debugging phase of data and control cards of the module, the "1" in column 64 asks for printing of the FIXSYS and VARSYS files.

The second input line is of type-1 INDEX = 2 calling for a type-2 card to follow. In the sample problem, a number less than 0 (-1.0) is shown in the 1st field of the type-2 card, indicating to the program that a predetermined loading order of the plants will be used for the first year of study (1997). Column 20 gives a zero for NOLO, but this value is not considered because of the negative value in the first field (SPNVAL). Column 25 of the same card gives as 2 the percentage of the total available capacity of hydro plant type A (HYD1) that can be used as spinning reserve, and column 30 a 5(%) for the hydro plant type B (HYD2). Since case (a) of SPNVAL applies in this year, these percentages are not required by MERSIM, but they have been included in the type-2 card for convenience.

The next input lines are two type-2a cards giving the predetermined loading order of the plants to be used in the simulations; therefore, base and peak portions of plant capacity are specified in these cards for all thermal plants in the system. Baseload portions are given by the same number in which the plants appear in the combined listing of fixed-system (Fig. 4.2) and variable-system (Fig. 5.2) plants, and the peak-load portions by adding 1000 to that number. In our sample problem, there are 8 plants in the fixed system plus 6 in the variable system, a total of 12 (the two composite hydro plants are repeated in both FIXSYS and VARSYS); however, since hydro plants are not to be included in the L.O., only 10 plants are considered. Thus the type-2a cards indicate the following L.O.:

Order	Plant No.	Type	Order	Plant No.	Type
1	11	Base VNUC	10	10	Base VFOL
2	7	Base FLIG	11	1004	Peak FCO2
3	3	Base FCO1	12	5	Base FOIL
4	1011	Peak VNUC	13	1010	Peak VFOL
5	1007	Peak FLIG	14	1005	Peak FOIL
6	9	Base VCOA	15	12	Base V-GT
7	4	Base FCO2	16	6	Base F-GT
8	1003	Peak FCO1	17	8	Base IMPT
9	1009	Peak VCOA			

Since plant 12 (V-GT), plant 6 (F-GT), and plant 8 (IMPT) have MWB equal to MWC, they appear only once in the loading order, represented by the corresponding base-load portion (no peak portion is given for these plants).

```
   CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL       1
   2
  -1.0              0    2    5
   11    7    3 1011 1007    9    4 1003 1009   10 1004    5
 1010 1005   12    6    8
   4
   2
   5
  20
   6
   5      10.
   1          (END OF 1997)
   2
300.0         1    0    2    5
   11    7    3    9    4   10    5   12    6    8
   1          (END OF 1998)
   2
  1.0-0.02    1    1    2    5
   6
   5      13.
   1          (END OF 1999)
   4
   1
   6
   5      26.
   1          (END OF 2000)
   6
   5      39.
   1          (END OF 2001)
   1          (END OF 2002)
   1          (END OF 2003)
   6
   5      65.
   1          (END OF 2004)
   4
   2
   1          (END OF 2005)
   4
   1
   1          (END OF 2006)
   1          (END OF 2007)
   1          (END OF 2008)
   1          (END OF 2009)
   4
   2
   1          (END OF 2010)
   4
   1
   1          (END OF 2011)
   1          (END OF 2012)
   1          (END OF 2013)
   1          (END OF 2014)
   1          (END OF 2015)
   1          (END OF 2016)
```

Figure 7.1 MERSIM Input Data for a Fixed Expansion Run of the Sample Problem (CASE93). MERSIM Run-1

The subsequent input line is a type-1 INDEX=4 card calling for a type-4 card to specify the print output option. A "2" on this card calls for maximum output for the current year and all subsequent years until a new card type-4 changes this option. In the sample problem, maximum output is requested for the years 1997 throughout 1999, and in year 2000 the printout option is changed to "1" (intermediate output) from this year on. (Note: maximum output is also requested for years 2005 and 2010). If the type-1 INDEX=4 and type-4 cards are omitted, MERSIM will give the so-called minimum output (default).

The input line number 8 is a type-1 INDEX = 5. This is followed by a type-5 card specifying the number of Fourier coefficients to be used in the simulations. In the sample problem, this number was reduced from 50 (used in Module 1) to 20. This represents a good compromise between the accuracy of the simulations carried out by MERSIM and the computer time required to perform them[3].

The next input lines of Fig. 7.1 consist of one type-1 INDEX = 6 and one type-6 data cards. These are used to specify new values for fuel limitations applicable to certain fuel types. In this case, new limits are specified for fuel type number 5 (LIGN) and the amount of fuel that is available for generation by the associated thermal plants is 10. (thousand 10^6 kcal/day)[4]. The input data continues with a type-1 INDEX = 1 card indicating that all data for the first year of the study (1997) have been completed. The information in columns 16 to 28 of this card is for the convenience of the user and is not read by the computer.

The data for the second year (1998) starts with a type-1 INDEX = 2 card, followed by a type-2 card with the instructions for calculating loading order and spinning reserve. In the sample problem the value of 300. in the first field of the card is greater than 5.0 (i.e. case (c) of SPNVAL). Therefore, this defines the spinning reserve (SPNRES) requirements for the system for calculation of the loading order of thermal plants in the system. The 2nd field of this card is left blank, and the integer "1" in the 3rd field calls for calculation of the L.O. on unit by unit basis[5]. The integer on the 4th field of the card, in this case a zero (NOLO), tells the computer that type-2a cards will follow. Finally, the last two integers on the card specify the spinning reserve of the composite hydro plants (these percentages are kept constant in the sample problem).

The next input line is a type-2a card with the basic economic loading order of the plants to be used by the program for calculating the loading order. In this case one type-2a card is sufficient to indicate the basic economic loading order since the plants are not split into base and peak blocks of capacity. Again the loading order does not include any of the hydro plants as they are handled automatically by the program. After this card, a new type-1 INDEX = 1 card is included to indicate that all data for the year 1998 have been completed, so that the program can proceed to carry out the calculations for this year.

The input data for the next year (1999) begins with a type-1 INDEX = 2 card, followed by a type-2 card specifying a change in the instructions for calculating loading order and spinning reserve. The value 1.0 in the first field corresponds to case (b) of SPNVAL; therefore, this is the multiplier of the largest unit capacity block already loaded for

---

[3] Selection of the adequate number of Fourier coefficients to be used in the simulation requires the execution of several fixed expansion runs for the case study where the execution time per configuration is to be weighed against the accuracy of the results. Of particular importance are the resulting values of LOLP and Energy not Served of the configurations.

[4] This card type can only be used for new limits on the amount of fuel available for fuel limited types specified in the type-Y cards of FIXSYS. In the case example, the "new" limit could have been simply changed by correcting the appropriate value specified in the respective columns of the type-Y card for this fuel type in FIXSYS and rerunning FIXSYS. They have been included in the input data for illustration purposes.

[5] The option for L.O. calculation on a plant by plant basis ("0") may produce some savings in computer time required to carry out the simulations, though the results are less accurate in this case. However, for large systems composed of many multiple-unit plants, this option ("0") may be a good compromise between accuracy and computer time requirements.

calculating the fast spinning reserve requirements of the system. The value -0.02 (PEAKF) in the second field multiplies the period peak load (PKMW) by 0.02 and subtracts this from the largest unit capacity block already loaded x 1.0 to give the desired fast spinning reserve. Again, the loading order is to be calculated on a unit by unit basis ("1" in the third field). The "1" in the fourth field (NOLO) of the card indicates that no loading order will follow so that the program must use the same basic economic L.O. specified for the previous year. Finally the spinning reserve of the composite hydro plants type A and type B are also shown on the last two fields of the card. As explained before, these percentages of hydro spinning reserve must be repeated in the card type-2, even if they are equal to the ones applicable for preceding years (otherwise they would be assumed as zero since both are read each time this card is used).

The next input lines in Fig. 7.1 are used to specify new limits for the amount of fuel allocated for generation by thermal plants using fuel type 5. In this case, the new limit is 13. (10^3 million kcal/day). These are followed by the usual end of the year card for the current year of study (1999).

The subsequent input lines introduce a change to the printout option asking for intermediate output ("1") to be produced from this year on (until new type-4 cards are used). In this year, a new limit for fuel type 5 is also specified, as shown in the respective type-6 card and the new limit is 26 x 10^3 million kcal/day. The end of year card follows in the sequence. The remaining input lines in Fig. 7.1 are groups of type-1 INDEX=1 cards covering each of the remaining years of the study period (2001-2016), including, for some years, sets of type-1 INDEX=4 (or 6) and type-4 (or 6) cards to specify changes in the required printing option (or variations in the limitations of fuel type 5) in certain years.

In the run illustrated here, maximum output option ("2") is specified for years 2005 and 2010. In addition, the limits for the amount of fuel available for generation by thermal plants using fuel type 5 are increased to 39 (10^3 million kcal/day) in year 2001 and will remain applicable until year 2004 when a new limit is specified (65 x 10^3 million kcal/day)[6]. This new limit will apply until the last year of study. The implications of these specifications will be discussed in the description of the printed output for the run made in Section 7.4.

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[6] In the sample problem, only thermal plant 8 (FLIG of FIXSYS) is associated with a limited fuel type (LIGN). The theoretical maximum amount of fuel (MAXFUEL) needed by one generating unit of this plant on a daily basis (i.e. disregarding maintenance and forced outages, and considering the whole plant operating at baseload) can be calculated from the following equation (all variables use the same units as identified in FIXSYS) :

$$\begin{aligned} MAXFUEL &= (NPER/365) * 10^{-3} * [\,(MWB*BHRT) + (MWC-MWB)*CRMHRT\,] * 8.76/NPER \\ &= (8.76/365) * 10^{-3} * [\,(120 * 2560 + (294 - 120) * 2250\,] \\ &= 16.77 * 10^3 \text{ Million Kcal} \end{aligned}$$

In the simulation process, maintenance and forced outage rates of the plants will be taken into account and the resulting generation will be dependent on their position under the L.O. with respect to the load curve of the system, so that the daily needs would be lower than the above value. The limits assigned for fuel type LIGN along the years take into account this fact. The actual limits were selected for demonstration purposes. Note that the value of 65,000 Million kcal/day for the existing 4 units of FLIG from year 2004 on, is hardly a constraint in the amount of fuel (see description of the algorithm in Appendix D, Section D.10.5).

7.4 Printout for a Fixed Expansion Plan (MERSIM Run-1)

Figure 7.2 illustrates the MERSIM printout for the fixed expansion plan of the sample problem (using the data of Fig. 7.1). As the file printing option for this run was set to "1", the first pages of output are in sequence: the *description of the fuel types* as read from the FIXSYS file; the *description of the Fixed System* for the first year of study (1997); and the *description of the Variable System*. None of these pages is shown in Fig. 7.2 since they include the same information displayed on pages 1 and 2 of Figure 6.2.

Page 1 of Fig. 7.2 is the cover page printed by MERSIM to identify the run. This shows the title of study and the list of the variable expansion candidates, beginning with the thermal candidates and ending with the hydro plants. Each candidate is identified by its code name (in the central column of the list) and two sequence numbers. The number to the left corresponds to the number of the plant in the same order as it appears in the configurations generated by CONGEN, and the one to the right gives the number in which the plant is to be considered for simulation purposes (i.e. the number in which the plant appears in the combined listing of fixed-system and variable-system plants). It can be seen that hydro type A (HYD1) and type B (HYD2) are assigned positions 1 and 2, respectively, in the simulation. At the bottom of the list, the printout informs any limits associated with thermal fuel types, together with the corresponding substitution plant, as read from FIXSYS.

Data for the sample problem gave a value of SPNVAL less than zero (-1.0) for 1997; therefore, a fixed loading order was called for. This is shown on page 2 of Fig. 7.2 (top part)[7] which presents the loading order control data followed by the given loading order both by plant number and by plant type. Page 2 also shows all other input data for year 1997.

Since the print output option for this year (through 1999) was set to "2" (maximum output), the program prints the detailed results of the simulation calculations for each period and hydrocondition in each of these years. The bottom part[7] of page 2 of the figure shows these results for period 1 and hydrocondition 1 of 1997. First the configuration being simulated is shown, followed by the number of the hydrocondition and its probability (1 and 75%, respectively). Then data are listed for each plant in the system starting with the two composite hydro plants, if any, followed by the thermal plants. The data for each plant are given on 16 columns of a table under the headings of *HYDROPLANTS OPERATIONAL SUMMARY* and *THERMAL PLANTS OPERATIONAL SUMMARY*.

The *HYDROPLANTS OPERATIONAL SUMMARY* table gives for each composite hydro plant (if any) the following information: in the 1st column the *number of the plant* in the combined listing of fixed- and variable-system plants; in the 2nd column the *plant code name*; in the 3rd column the *number of projects* composed in the plant (FIXSYS plus VARSYS). The remaining columns show the results of the simulation, identifying in the 4th and 5th columns the *plant number capacity block* (base or peak) and the *unit number* of the last thermal unit which was off-loaded by the peak capacity of the given hydro plant (see below); in columns 6th and 7th the *base* and *peak capacity* of the plant, and in column 8th the *total capacity* (sum of these two columns (all values in MW); columns 9th to 11th give in the same order the *base, peak and total energy* generated (all in GWh) by the plant; column 12th gives the *minimum requirements of peaking energy* (GWh) at the beginning of the simulation; column 13th shows the *spilled energy* (if any) and column 14th the *energy shortage* (if any) of the plant (both in GWh); column 15th gives the *Operation and*

[7] The information shown in this page actually spreads over two separate pages of the printout. These have been compressed into a single page to reduce the size of the manual.

Maintenance (O&M) costs in thousand $ (these are considered as local costs); and the last column (16th) shows *plant capacity factors* (expressed in %). Some additional comments on the meaning of the above information follow.

Off-loading of thermal plants by the peaking capacity of hydro plants is carried out by MERSIM as part of the simulation, trying to make use of all available hydro energy so as to reduce the total operating costs of the system. The minimum requirements for peaking energy (column 12 of the table) correspond to the value determined by MERSIM before the off-loading process begins; therefore, if this value is lower than the peaking energy (column 10) of the plant, off-loading of thermal plants by this hydro plant is possible. Page 2 of the figure illustrates this point showing in columns 4 and 5 of the hydro plant table that the last block of capacity off-loaded by both hydro plants corresponds to the base portion of the 4th unit of thermal plant number 5 (FOIL).

Two additional cases are possible for the number reported in column 4th:

- a zero (0) means that no off-loading of thermal plants is possible (i.e. minimum energy requirements for peak are equal or greater than the energy available for peaking);
- asterisks (****) indicate that no further off-loading of thermal plants can be achieved since the peak block of the corresponding hydro plant has reached the minimum load of the period.

Concerning the peak and total plant capacities (columns 7 and 8 of table), these values are normally equal to the peak and total capacity of the plant which are available in the period and hydrocondition considered. In some cases, however, these values can be lower than the available ones. This situation occurs when the minimum energy requirements for peaking exceed the energy available for peaking of the respective plant. In this case, MERSIM reduces the peak capacity of the plant accordingly (see description of System Operational Summary below):

- If column 13 of the table shows a value of energy spilled greater than 0.0 (GWh) for a given hydro plant, it means that no more off-loading of thermal capacity can be achieved with this plant as explained before.
- Similarly, if column 14 shows a value of energy shortage greater than 0.0 (GWh), this means that the minimum peaking requirements exceed the available peaking energy of the respective hydro plant. Energy shortage less than 0.0 means that surplus of energy of one hydro plant could not be used due to shortage in energy of the other hydro plant.
- Finally, the plant capacity factor reported in column 16 is calculated by MERSIM dividing the total energy generated by the plant (col. 11) by the installed capacity of the respective hydro plant and by the total hours in the period.

The *THERMAL PLANTS OPERATIONAL SUMMARY* table is organized as follows: Columns 1 to 3 give similar information as explained before for the hydro plants, except that the numbers in column 3 are the *number of units* in the thermal plant. The 4th and 5th columns give the *unit capacities*: MWB and MWC respectively. Column 6 is the *total plant capacity* (col. 5 times the NO. of sets in col. 3). Columns 7 to 9 are the *base, peak* and *total* energy generated by the plant. The generation of thermal plants for which MWB = MWC (appearing in the loading order list only once; plant 6 and plant 8 in this case) is listed under BASE ENERGY (col 7) even though they actually are peak-loaded plants because here, the term "base" refers to the MWB portion and "peak" refers to the remaining (MWC minus MWB) portion, rather than to plant position in the loading order. Columns 10 to 11 give the plant *fuel costs* in *local* and *foreign* components, and column 12 the *total plant fuel costs*; all values in 1000 \$. Column 13 reports the *O&M costs* of the plant, and column 14 the plant's *maintenance probability*, i.e. the percentage of plant capacity which is accorded to maintenance in the period. Thus, the actual available capacity of plant 4 (FC02) discounting maintenance is: 3 x 400 x (1 - 0.129) = 1045.2 MW. Column 15 lists the unit *forced outage rate* of thermal plants and column 16 the plant *capacity factor* (also referred to the installed capacity of the respective plant) in the period and hydrocondition considered.

In the Operational Summary tables described above, additional lines show the totals for all hydro plants and all thermal plants, respectively, but only for the applicable information (columns) in each case. After the totals for the thermal plants, MERSIM reports the *SYSTEM OPERATIONAL SUMMARY* which lists, on the left-hand side, data on system capacities and loads, and on the right-hand side the summary of system generation (see bottom of page 2 of Fig. 7.2).

The information on system capacities and loads starts with the summary of thermal and hydro capacities, broken down by plant ("fuel") type. At this level, if plants associated with limited fuel types exceed the limit, the reduced capacity of the thermal plants using this fuel type is printed on the right hand side (THERMAL GENERATION). If any FIXSYS thermal plant has been specified as substitution plant for this limited fuel type, the printout will also report between brackets the resulting capacity of the substitution thermal "fuel" plant (Note that this plant does not contribute to the total installed capacity).

The information on plant capacities by fuel type is followed by a summary of: *total system capacity* (sum of *installed capacity of thermal* plants plus *available hydro* capacity); the *peak* and *minimum* loads of the period; the period maintenance space (equal to the total system capacity minus period peak load); and the actual reserve capacity subtracting from the maintenance space the capacity under maintenance in the period, i.e.:

$$\sum \ (1/100)*(\text{Col. } 6 * \text{Col. } 14 \text{ of thermal plants})$$

where Col. 6 is expressed in MW and Col. 14 in %.

If as a result of the simulation the capacity of any hydro plant type has been reduced by the program (i.e. when the minimum energy requirements for peaking exceed the energy available for peaking of the respective plant), this is shown in the summary of hydro capacity after MW, as: RED. XXXX ==> YYYY; indicating reduction of the available capacity (XXXX), and after the arrow the reduced value (YYYY) that was calculated in the simulation.

The data on system generation (on the right-hand side of the *System Operational Summary*) starts with the thermal and hydro generation, also broken down by plant ("fuel") type. As discussed before, if the fuel consumption of a limited thermal fuel type exceeded the specified limit, the table will report the results of the simulation after reduction of the capacity of the associated thermal plants, specifying the factor by which the capacities of the associated plants was reduced.

For example, in page 2 of Fig. 7.2, the capacity of the plants associated with the limited fuel type (5) has been reduced to 0.74 of the total. At the same time, the capacity of the substitution thermal "fuel" type 6 is reported as (65.4), which should be equal to the capacity of fuel type 5 (FLIG: 1*294 MW) x (1-0.74) x (1-0.129) = 67.4 MW[8]. The resulting fuel cost for this extra generation by the substitution plant are also reported under the Thermal Plants Operational Summary.

It should be noticed that the generation by the substitution plant in the sample problem is very small because it is the last plant in the L.O. and most of the extra generation required to substitute for fuel type LIGN is taken up by other thermal plants above the FLIG and below IMPT under the L.O.

The report of energy generation by plant type is followed by: the *total system generation* (sum of the energy generated by all plants in the system); *energy demand* of the system (as measured from the inverted load duration curve); the *unserved energy* and *energy balance*; all values expressed in GWh. The "unserved energy" is the value of the energy demand which cannot be served by the system and the "energy balance" is equal to the energy generated by all plants plus the energy not served minus the energy under the load duration curve. It is important that this energy balance be a small value since this represents the accuracy of the simulation. The last information in the system operational summary is the loss-of-load probability (%) for this period and hydrocondition.

A similar detailed output as explained before for period 1 and hydrocondition 1 is produced by MERSIM for the same period and each of the remaining hydroconditions (in this case the second and third hydroconditions). The same printout is also produced in sequence for the remaining periods of the year (1997 in this case). This part of the printout is not shown in the figure.

After having considered the last hydrocondition for the last period of the year; the printout continues with the information for the next year of the study (1998). Since IOFILE was set to "1" for this run, the printout includes the description of the fixed-system on the FIXPLANT file for this year. This is followed by the input data given to MERSIM in the same year. Page 3 of Fig. 7.2 (upper part) shows these portions of the output[7]. For the present run of CASE93 the calculation of loading order (L.O.) within the program commenced in 1998 as shown on page 3, which also reproduces the L.O. control data (card type-2), the basis for calculating the L.O. (unit by unit) and the basic economic L.O. given as input data.

The rest of the information on page 3 of Fig. 7.2 (bottom part)[7] are the results of the loading order calculated by MERSIM. This starts identifying: the *period, year* and *configuration* considered; the applicable *hydrocondition* and its *probability.* Next come the *hydro-indices* and *hydro-spinning reserves* (%); the *number of thermal plants* (10 in this case) considered in the basic economic L.O. and the *basis for calculating L.O.* Then follows data on the plants which are actually operating (those with zero sets are not included). In the sample run only plants 1 through 8 (i.e. the FIXSYS plants) are operating in 1998 since no VARSYS thermal candidate plant has been added by the configuration considered. This is tabulated in 10 columns reporting in sequence: *number of units, availability (%), Total Capacity (MW), Base Capacity (MW), Spinning Reserve (%), Spinning Reserve (MW),* and the derated values for *Total , Base,* and *Peak Capacity (MW),* and *Spinning Reserve (%).*

---

[8] The printing formats used in the table round to two decimal digits the values of the maintenance probability of thermal plants and capacity reduction fraction of plants with limited fuel type, which explains the inequality of the given figures. For example, assume that the maintenance probability of the IMPT plant is 0.1285 and the reduction of capacity of FLIG is 0.7449, then the capacity of the substitution plant is equal to:

$$294*(1-0.7449)*(1-0.1285) = 65.362 \approx 65.4$$

The calculated loading order along with the number of units being loaded in each plant, the cumulative derated spinning reserve, cumulative derated capacity and required spinning reserve of the system are tabulated next[9].

Since the print output option applicable for this year is still "2," the printout continues with a detailed listing of the results of the simulation for this period and hydrocondition (similar to the one at the bottom of page 2 of Fig. 7.2). Note that this listing is not included in Fig. 7.2. A similar printout is also produced for each period and hydrocondition of each year, unless the user specifies something different for subsequent years. In the sample problem, a change in the loading order instructions was introduced in year 1999 as shown on page 4 of Fig. 7.2, which lists first the input data for the year, followed by the results of the loading order calculations according to the new instructions[7]. Detailed results of the simulation (not shown in Fig. 7.2) follow and the report continues in the same fashion for all periods and hydroconditions in 1999.

In year 2000 the printout option for subsequent years (including 2000) was changed to "1"; thus the printout continues with the listing of the FIXPLANT file information and the MERSIM input data for the corresponding year (similar to the one on the top part of pages 3 and 4 of Fig. 7.2) until the last year of the study has been considered or the print option is changed again. For example, in year 2005, IOPT is reset to 2 so that a similar type of output as the one discussed for the first years of study will be produced. In year 2006, IOPT is specified to 1 so that the output will continue with a listing of the FIXSYS description and input data for the year until a change is introduced in the IOPT value. A similar situation occurs for years 2010 and 2011.

After the above information is printed, MERSIM reports the list of the configurations (states) which were simulated in the present run for each year. Page 5 of Fig. 7.2 shows the first part of the listing (up to year 2009) of the configurations simulated in the present run of the sample problem (MERSIM Run-1).

This *Listing of Configurations* includes: the *number* of the configuration (STATE) as it appears in the SIMULNEW file, along with data on the corresponding *total operation costs* (COST K$); the *expected average annual LOLP* (%) resulting from the simulation (i.e. considering maintenance of thermal units) and the one calculated (if any) by CONGEN (without maintenance), both also given in equivalent days/year[10]. After this information, the configuration is also reproduced. Finally, if applicable, the program reports: the *energy not served* (ENS GWH) for each hydrocondition (sum of energy not served in each period for the same hydrocondition); the *hydro shortage* (HY-SH GWH) and/or *hydro spillage* (HY-SP GWH) per hydrocondition[11].

---

[9] Note that this loading order is the one at beginning of the simulation and therefore the peak blocks of the two hydro plant types are set at the last position of the L.O. Their final position will be found by MERSIM and reported as part of the tables with the operational summary.

[10] In the preceding CONGEN run of the sample problem, the option for LOLP calculation was set to 0. Thus, LOLP values without maintenance were not calculated by CONGEN and therefore not reported in the MERSIM output.

[11] In the sample problem, none of the configurations simulated in this run leads to hydro shortage or hydro spillage in any hydrocondition; thus, only the values of energy not served are reported as can be seen on page 5 of Fig. 7.2.

Since the printout option for this run was set to a value "1" or "2" for all years of the study period, a summary of the yearly results for each configuration is printed by the program after the list of configurations shown on page 5 of Fig. 7.2. A sample of this part of the output is shown on page 6 of the figure[7]. A similar output (not shown here) follows for the remaining years of the study.

The annual summaries are printed in two separate pages. The upper part of page 6 illustrates the annual summary of the cost and reliability results for the first configuration (1997). This lists the plant (installed) capacities and operational costs for each plant ("fuel") type, first for the thermal fuel types and then for the composite hydro plant types (if any), followed by the totals for the system. The summary includes also the values of unserved energy (GWh) and the loss-of-load probability (%) for each hydrocondition along with the expected annual value of LOLP (weighted by the hydroconditions' probabilities). The second type of annual summary of results reports the generation by each power plant in the same order as the combined listing of FIXSYS and VARSYS. The results are shown by period and for the total. This summary for year 1997 is shown at the bottom part of page 6.

```
                    WASP  COMPUTER PROGRAM  PACKAGE

                           MERSIM  MODULE

                             CASE  STUDY

          CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL


*****************************************************
*                                                   *
*      LIST OF VARIABLE EXPANSION  CANDIDATES       *
*                                                   *
*****************************************************
*                                                   *
*                 THERMAL   PLANTS                  *
*                                                   *
*                                                   *
*     SEQU.NUMBER        NAME        SEQU.NUMBER    *
*    CONFIGURATION                  IN SIMULATION   *
*                                                   *
*          1             VCOA             9         *
*          2             VFOL            10         *
*          3             VNUC            11         *
*          4             V-GT            12         *
*                                                   *
*****************************************************
*                                                   *
*              HYDROELECTRIC   PLANTS               *
*                                                   *
*                                                   *
*     SEQU.NUMBER        NAME        SEQU.NUMBER    *
*    CONFIGURATION                  IN SIMULATION   *
*                                                   *
*          5             HYD1             1         *
*          6             HYD2             2         *
*                                                   *
*****************************************************

ENERGY LIMIT FOR FUEL TYPE  5 IS  13000. MILLION KCAL/DAY
EXTRA CAPACITY TAKEN UP BY PLANT  8
```

Figure 7.2 (page 1) MERSIM Printout for a Fixed Expansion Plan of the Sample Problem. MERSIM Run-1. Cover Page

```
FILE 12 (LOADS)   SUCCESSFULLY OPENED
FILE 13 (CONFIGURATIONS)   SUCCESSFULLY OPENED

INDEX READ =   2        YEAR 1997

LOADING ORDER INPUT DATA:

LOADING ORDER CONTROL DATA :   SPNVAL   PEAKF LBASE NOLO ISPIN-1 ISPIN-2
                                 -1.0     0.0    0     0     2       5

GIVEN LOADING ORDER IS CONSTANT, READ FROM CARDS AND ON A PLANT BASIS
NORDER
      11              7              3             1011            1007            9
       4           1003           1009               10            1004            5
    1010           1005             12                6               8

*********************************** L O A D I N G   O R D E R ***********************************

    VNUC (BASE)     FLIG (BASE)     FCO1 (BASE)     VNUC (PEAK)     FLIG (PEAK)     VCOA (BASE)
    FCO2 (BASE)     FCO1 (PEAK)     VCOA (PEAK)     VFOL (BASE)     FCO2 (PEAK)     FOIL (BASE)
    VFOL (PEAK)     FOIL (PEAK)     V-GT (BASE)     F-GT (BASE)     IMPT (BASE)

*************************************************************************************************


INDEX READ =   4        YEAR 1997
IOPT =    2

INDEX READ =   5        YEAR 1997

INDEX READ =   6        YEAR 1997
NEW ENERGY LIMIT FOR FUEL TYPE  5 IS   10000. MILLION KCAL/DAY
NUMBER OF FOURIER COEFF. USED IN THIS SIMULATION    20
```

```
PERIOD   1  OF YEAR  1997    CONFIGURATION SIMULATED     0   0   0   0   0   0
HYDROCONDITION      1        PROBABILITY   75.0 %
```

** HYDROPLANTS OPERATIONAL SUMMARY **

HYDRO PLANT NAME	NO. OF PROJ.	LORD. POS. PL	U	BASE CAPAC. (MW)	PEAK CAPAC. (MW)	TOTAL CAPAC. (MW)	BASE ENERGY (GWH)	PEAK ENERGY (GWH)	TOTAL ENERGY (GWH)	PEAK MINENG. (GWH)	ENERGY SPILLED (GWH)	ENERGY SHORTAGE (GWH)	O&M (LOCAL) (K$)	CAPAC. FACTOR (%)
1 HYD1	3	5	4	241.8	137.0	378.8	529.6	84.4	614.0	0.3	0.0	0.0	1050.0	56.1
2 HYD2	2	5	4	210.0	1240.0	1450.0	460.0	1340.0	1800.0	44.7	0.0	0.0	2640.0	51.4
TOTALS	5			451.9	1376.9	1828.8	989.6	1424.4	2414.0	44.9	0.0	0.0	3690.0	52.5

** THERMAL PLANTS OPERATIONAL SUMMARY **

THERMAL PLANT NAME	NO. OF UNTS	UNIT BASE (MW)	CAPAC. TOTAL (MW)	PLANT CAPAC. (MW)	BASE ENERGY (GWH)	PEAK ENERGY (GWH)	TOTAL ENERGY (GWH)	FUEL DOMESTIC (K$)	FUEL FOREIGN (K$)	FUEL TOTAL (K$)	O&M (DMSTC) (K$)	MAINT PROB. (%)	FOR (%)	CAPAC. FACTOR (%)
3 FCO1	6	67.0	200.0	1200.0	689.6	1369.0	2058.6	31356.2	0.0	31356.2	13860.0	16.7	6.0	78.3
4 FCO2	3	133.0	400.0	1200.0	692.4	1282.1	1974.4	3593.8	32793.3	36387.0	10620.0	12.9	9.0	75.1
5 FOIL	4	133.0	400.0	1600.0	173.5	81.9	255.4	360.7	7153.6	7514.2	9360.0	12.9	7.0	7.3
6 F-GT	8	100.0	100.0	800.0	7.3	0.0	7.3	12.7	444.1	456.7	1800.0	2.9	1.2	0.4
7 FLIG	1	120.0	294.0	294.0	156.7	227.2	384.0	5794.4	0.0	5794.4	2690.1	12.9	8.0	59.6
8 IMPT	1	1.0	65.4	65.4	0.1	0.0	0.1	0.0	6.9	6.9	608.5	0.0	3.0	0.1
9 VCOA	0	200.0	600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0
10 VFOL	0	200.0	600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0
11 VNUC	0	600.0	900.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0
12 V-GT	0	200.0	200.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0
TOTALS	23			5094.0	1719.6	2960.2	4679.8	41117.8	40397.8	81515.4	38938.6			41.9

```
****************************************** SYSTEM OPERATIONAL SUMMARY ******************************************

THERMAL CAPACITY            (MW)             5094.0              THERMAL GENERATION       (GWH)            4679.8
   PLANT TYPE    0          0.0                                      PLANT TYPE    0        0.0
   PLANT TYPE    1       1200.0                                      PLANT TYPE    1     2058.6
   PLANT TYPE    2       1200.0                                      PLANT TYPE    2     1974.4
   PLANT TYPE    3       1600.0                                      PLANT TYPE    3      255.4
   PLANT TYPE    4        800.0                                      PLANT TYPE    4        7.3
   PLANT TYPE    5        294.0                                      PLANT TYPE    5      384.0   - LIMITED  *0.74
   PLANT TYPE    6     (   65.4 )                                    PLANT TYPE    6        0.1
   PLANT TYPE    7          0.0                                      PLANT TYPE    7        0.0
   PLANT TYPE    8          0.0                                      PLANT TYPE    8        0.0
   PLANT TYPE    9          0.0                                      PLANT TYPE    9        0.0

HYDRO CAPAC. AVAILABLE   (MW)                1828.8              HYDRO GENERATION         (GWH)            2414.0
   HYDRO TYPE HYD1       378.8                                      HYDRO TYPE HYD1       614.0
   HYDRO TYPE HYD2      1450.0                                      HYDRO TYPE HYD2      1800.0

TOTAL CAPACITY                      (MW)     6922.8              TOTAL GENERATION                 (GWH)    7093.8
PEAK LOAD                           (MW)     5400.0              ENERGY DEMAND                    (GWH)    7095.6
MINIMUM LOAD                        (MW)     2160.0              UNSERVED ENERGY                  (GWH)       0.0
MAINTENANCE SPACE                   (MW)     1522.8              ENERGY BALANCE                   (GWH)      -1.8
RESERVE CAPACITY                    (MW)      900.8              LOSS-OF-LOAD PROBABILITY         (%)      0.0521
```

Figure 7.2 (page 2) MERSIM Printout for a Fixed Expansion Plan of the Sample Problem. MERSIM Run-1. Input Data for 1997 and Detailed Operational Summary for Period 1 and Hydrocondition 1 in 1997

```
   2    33 1998     4     6     3 HYD1 HYD2     0.70     0.55  0.7500  0.1500  0.1000  0.0000  0.0000
FCO1     5   67.   200. 2490. 2190.  665.      0.     1   10   6.0   35  200.     3.85    0.00
FCO2     4  133.   400. 2470. 2170.   80.   730.     2   10   9.0   42  400.     2.95    0.00
FOIL     4  133.   400. 2450. 2150.   60.  1190.     3   10   7.0   42  400.     1.95    0.00
F-GT     8  100.   100. 3480. 3480.   50.  1750.     4    0   1.2   14  100.     0.75    0.00
FLIG     1  120.   294. 2560. 2250.  635.      0.     5   10   8.0   42  400.     3.05    0.00
IMPT     1    1.     1. 2560. 2560.    0.  3000.     6    0   3.0    0  100.     3.10    1.55
 5295.     0. 1000. 1600. 1600.   800.   294.    1.     0.     0.     0.     3      2
 HYD1     3 1998     500.0     241.8     137.0     378.8     529.6      84.4     614.0
 HYD1     3 1998     500.0     266.2     142.2     408.4     583.0     112.0     695.0
 HYD1     3 1998     500.0     210.3     109.3     319.7     460.6      24.4     485.0

  .      .   .      .          .          .          .          .         .          .
  .      .   .      .          .          .          .          .         .          .
  .      .   .      .          .          .          .          .         .          .
  .      .   .      .          .          .          .          .         .          .

 HYD2     2 1998    1600.0     210.0    1310.0    1520.0     460.0    1740.0    2200.0
 HYD2     2 1998    1600.0     200.9    1399.1    1600.0     440.0    2260.0    2700.0
 HYD2     2 1998    1600.0     214.6    1165.4    1380.0     470.0    1330.0    1800.0
 1998
 NAME  NCH   JAV     CMNI      CMNB      CMNP      CMNC       CEM       CEP       CEA

INDEX READ =   2     YEAR 1998

LOADING ORDER INPUT DATA:

LOADING ORDER CONTROL DATA :  SPNVAL  PEAKF LBASE NOLO ISPIN-1 ISPIN-2
                               300.0    0.0   1     0     2      5
LOADING ORDER CALCULATED ON A UNIT BASIS

CALCULATED LOADING ORDER BASED ON THE FOLLOWING SEQUENCE, READ FROM CARDS
NORDER
        11              7              3              9              4              10
         5             12              6              8
```

```
PERIOD   1  OF YEAR  1998    CONFIGURATION SIMULATED    0   0   0   0   0   0
HYDROCONDITION      1        PROBABILITY   75.0 %

     HYDRO INDICES                       1 , 2
     % SP.RES OF AVAIL. HYDRO CAP.       2   5
     PLANTS IN BASIC L.O.               10
     L. O. OPTION                        1
     PEAKLOAD FACTOR (PEAKF)             0.0000
     SPINNING RESERVE                  300.0 MW ( CONSTANT )
```

PLANT	UNIT	AVLBTY %	CAP MW	BASE MW	SPIN. RES %	SPIN. RES MW	DERATED TOTAL CAP (MW)	DERATED BASE CAP (MW)	DERATED PEAK CAP (MW)	DERATED SPINNING RES (MW)
1	3	100.0	500.0	0.0	2	7.6	378.8	241.8	137.0	7.6
2	2	100.0	1600.0	0.0	5	72.5	1450.0	210.0	1240.0	72.5
3	5	94.0	160.0	53.6	10	16.0	150.4	50.4	100.0	15.0
4	4	91.0	352.7	117.3	10	35.3	321.0	106.7	214.2	32.1
5	4	93.0	352.7	117.3	10	35.3	328.0	109.1	219.0	32.8
6	8	98.8	97.1	97.1	0	0.0	96.0	96.0	0.0	0.0
7	1	92.0	259.2	105.8	10	25.9	238.5	97.4	141.2	23.9
8	1	97.0	1.0	1.0	0	0.0	1.0	1.0	0.0	0.0

PLANT	UNIT	CUMULATIVE DERATED SPIN. RES.	CUMULATIVE DERATED CAPACITY	SYSTEM REQUIRED SPIN. RES.
2	2	72.5	210.0	300.0
1	3	80.1	451.9	300.0
7	1	103.9	549.2	300.0
3	5	179.1	801.1	300.0
4	4	307.5	1228.0	300.0
5	1	340.3	1337.1	300.0
1007	1	316.5	1478.3	300.0
1003	1	301.4	1578.3	300.0
5	1	334.2	1687.4	300.0
1003	2	304.2	1887.4	300.0
5	1	337.0	1996.5	300.0
1003	2	306.9	2196.5	300.0
5	1	339.7	2305.6	300.0
1004	1	307.6	2519.8	300.0
1004	3	211.3	3162.6	300.0
1005	4	80.1	4038.4	300.0
6	8	80.1	4806.1	300.0
8	1	80.1	4807.0	300.0
2	2	0.0	6047.0	300.0
1	3	0.0	6184.0	300.0

Figure 7.2 (page 3) MERSIM Printout for a Fixed Expansion Plan of the Sample Problem. MERSIM Run-1. Input Data and L.O. Output for Period 1 and Hydrocondition 1 in 1998

```
    3    33 1999     4     6     3 HYD1 HYD2     0.70      0.55  0.7500  0.1500  0.1000  0.0000  0.0000
FCO1     5    67.   200. 2490. 2190.   665.      0.      1    10    6.0   35  200.     3.85    0.00
FCO2     5   133.   400. 2470. 2170.    80.    730.      2    10    9.0   42  400.     2.95    0.00
FOIL     4   133.   400. 2450. 2150.    60.   1190.      3    10    7.0   42  400.     1.95    0.00
F-GT     6   100.   100. 3480. 3480.    50.   1750.      4     0    1.2   14  100.     0.75    0.00
FLIG     1   120.   294. 2560. 2250.   635.      0.      5    10    8.0   42  400.     3.05    0.00
IMPT     1     1.     1. 2560. 2560.     0.   3000.      6     0    3.0    0  100.     3.10    1.55
 5495.     0. 1000. 2000. 1600.   600.   294.      1.      0.      0.      0.      3       2
 HYD1     3 1999    500.0    241.8    137.0    378.8    529.6     84.4    614.0
 HYD1     3 1999    500.0    266.2    142.2    408.4    583.0    112.0    695.0
 HYD1     3 1999    500.0    210.3    109.3    319.7    460.6     24.4    485.0

  .       .   .       .        .        .        .        .        .        .
  .       .   .       .        .        .        .        .        .        .
  .       .   .       .        .        .        .        .        .        .
  .       .   .       .        .        .        .        .        .        .
  .       .   .       .        .        .        .        .        .        .

 HYD2     2 1999   1600.0    210.0   1310.0   1520.0    460.0   1740.0   2200.0
 HYD2     2 1999   1600.0    200.9   1399.1   1600.0    440.0   2260.0   2700.0
 HYD2     2 1999   1600.0    214.6   1165.4   1380.0    470.0   1330.0   1800.0
 1999
 NAME  NCH  JAV     CMWI     CMWB     CMWP     CMWC      CEM      CEP      CEA

INDEX READ =   2      YEAR 1999

LOADING ORDER INPUT DATA:

LOADING ORDER CONTROL DATA :  SPNVAL  PEAKF LBASE NOLO ISPIN-1 ISPIN-2
                                 1.0     0.0    1    1      2       5
LOADING ORDER CALCULATED ON A UNIT BASIS

INDEX READ =   6      YEAR 1999
NEW ENERGY LIMIT FOR FUEL TYPE  5 IS  13000. MILLION KCAL/DAY
```

```
PERIOD   1  OF YEAR  1999    CONFIGURATION SIMULATED     0   0   0   0   1   0
HYDROCONDITION      1        PROBABILITY    75.0 %

      HYDRO INDICES                        1 , 2
      % SP.RES OF AVAIL. HYDRO CAP.        2   5
      PLANTS IN BASIC L.O.                10
      L. O. OPTION                         1
      PEAKLOAD FACTOR (PEAKF)             -0.0200
      SPINNING RESERVE (SPNVAL * MAX.BLOCK CAP. + PEAKF * PKMW) =  1.000 * CAP + (    -121.1 )
```

PLANT	UNIT	AVLBTY %	CAP MW	BASE MW	SPIN. RES %	SPIN. RES MW	DERATED TOTAL CAP (MW)	DERATED BASE CAP (MW)	DERATED PEAK CAP (MW)	DERATED SPINNING RES (MW)
1	4	100.0	680.0	0.0	2	9.4	470.1	333.2	137.0	9.4
2	2	100.0	1600.0	0.0	5	72.5	1450.0	210.0	1240.0	72.5
3	5	94.0	200.0	67.0	10	20.0	188.0	63.0	125.0	18.8
4	5	91.0	338.7	112.6	10	33.9	308.2	102.5	205.7	30.8
5	4	93.0	338.7	112.6	10	33.9	315.0	104.7	210.2	31.5
6	6	98.8	84.7	84.7	0	0.0	83.7	83.7	0.0	0.0
7	1	92.0	248.9	101.6	10	24.9	229.0	93.5	135.5	22.9
8	1	97.0	1.0	1.0	0	0.0	1.0	1.0	0.0	0.0

PLANT	UNIT	CUMULATIVE DERATED SPIN. RES.	CUMULATIVE DERATED CAPACITY	SYSTEM REQUIRED SPIN. RES.
2	2	72.5	210.0	**********
1	4	81.9	543.2	**********
7	1	104.8	636.7	-1.1
3	5	198.8	951.6	-1.1
1007	1	175.9	1087.1	172.9
4	1	206.7	1189.6	172.9
1003	1	187.9	1314.6	172.9
4	1	218.7	1417.1	172.9
1003	2	181.1	1667.1	172.9
4	1	212.0	1769.6	172.9
1003	2	174.4	2019.6	172.9
4	2	236.0	2224.6	172.9
5	3	330.5	2538.8	172.9
1004	1	299.7	2744.5	278.9
5	1	331.2	2849.2	278.9
1004	1	300.3	3054.9	278.9
1004	3	207.9	3672.1	278.9
1005	4	81.9	4513.0	278.9
6	6	81.9	5014.9	278.9
8	1	81.9	5015.9	278.9
2	2	0.0	6255.9	0.0
1	4	0.0	6392.8	0.0

Figure 7.2 (page 4) MERSIM Printout for a Fixed Expansion Plan of the Sample Problem. MERSIM Run-1. Input Data and L.O. Output for Period 1 and Hydrocondition 1 in 1999

```
STATE   COST K$  LOLP % - DAYS/YEAR    1997   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  1     517784.  0.0667     0.244 <- WITH MAINT   0    0    0    0    0    0
                                     ENS  GWH ->        0.2            0.1        1.2

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    1998   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  2     594991.  0.1592     0.581 <- WITH MAINT   0    0    0    0    0    0
                                     ENS  GWH ->        0.8            0.3        3.9

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    1999   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  3     619256.  0.2895     1.057 <- WITH MAINT   0    0    0    0    1    0
                                     ENS  GWH ->        2.6            0.7        9.1

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2000   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  4     662224.  0.4085     1.491 <- WITH MAINT   0    0    0    1    1    0
                                     ENS  GWH ->        4.1            1.6       12.8

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2001   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  5     698819.  0.1352     0.494 <- WITH MAINT   1    0    0    1    1    1
                                     ENS  GWH ->        0.8            0.3        4.7

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2002   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  6     725188.  0.1582     0.577 <- WITH MAINT   1    0    0    2    2    1
                                     ENS  GWH ->        1.1            0.2        5.6

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2003   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  7     718316.  0.1047     0.382 <- WITH MAINT   1    0    0    2    2    2
                                     ENS  GWH ->        0.5            0.1        3.6

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2004   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  8     751508.  0.0825     0.301 <- WITH MAINT   2    0    0    2    3    2
                                     ENS  GWH ->        0.3            0.1        2.7

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2005   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

  9     751551.  0.1840     0.672 <- WITH MAINT   2    0    0    3    3    3
                                     ENS  GWH ->        2.8            0.9        7.8

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2006   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

 10     692189.  0.0717     0.262 <- WITH MAINT   2    0    1    3    3    4
                                     ENS  GWH ->        1.0            0.4        3.9

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2007   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

 11     741985.  0.1406     0.513 <- WITH MAINT   3    0    1    4    3    4
                                     ENS  GWH ->        2.6            0.6        6.9

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2008   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

 12     790622.  0.0267     0.097 <- WITH MAINT   3    1    2    4    3    4
                                     ENS  GWH ->        0.1            0.1        0.5

                                                  -1

STATE   COST K$  LOLP % - DAYS/YEAR    2009   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * *

 13     838174.  0.0730     0.266 <- WITH MAINT   4    1    2    4    3    4
                                     ENS  GWH ->        0.4            0.1        2.4

                                                  -1
```

Figure 7.2 (page 5) MERSIM Printout for a Fixed Expansion Plan of the Sample Problem. MERSIM Run-1. List of Configurations Simulated in the Run.

YEAR 1997

SUMMARY OF RESULTS FOR CONFIGURATION SIMULATED 0 0 0 0 0 0

	CAPACITY (MW)	***** EXPECTED TOTAL COSTS	GENERATION O&M COSTS	COSTS **** F U E L TOTAL	(K$) ***** C O S T S DOMESTIC	**** FOREIGN
THERMAL PLANTS						
TYPE 0	0.0	0.0	0.0	0.0	0.0	0.0
TYPE 1	1200.0	191462.8	55440.0	136022.9	136022.9	0.0
TYPE 2	1200.0	183973.4	42480.0	141493.4	13974.7	127518.8
TYPE 3	1600.0	81815.7	37440.0	44375.7	2130.0	42245.7
TYPE 4	800.0	9219.9	7200.0	2020.0	56.1	1963.8
TYPE 5	294.0	33937.9	10760.4	23177.5	23177.5	0.0
TYPE 6	103.4	2614.0	2586.2	27.9	0.0	27.9
TYPE 7	0.0	0.0	0.0	0.0	0.0	0.0
TYPE 8	0.0	0.0	0.0	0.0	0.0	0.0
TYPE 9	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL THERMAL	5094.0	503023.9	155906.2	347117.7	175361.4	171756.2
HYDRO PLANTS						
TYPE HYD1	500.0		4200.0			
TYPE HYD2	1600.0		10560.0			
TOTAL HYDRO	2100.0		14760.0			
TOTAL SYSTEM	7194.0	517783.9	170666.4	347117.7	175361.4	171756.2

HYDROCONDITION	1	2	3
PROBABILITY (%)	75.0	15.0	10.0
UNSERVED ENERGY (GWH)	0.2	0.1	1.2
LOSS-OF-LOAD PROBABILITY (%)	0.0603	0.0314	0.1683
EXPECTED LOLP (WEIGHED) (%)	0.0667		

ENERGY OUTPUT (GWH) BY PLANT FOR YEAR 1997

PLANT	PERIODS: 1	2	3	4	TOTAL
HYD1	613.2	643.2	689.9	657.8	2604.2
HYD2	1813.0	1915.0	2122.5	2235.0	8085.5
FCO1	2058.6	2314.3	2087.0	2470.3	8930.2
FCO2	1916.2	1723.0	2138.3	1883.5	7660.9
FOIL	300.8	441.8	511.9	243.5	1498.0
F-GT	7.9	8.5	8.3	7.6	32.2
FLIG	384.0	384.0	384.0	384.0	1535.9
IMPT	0.1	0.0	0.1	0.2	0.4
VCOA	0.0	0.0	0.0	0.0	0.0
VFOL	0.0	0.0	0.0	0.0	0.0
VNUC	0.0	0.0	0.0	0.0	0.0
V-GT	0.0	0.0	0.0	0.0	0.0

Figure 7.2 (page 6) MERSIM Printout for a Fixed Expansion Plan of the Sample Problem. MERSIM Run-1. Yearly Summaries of the Results of Simulation for 1997.

The Listing of Configurations illustrated in page 5 of Fig. 7.2 corresponds to the so-called "minimum output" (print output option "0", default value) which will be always obtained regardless of the printout option chosen for the run.

The so-called "intermediate output" (print output option "1") would add to the above listing, yearly summaries of the results for each configuration (page 6 of Fig. 7.2)

Finally, the "maximum output" (print output option "2") would include, in addition, the detailed outputs with the loading order calculations (or the loading order given as fixed input data) and results of the simulations for each configuration, per period and hydrocondition, similar to the ones illustrated in pages 2 to 4 of Figure 7.2.

It can be realized that the amount of information printed by the computer for printout options different to "0" is quite large. Thus, it is recommended to use the intermediate and maximum output options with special care.

Maximum output option may be used for some years in the debugging phase ("initial" mode) of the input cards of the MERSIM runs or when a detailed output of a fixed expansion schedule is required (This will be the case for the REMERSIM run for the optimum solution as explained in Section 7.6). Intermediate output may be asked for when only a few new configurations are included in the last current EXPANALT file. However, during the optimization process, when a series of dynamic expansion plans are examined, the user should always remove the type-1 INDEX=4 and type-4 cards from the MERSIM data deck (i.e. printout option is "0" by default).

A variety of error messages may appear in the MERSIM printout. Some of these errors can be detected by careful perusal of the printout. The maintenance space, for example, should not be negative (installed capacity less than peak demand). The number of units should not be negative (results or erroneous retirements in the fixed system). If capacity factors exceed 100% or if the energy balance (or the unserved energy) is very large, something is clearly wrong but just what it is may not be so obvious.

During program execution, MERSIM verifies the validity of some input data and the compatibility of the information of the files called upon by the program, and in case of an "error" the execution of the program will be stopped and a message is reported in the printout. Section B.5 of Appendix B describes the error and warning messages included in the MERSIM module.

A MERSIM run may be terminated manually by the computer operator if the total elapsed time exceeds the estimated time shown on the job card. Also it may be terminated automatically by the machine itself when the CPU time reaches the limit shown on the first MERSIM control card or, eventually, by a power supply failure (or a system failure).

Any abnormal termination will leave the SIMULNEW file improperly closed and it will be necessary to recover the information, using the RECSIM code before proceeding to further runs (see Chapter 10 for description of RECSIM). The alternative is to lose the information already in the SIMULNEW file by repeating the run (with time estimated and/or time limit changed appropriately) without using the RENAME control cards. This alternative is acceptable if the number of configurations on the incomplete SIMULNEW file is not too many more than on the file SIMULOLD (e.g. in the case of a MERSIM run in the "initial" mode for a pre-determined expansion plan).

7.5 Input Data for Dynamic Expansion Plans

Before executing the series of MERSIM runs considering dynamic (or variable) expansion plans, it is important to understand how files 15 and 16 are used in the program. With each MERSIM run, the computer reads the information on file 16 (input) and writes it on file 15 (output) along with the new information being generated. Normally, SIMULNEW is assigned to file 15 and the SIMULOLD is assigned to file 16. Thus, each MERSIM run reads the SIMULOLD file and creates a new SIMULNEW files. In order to use this information in each subsequent run, the SIMULNEW field must be renamed SIMULOLD and the SIMULOLD renamed SIMULNEW. The renaming can be done by interchanging the names assigned to files 15 and 16 or by the use of the RENAME subprogram as discussed in Section 7.1. Changing the names of files 15 and 16 has the advantage that if the run is terminated prematurely by a computer malfunction, the operator can re-run it. With the RENAME control cards included in the same job, however, a re-run would destroy the file containing the simulations to be saved. Thus one has to instruct the operator not to re-run it, which in some cases could imply loss of valuable time. Alternatively, the RENAME run can be done alone and the user can proceed with the CONGEN and MERSIM runs only after the RENAME run is successfully executed.

After executing the corresponding CONGEN run as discussed in Section 6.5 and having made the "initial" MERSIM run as discussed in Sections 7.3 and 7.4, a series of MERSIM runs of CASE93 was carried out for different variable expansion plans. These were executed using the same input data shown in Figure 7.3. The MERSIM printouts for two of these runs are shown in Figures 7.4 and 7.5.

Comparing the data cards of Figure 7.3 with the ones used for the fixed expansion plan run (MERSIM Run-1 using the data in Fig. 7.1), it can be seen that they are essentially the same except for a few minor changes introduced for dynamic expansion plans which do not affect the numerical calculations carried out by the program. For example, the first line on Fig. 7.3 specifies a "0" for the file printing option (IOFILE). Also, and in order to reduce the printout which would be associated with a variable expansion plan run of MERSIM, the printout option has been set to the default value ("0" or minimum output) by simply omitting the type-1 INDEX=4 and type-4 data cards which were used for the fixed expansion MERSIM run.

7.6 Printouts for Dynamic Expansion Plans

The MERSIM printout for variable expansion runs is essentially the same as for the fixed expansion plan described in Section 7.4 with the difference that both, the file printing option and the print output option have been set to "0" for variable expansion runs. Thus, the printout for these runs includes only: the cover page identifying the run (equal to page 1 of Fig. 7.2), followed by input data read by cards (similar to page 2 of Fig. 7.2) and finally, the listing of the configurations which were simulated in the run (similar to page 5 of Fig. 7.2), i.e. those configurations simulated in previous runs and contained in the current SIMULOLD file are not repeated in the printout.

Figures 7.4 and 7.5 illustrate a sample of the MERSIM printout for two different dynamic expansion plans. Fig. 7.4 corresponds to the first of such runs (called MERSIM Run-2), using the EXPANALT file created by CONGEN Run-2 presented in Section 6.5.1 and Fig. 7.5 to the last run (MERSIM Run-3) of the series made while searching for the optimum solution of the sample problem and using the EXPANALT file created by CONGEN Run-3 (Section 6.5.2). Each figure shows only the listing of the configurations simulated in the run.

```
CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL        0
  2
 -1.0            0    2    5
  11    7    3 1011 1007    9    4 1003 1009   10 1004    5
 1010 1005   12    6    8
  5
  20
  6
  5      10.
  1           (END OF 1997)
  2
300.0         1    0    2    5
  11    7    3    9    4   10    5   12    6    8
  1           (END OF 1998)
  2
  1.0-0.02    1    1    2    5
  6
  5      13.
  1           (END OF 1999)
  6
  5      26.
  1           (END OF 2000)
  6
  5      39.
  1           (END OF 2001)
  1           (END OF 2002)
  1           (END OF 2003)
  6
  5      65.
  1           (END OF 2004)
  1           (END OF 2005)
  1           (END OF 2006)
  1           (END OF 2007)
  1           (END OF 2008)
  1           (END OF 2009)
  1           (END OF 2010)
  1           (END OF 2011)
  1           (END OF 2012)
  1           (END OF 2013)
  1           (END OF 2014)
  1           (END OF 2015)
  1           (END OF 2016)
```

Figure 7.3 MERSIM Input Data for Variable Expansion Runs of the Sample Problem (CASE93).

For the first variable expansion MERSIM run, only the configurations simulated in this run for the first four years of study are shown in Fig. 7.4. Each configuration is reported in a similar way as discussed for the fixed expansion MERSIM run. The number of the configuration (STATE) corresponds to the same number on the SIMULNEW file, taking into account the list of configurations contained in the current EXPANALT and SIMULOLD files. Thus, the first configuration in Fig. 7.4 is shown as number 2 (number 1 having been given to the first configuration on SIMULNEW for this year, that is the configuration for year 1997 in MERSIM Run-1 which was saved by means of the RENAME subprogram). Similarly, state 3 does not appear in the listing for year 1998 since this corresponds to the configuration already simulated in MERSIM Run-1. After a series of variable expansion MERSIM runs and provided the "merge" mode has been used, the SIMULNEW file keeps increasing as new configurations are being simulated and added to the listing for each year. The advantage of printing only the configurations simulated in each run stems from the fact that relatively short printout is produced for each year, permitting quick revision of the results. This is illustrated by Figure 7.5 which shows the listing of configurations simulated in MERSIM Run-3 (in fact, no new configuration was added to the SIMULNEW file in this run).

```
STATE    COST K$   LOLP % - DAYS/YEAR     1997   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * *

  2     519496.   0.0244      0.089 <- WITH MAINT   0    0   0    1    0   0
                                      EMS  GWH ->        0.0         0.0        0.2

                                               -1

STATE    COST K$   LOLP % - DAYS/YEAR     1998   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * *

  4     596724.   0.0656      0.239 <- WITH MAINT   0    0   0    1    0   0
                                      EMS  GWH ->        0.2         0.0        0.9
  5     598409.   0.0246      0.090 <- WITH MAINT   0    0   0    2    0   0
                                      EMS  GWH ->        0.0         0.0        0.1

                                               -1

STATE    COST K$   LOLP % - DAYS/YEAR     1999   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * *

  6     656960.   0.0374      0.136 <- WITH MAINT   0    1   0    1    0   0
                                      EMS  GWH ->        0.1         0.0        0.4
  7     639215.   0.0936      0.342 <- WITH MAINT   0    0   0    2    0   0
                                      EMS  GWH ->        0.3         0.1        1.9
  8     658766.   0.0156      0.057 <- WITH MAINT   0    1   0    2    0   0
                                      EMS  GWH ->        0.1         0.0        0.1
  9     640926.   0.0383      0.140 <- WITH MAINT   0    0   0    3    0   0
                                      EMS  GWH ->        0.0         0.0        0.3
 10     660664.   0.0057      0.021 <- WITH MAINT   0    1   0    3    0   0
                                      EMS  GWH ->        0.0         0.0        0.1
 12     640295.   0.0229      0.083 <- WITH MAINT   0    1   0    1    1   0
                                      EMS  GWH ->        0.0         0.0        0.2
 13     622857.   0.0564      0.206 <- WITH MAINT   0    0   0    2    1   0
                                      EMS  GWH ->        0.1         0.0        1.1
 14     641941.   0.0089      0.033 <- WITH MAINT   0    1   0    2    1   0
                                      EMS  GWH ->        0.1         0.1        0.1
 15     624578.   0.0223      0.082 <- WITH MAINT   0    0   0    3    1   0
                                      EMS  GWH ->        0.0         0.0        0.1
 16     643551.   0.0030      0.011 <- WITH MAINT   0    1   0    3    1   0
                                      EMS  GWH ->        0.0         0.0        0.0

                                               -1

STATE    COST K$   LOLP % - DAYS/YEAR     2000   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

 17     697987.   0.1265      0.462 <- WITH MAINT   0    1   0    1    0   0
                                      EMS  GWH ->        0.6         0.2        3.0
 18     734913.   0.0270      0.099 <- WITH MAINT   1    1   0    1    0   0
                                      EMS  GWH ->        0.1         0.1        0.3
 19     713566.   0.0245      0.090 <- WITH MAINT   0    2   0    1    0   0
                                      EMS  GWH ->        0.1         0.1        0.3
 20     761828.   0.0044      0.016 <- WITH MAINT   1    2   0    1    0   0
                                      EMS  GWH ->        0.0         0.0        0.1
 21     707874.   0.0649      0.237 <- WITH MAINT   1    0   0    2    0   0
                                      EMS  GWH ->        0.2         0.1        1.1
 22     699888.   0.0592      0.216 <- WITH MAINT   0    1   0    2    0   0
                                      EMS  GWH ->        0.1         0.0        0.9
 23     736674.   0.0115      0.042 <- WITH MAINT   1    1   0    2    0   0
                                      EMS  GWH ->        0.1         0.1        0.1
 24     715132.   0.0103      0.038 <- WITH MAINT   0    2   0    2    0   0
                                      EMS  GWH ->        0.1         0.1        0.1
 25     763155.   0.0017      0.006 <- WITH MAINT   1    2   0    2    0   0
                                      EMS  GWH ->        0.0         0.0        0.0
 26     709301.   0.0295      0.108 <- WITH MAINT   1    0   0    3    0   0
                                      EMS  GWH ->        0.1         0.0        0.2
 27     701688.   0.0266      0.097 <- WITH MAINT   0    1   0    3    0   0
                                      EMS  GWH ->        0.1         0.0        0.2
 28     738076.   0.0046      0.017 <- WITH MAINT   1    1   0    3    0   0
                                      EMS  GWH ->        0.0         0.0        0.1
 29     716423.   0.0040      0.015 <- WITH MAINT   0    2   0    3    0   0
                                      EMS  GWH ->        0.0         0.0        0.1
 30     764839.   0.0005      0.002 <- WITH MAINT   1    2   0    3    0   0
                                      EMS  GWH ->        0.0         0.0        0.0
 32     680219.   0.0832      0.304 <- WITH MAINT   0    1   0    1    1   0
                                      EMS  GWH ->        0.3         0.1        2.0
 33     719064.   0.0167      0.061 <- WITH MAINT   1    1   0    1    1   0
                                      EMS  GWH ->        0.1         0.1        0.2
 34     694704.   0.0150      0.055 <- WITH MAINT   0    2   0    1    1   0
                                      EMS  GWH ->        0.1         0.1        0.2
 35     745411.   0.0025      0.009 <- WITH MAINT   1    2   0    1    1   0
                                      EMS  GWH ->        0.0         0.0        0.1
 36     691923.   0.0415      0.151 <- WITH MAINT   1    0   0    2    1   0
                                      EMS  GWH ->        0.0         0.0        0.5
 37     681754.   0.0376      0.137 <- WITH MAINT   0    1   0    2    1   0
                                      EMS  GWH ->        0.0         0.0        0.4
 38     720517.   0.0068      0.025 <- WITH MAINT   1    1   0    2    1   0
                                      EMS  GWH ->        0.1         0.0        0.1
 39     696731.   0.0061      0.022 <- WITH MAINT   0    2   0    2    1   0
                                      EMS  GWH ->        0.1         0.0        0.1
 40     746083.   0.0009      0.003 <- WITH MAINT   1    2   0    2    1   0
                                      EMS  GWH ->        0.0         0.0        0.0
 41     665848.   0.0905      0.330 <- WITH MAINT   0    0   0    3    1   0
                                      EMS  GWH ->        0.3         0.1        2.2
 42     693616.   0.0179      0.065 <- WITH MAINT   1    0   0    3    1   0
                                      EMS  GWH ->        0.1         0.0        0.2
 43     683449.   0.0160      0.058 <- WITH MAINT   0    1   0    3    1   0
                                      EMS  GWH ->        0.0         0.0        0.1
 44     722248.   0.0026      0.010 <- WITH MAINT   1    1   0    3    1   0
                                      EMS  GWH ->        0.0         0.0        0.1
 45     698559.   0.0023      0.008 <- WITH MAINT   0    2   0    3    1   0
                                      EMS  GWH ->        0.0         0.0        0.0

                                               -1
```

Figure 7.4 MERSIM Printout (partial) for the First Variable Expansion Run of the Sample Problem (MERSIM Run-2). Listing of the Configurations Simulated in the Run

```
STATE   COST K$  LOLP % - DAYS/YEAR   1997   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   1998   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   1999   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2000   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2001   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2002   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2003   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2004   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2005   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2006   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2007   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2008   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2009   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2010   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2011   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2012   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2013   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2014   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2015   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
STATE   COST K$  LOLP % - DAYS/YEAR   2016   CONFIGURATIONS * * * * * * * * * * * * * * * * * *
                                               -1
                                               -1
```

Figure 7.5 MERSIM Printout (partial) for the Last Variable Expansion Run of the Sample Problem (MERSIM Run-3). Listing of the Configurations Simulated in the Run

---

7.7 Resimulation of the Optimum Solution (REMERSIM)

In carrying out MERSIM with a variable expansion schedule involving hundreds of configurations, the minimum print output option (IOPT = 0) was specified in order to avoid printing a large amount of unnecessary information. Some of this information, however, is useful for the analysis of the final results. Moreover, at the end of the dynamic optimization process, if Module 7 (REPROBAT) is to be run to obtain a full report of the optimal solution, it is necessary to execute first a resimulation of this optimal solution in order to create the appropriate SIMULRSM file needed by REPROBAT. Thus, there is provision in WASP-III Plus to reproduce this information for the optimum schedule of additions, by executing a run of REMERSIM (it stands for <u>RE</u>simulate <u>MERSIM</u>). The REMERSIM run uses the same program as MERSIM except for the input and output files used.

Page 2 of Fig. 2.3 shows the control cards required to execute a REMERSIM run for our sample problem, CASE93. The first two cards identify the program and its location in the computer system. Card 3 specifies the location of the input data. Cards 4 to 6 control the desired printout capabilities from the three separate printing files used by the program (note that cards 5 and 6 spread over two lines). Cards 7 to 9 identify the files containing information from Modules 1 to 3 respectively. Card 10 identifies the EXPANREP file which was created by the latest DYNPRO run. Cards 11 and 12 identify the SIMULRSM and SIMULINL files which are used in the resimulation in place of SIMULNEW and SIMULOLD, respectively. Cards 13 and 14 identify the SIMULREP and SIMGRAPH files, respectively. The last control card is the usual end-of-job card.

The data cards for execution of the resimulation run are the same as the ones used in the MERSIM runs for variable expansion plans, except that maximum output (IOPT =2) should be specified for all years of the study in order to get a detailed listing with the results of the simulations for each configuration per period and hydrocondition described in the study. Alternatively, the intermediate output (IOPT=1) or the minimum output (IOPT=0) may be specified by the user for some of the years in the REMERSIM run of the case study, particularly if the results of the simulations for the configurations included in the optimal solution have already been analyzed in previous runs. Figure 7.6 lists the input data used for the REMERSIM run of the sample problem. (Important note: IOPT must be greater than, or equal to 1 if the REMERSIM run is to be followed by a REPROBAT run requesting full report of the current DYNPRO solution or the optimal solution).

Comparing the data in Fig. 7.6 with the one used for variable expansion runs of MERSIM (see Fig. 7.3), it can be seen that they are essentially the same with the basic difference that more type-4 cards are used to specify different types of output in several years. In addition, type-7 cards are used in the resimulation run to provide information on specific fuel consumption and fuel stock by unit of each of the thermal plants. This information will be used by REMERSIM to calculate total fuel consumption and stock by plant which will be passed to REPROBAT.

In the sample problem, the type-7 cards (after the type-1 INDEX=7 card) are as follows. The first two (type-7a card) specify the domestic fuel consumption by unit (ton/GWh) for the FIXSYS+VARSYS thermal plants; i.e. 420. ton/GWh for plant 3 (FCO1) and zero for all other plants. Note that two cards are required since 10 thermal plants are included in the combined list of FIXSYS plus VARSYS thermal plants. The next two cards provide similar information but for the foreign fuel consumption (type-7b card). In this case a zero is specified for the FCO1 plant, 378 ton/GWh for FCO2, 233 ton/GWh for plant FOIL, and so on. These are followed by the cards specifying the domestic fuel stock by unit (next two cards of type-7c) and foreign fuel stock by unit (last two cards of type-7d). Both values are specified in ton. It should be noted that these cards must follow the sequence above described and include as many entries as the number of FIXSYS+VARSYS thermal plants (see Table 7.1).

For the REMERSIM run, the EXPANREP file contains the configurations (one per year) included in the optimal solution. Each configuration is taken by MERSIM for resimulating the system operation so as to report the same kind of information already described for a fixed expansion MERSIM run (see Section 7.4).

Figure 7.7 corresponds to a sample of the printout of the REMERSIM run for resimulation of the optimal solution for the sample problem, which is described in Section 8.5. The printout is similar as for other MERSIM runs (see page 5 of Fig. 7.2, and Figures 7.4 and 7.5). Normally, REMERSIM is run using IOFILE = 0 (no printing of FIXSYS or

VARSYS files). Thus, the printout begins with the cover page and the list of input data for the first year of study[12]. Since maximum output is normally requested for resimulation runs, a detailed output is reported by the program with the operational results of the simulation for each period, each hydro condition and each year of the study (similar to pages 2-4 of Fig. 7.2)[12]. The input data for each year is also printed by the program.

Then the program reports the summary output of the run as illustrated in Page 1 of Fig. 7.7 (similar to page 5 of Fig. 7.2). In this case, the listing of the yearly configurations bears a title "THIS IS A RESIMULATION OF THE FINAL SOLUTION FOUND BY THE DYNAMIC PROGRAM".

Again, since maximum (or intermediate) output is normally requested for resimulation runs, the printout includes the operational summaries for each year of study (similar to page 6 of Fig. 7.2)[12] as described for the output of the fixed expansion run of MERSIM. However, the REMERSIM printout includes additional summary tables for each year when IOPT>0. These are printed for each configuration and each hydrocondition (adding the values for the same hydrocondition for all periods). These are followed by a summary of the annual expected values (weighting the values for each hydrocondition by the hydrocondition probabilities). Page 2 of Fig. 7.7 illustrates this part of the output for hydrocondition 1 and the annual expected values for year 1997. Note that these tables also report the fuel consumption by each thermal plant. These summary tables are very convenient to review the results of the simulation of the DYNPRO solution under examination.

Another output of the REMERSIM run are the results written on the SIMGRAPH file that will be used by a subsequent run of REPROBAT. This file is discussed in Chapter 9.

The REMERSIM printout for the optimal solution of the case study should be revised very carefully by the user in order to make sure that the results are not obviously wrong, particularly concerning plant capacity factors, number of units in each plant, the amount of energy not served and the energy balance as it is explained at the end of Section 7.4. In addition, the REMERSIM printout should be checked by the user to determine whether the results of the simulations are reasonable. This revision should concentrate in such aspects as:

- the loading order calculated by the program (if applicable);
- the capacity factors resulting from the simulation for thermal plants which are supposed to be operating in a certain region of the load curve (base, intermediate or peak load);
- the amount of hydro energy shortage and/or energy spillage (if applicable); etc.

As a result of this analysis, it may be necessary to proceed to new optimization runs involving iterations of CONGEN-MERSIM-DYNPRO-RENAME in order to correct some of the results that are judged unacceptable. In some extreme cases, it may be necessary to initiate a new WASP study if the data to be corrected affect one of the three first modules of WASP or the data specified for the simulation runs. In view of the above, it is strongly recommended to run REMERSIM at certain stages of the optimization procedure in order to guarantee that the intermediate solution reported by DYNPRO satisfies all conditions above described.

---

[12] This part of the printout is not shown in Fig. 7.7

```
  CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL      0
  2
-1.0           0    2    5
  11    7    3 1011 1007    9    4 1003 1009   10 1004    5
1010 1005   12    6    8
  4
  1
  5
 20
  6
  5       10.
  7
  416.      0.      0.      0.      0.      0.      0.      0.      0.
    0.
    0.    378.    233.    335.    792.      0.    377.    213.  0.0222
  335.
 89954.  16342.   3360.    604.      0.      0.  24408.   4608.      0.
 1204.
    0. 147080.  63840.  11473.      0.      0. 219672.  87552.      0.
 22880.
  1          (END OF 1997)
  2
300.0        1    0    2    5
  11    7    3    9    4   10    5   12    6    8
  1          (END OF 1998)
  2
 1.0-0.02    1    1    2    5
  6
  5       13.
  1          (END OF 1999)
  4
  2
  6
  5       26.
  1          (END OF 2000)
  4
  1
  6
  5       39.
  1          (END OF 2001)
  1          (END OF 2002)
  1          (END OF 2003)
  6
  5       65.
  1          (END OF 2004)
  1          (END OF 2005)
  4
  2
  1          (END OF 2006)
  4
  1
  1          (END OF 2007)
  1          (END OF 2008)
  1          (END OF 2009)
  1          (END OF 2010)
  1          (END OF 2011)
  4
  2
  1          (END OF 2012)
  4
  1
  1          (END OF 2013)
  1          (END OF 2014)
  1          (END OF 2015)
  4
  2
  1          (END OF 2016)
```

Figure 7.6 Input Data of the REMERSIM Run for the Sample Problem (CASE93)

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
THIS IS A SIMULATION OF THE FINAL SOLUTION FOUND BY THE DYNAMIC PROGRAM
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

    STATE   COST K$  LOLP % - DAYS/YEAR    1997   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *
      1     517784.  0.0667     0.244 <- WITH MAINT   0   0   0   0   0   0
                                              ENS  GWH ->        0.2         0.1         1.2

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    1998   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      2     596724.  0.0656     0.239 <- WITH MAINT   0   0   0   1   0   0
                                              ENS  GWH ->        0.2         0.0         0.9

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    1999   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      3     639215.  0.0936     0.342 <- WITH MAINT   0   0   0   2   0   0
                                              ENS  GWH ->        0.3         0.1         1.9

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2000   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      4     665848.  0.0905     0.330 <- WITH MAINT   0   0   0   3   1   0
                                              ENS  GWH ->        0.3         0.1         2.2

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2001   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      5     675394.  0.0636     0.232 <- WITH MAINT   0   0   0   4   1   1
                                              ENS  GWH ->        0.2         0.1         1.6

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2002   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      6     735601.  0.0640     0.234 <- WITH MAINT   0   1   0   4   1   1
                                              ENS  GWH ->        0.2         0.0         1.5

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2003   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      7     720313.  0.0407     0.149 <- WITH MAINT   0   1   0   4   1   2
                                              ENS  GWH ->        0.2         0.1         0.7

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2004   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      8     738674.  0.0418     0.153 <- WITH MAINT   0   1   0   6   2   2
                                              ENS  GWH ->        0.2         0.1         0.9

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2005   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

      9     753871.  0.0230     0.084 <- WITH MAINT   0   1   0   9   2   3
                                              ENS  GWH ->        0.1         0.0         0.4

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2006   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

     10     814183.  0.0344     0.126 <- WITH MAINT   1   1   0  10   3   3
                                              ENS  GWH ->        0.1         0.0         0.7

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2007   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

     11     804814.  0.0232     0.085 <- WITH MAINT   2   1   0  10   3   4
                                              ENS  GWH ->        0.0         0.2         1.3

                                                            -1

    STATE   COST K$  LOLP % - DAYS/YEAR    2008   CONFIGURATIONS * * * * * * * * * * * * * * * * * * * *

     12     881130.  0.0334     0.122 <- WITH MAINT   3   1   0  10   3   4
                                              ENS  GWH ->        0.1         0.0         0.9

                                                            -1
```

Figure 7.7 (Page 1) REMERSIM Printout for the Optimum Solution of CASE93. Summary Output of the List of Configurations Simulated in the Run.

*** SUMMARY OF YEAR 1997 ***

CONFIGURATION SIMULATED 0 0 0 0 0 0

*** HYDROCONDITION 1 ***

	PLANT NAME	PLANT TYPE	UNIT CAPACITY (MW)	NO.OF UNITS	CAPACITY FACTOR (%)	ENERGY (GWH)	FUEL CONSUMPTION DOMESTIC (TON)	FOREIGN (TON)	GENERATION COSTS (K$)
1	HYD1	10	500.0	1	58.79	2575.00	0.00	0.00	4199.996
2	HYD2	11	1600.0	1	57.08	7999.99	0.00	0.00	10559.988
3	FCO1	1	200.0	6	84.95	8930.20	3714963.00	0.00	191463.125
4	FCO2	2	400.0	3	74.83	7865.97	0.00	2973335.00	187577.187
5	FOIL	3	400.0	4	10.06	1409.74	0.00	328468.62	79249.812
6	F-GT	4	100.0	8	0.43	30.41	0.00	10187.54	9104.914
7	FLIG	5	294.0	1	59.63	1535.85	0.00	1216396.00	33937.914
8	IMPT	6	1.0	1	0.05	0.36	0.00	0.00	2613.526
9	VCOA	2	600.0	0	0.00	0.00	0.00	0.00	0.000
10	VFOL	3	600.0	0	0.00	0.00	0.00	0.00	0.000
11	VNUC	0	900.0	0	0.00	0.00	0.00	0.00	0.000
12	V-GT	4	200.0	0	0.00	0.00	0.00	0.00	0.000
TOTALS						30347.46			518705.125

************************************ THERMAL PLANTS AGGREGATED BY PLANT TYPE ************************************

PLANT TYPE	TOTAL CAPACITY (MW)	CAPACITY FACTOR (%)	TOTAL ENERGY (GWH)	TOTAL FUEL CONSUMPTION DOMESTIC (TON)	FOREIGN (TON)	GENERATION COSTS (K$)
0	0	0.00	0.00	0.00	0.00	0.00
1	1200	84.95	8930.20	3714963.00	0.00	191463.12
2	1200	74.83	7865.97	0.00	2973335.00	187577.19
3	1600	10.06	1409.74	0.00	328468.62	79249.81
4	800	0.43	30.41	0.00	10187.54	9104.91
5	294	59.63	1535.85	0.00	1216396.00	33937.91
6	1	0.05	0.36	0.00	0.00	2613.53
7	0	0.00	0.00	0.00	0.00	0.00
8	0	0.00	0.00	0.00	0.00	0.00
9	0	0.00	0.00	0.00	0.00	0.00

*** SUMMARY OF YEAR 1997 ***

CONFIGURATION SIMULATED 0 0 0 0 0 0

HYDROCONDITION: 1 2 3
PROBABILITY: 0.750 0.150 0.100

************************ SIMULATION RESULTS WEIGHTED BY PROBABILITY OF EACH HYDROCONDITION ************************

	PLANT NAME	PLANT TYPE	UNIT CAPACITY (MW)	NO.OF UNITS	CAPACITY FACTOR (%)	ENERGY (GWH)	FUEL CONSUMPTION DOMESTIC (TON)	FOREIGN (TON)	GENERATION COSTS (K$)
1	HYD1	10	500.0	1	59.46	2604.25	0.00	0.00	4199.992
2	HYD2	11	1600.0	1	57.69	8085.48	0.00	0.00	10559.980
3	FCO1	1	200.0	6	84.95	8930.20	3714962.00	0.00	191463.062
4	FCO2	2	400.0	3	72.88	7660.94	0.00	2895835.00	183973.437
5	FOIL	3	400.0	4	10.69	1498.03	0.00	349040.25	81815.625
6	F-GT	4	100.0	8	0.46	32.25	0.00	10802.78	9219.949
7	FLIG	5	294.0	1	59.63	1535.85	0.00	1216395.00	33937.902
8	IMPT	6	1.0	1	0.05	0.36	0.00	0.00	2614.035
9	VCOA	2	600.0	0	0.00	0.00	0.00	0.00	0.000
10	VFOL	3	600.0	0	0.00	0.00	0.00	0.00	0.000
11	VNUC	0	900.0	0	0.00	0.00	0.00	0.00	0.000
12	V-GT	4	200.0	0	0.00	0.00	0.00	0.00	0.000
TOTALS						30347.32			517782.812

************************************ THERMAL PLANTS AGGREGATED BY PLANT TYPE ************************************

PLANT TYPE	TOTAL CAPACITY (MW)	CAPACITY FACTOR (%)	TOTAL ENERGY (GWH)	TOTAL FUEL CONSUMPTION DOMESTIC (TON)	FOREIGN (TON)	GENERATION COSTS (K$)
0	0	0.00	0.00	0.00	0.00	0.00
1	1199	84.95	8930.20	3714962.00	0.00	191463.06
2	1199	72.88	7660.94	0.00	2895835.00	183973.44
3	1599	10.69	1498.03	0.00	349040.25	81815.62
4	799	0.46	32.25	0.00	10802.78	9219.95
5	293	59.63	1535.85	0.00	1216395.00	33937.90
6	0	0.05	0.36	0.00	0.00	2614.03
7	0	0.00	0.00	0.00	0.00	0.00
8	0	0.00	0.00	0.00	0.00	0.00
9	0	0.00	0.00	0.00	0.00	0.00

Figure 7.7 (Page 2) REMERSIM Printout for the Optimum Solution of CASE93. Operational Summary for Hydrocondition 1 and Yearly Averages for Year 1997.

CHAPTER 8

EXECUTION OF DYNPRO

Before explaining how to use the DYNPRO module of WASP, it is convenient to describe the capabilities of this program. DYNPRO reads the information written on the files created by Modules 3-5; the LOADDUCU and FIXPLANT files are not used by DYNPRO. This, together with the program input data given on cards, is used by the program to carry out the economic evaluation of all alternative expansion schedules or plans permitted by the current EXPANALT file and to select among them, the one having the least total costs.

As discussed in Section 1.1, the total costs of an expansion plan are expressed by the objective function which in turn is defined as the sum of capital investment costs (corrected by salvage value) of the VARSYS plants added by the plan plus the total operating costs (including energy not served costs) of the system for each year; all costs discounted to a reference year. For each year of the study, DYNPRO evaluates the objective function for each configuration included in the EXPANALT file. In doing so, the program also chooses the optimum path to reach this configuration using a dynamic programming algorithm. Thus, at each stage (year) the program calculates the optimal way of reaching a given configuration, the corresponding value of the objective function and the configuration in the preceding year connected to the optimum path. Obviously, the configuration in the last year which has the least value of objective function must be included in the optimum (best) expansion plan.

The configurations for precedent years contained in this optimum plan are retrieved by the program simply tracing back through the stage-by-stage optimal decisions. During the traceback process, DYNPRO also examines the restrictions that were defined in CONGEN and identifies on the printout the states on the optimal trajectory for which these restrictions acted as a constraint to the solution. Interpreting the DYNPRO printout, the user can proceed to a new dynamic iteration involving sequential runs of CONGEN-MERSIM-DYNPRO-RENAME; with the restrictions in the CONGEN run modified accordingly. The process is repeated until the best solution reported by DYNPRO, not "constrained" by the CONGEN restrictions, is obtained. This will be the optimum solution for the case under study.

The DYNPRO module can also be used to evaluate any specific expansion schedule, such as the predetermined expansion plan of CASE93 described in Section 6.3.1 for which the user explicitly defines the number of units or projects of each expansion candidate that are to be added to the system in each year of the study. In this case, DYNPRO simply performs as a cash flow program. This procedure can be used to evaluate a number of expansion patterns of system expansion to select a favorable area to be used as starting point in full-scale dynamic optimization runs. Also the fixed expansion mode for execution of DYNPRO is recommended during the debugging phase of the input data cards and control cards of the WASP modules. Sections 8.3 and 8.4 describe how to run DYNPRO in the "initial" mode and Sections 8.5 and 8.6 for dynamic expansion plans.

8.1 Control Cards

The 12 control cards for execution of DYNPRO are listed in Figure 2.3. The job control cards 1 and 2 identify module 6 (DYNPRO) and its location in the computer system, while card 3 specifies the location of the input data to be used in the run. Cards 4 and 5 correspond to output files number 6 and 8, respectively; file 6 prints the input data, the dynamic program optimization pattern and the solutions; file 8 prints the list of configurations (or states) corresponding to the CONGEN file used in the current optimization. Card 7, file 9, shown as a DUMMY in this case, is activated only when there is the need of executing a debugging run. Card 8 corresponds to file OSDYNDAT (file 7), needed to store the information generated in DYNPRO and which is to be used by module REPROBAT. Cards 9 to 11 call for files 11, 13 and 15, which keep the information of VARPLANT, EXPANALT (the latest CONGEN data) and SIMULNEW (the latest most complete simulation file). Card 11 identifies file 18 (EXPANREP) where the configurations for the optimum solution will be stored (one per year) for later use in the resimulation of the optimum solution (see Section 7.6).

8.2 Data Cards

Table 8.1 lists 22 types of data cards used by the WASP-III Plus version of DYNPRO (type-5 and -10 cards are not used). As for all other WASP modules, the first card is the usual type-X card specifying the title of the study and the printing options for the VARSYS file (IOFILE) and the listing of states considered in the run (IOPT).

Card type-A gives the information required for economic calculations of present worth discounting values of costs and cost escalation. Card type-B applies to the discounting calculations of capital costs and specifies the option selected (IOPW) and the number of sets of discount rates (NUM1) to be used during the study period (NUM1 also defines how many type-C1 or type-C2 cards must be used).

If the value of IOPW on card type-B is zero (or left blank), type-C1 cards will be used to give ***single discount rates*** (one for domestic and one for foreign) on capital costs for all expansion candidates and the last year for which they are to be used. On the other hand, if IOPW on card type-B is > 0, the card type-B must be followed by groups of type-C2 and type-C3 cards in order to give ***individual discount rates*** (one for domestic and one for foreign) on capital costs for each expansion candidate.

Cards type-1 INDEX indicate that the next card (or cards) are of a type equal to the INDEX number. Cards type-1 INDEX = 2 and type-2 are used to specify the economic data on capital costs, plant life and construction time of each VARSYS expansion candidate. For hydro candidates the corresponding card type-2 contains only information on plant life (leaving blank the rest of the card). This tells the computer that capital cost information for each VARSYS hydro project of this type follows on type-2a cards.

Cards type-1 INDEX = 1 are the usual end of year card and the remaining card types are used to give instructions for the economic calculations to be carried out by DYNPRO or to control the printout of the run.

Similarly to the other WASP modules, it is important to use the proper sequence of data cards for the program to run. For the convenience of the user most of the variables required by DYNPRO are set automatically to default values by the program before reading any input data; thus permitting its execution with a relatively small number of input cards. It should be noted that some of the card types are exclusive one to another (e.g cards type-8 excludes the use of type-14 or type-15 cards, and viz.), otherwise the program will simply consider the last of the two cards read in. Finally, there is no special order in which type-1 through type-17 cards must appear in the input data (except that they should be preceded by a type-1 card of the same INDEX number).

Table 8.1 (page 1) Types of data cards used in DYNPRO

Card type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT	Title of study (centered to columns 30-31).
	61-64	I	IOFILE	File printing option; equals 1 to print the VARSYS file (default value = 0, i.e., no file printing).
	65-68	I	IOPT	Special printing option; equals 1 to print all states considered in the run; equal 2 to print debug information. (The default value = 0, prints neither information.)
A	1-5	I	JHRPWB	Base year for cost discounting calculation.
	6-10	I	JHRFUL	Base year for cost escalation calculation (normally the same value as JHRPWB).
	11-15	I	JAHR	First year of study.
	16-20	I	NJHRS	Number of years to be considered for the economic comparison carried out by DYNPRO.
				Note: See Section 8.7 for details on the definition of JHRPWB and JHRFUL.
B	1-5	I	IOPW	Option for discount rate on capital costs. If = 0 (normal recommended value) calls for a single discount rate on domestic capital costs for all expansion candidates and a single discount rate on foreign capital costs for all expansion candidates; = 1 calls for individual discount rates for each expansion candidate.
	6-10	I	NUM1	The set of annual discount rates to be used during the study period (normal recommended value is NUM1 = 1). A different set of discount rates can be used for periods composed of an integral number of years (one or more). NUM1 defines how many type C1 or C2 cards must be supplied (see below).
C1				Use if IOPW = 0; number of cards = NUM1.
	1-10	I	IYRL	Last year that single discount rates TEMPL and TEMPF are to be used (if NUM1 = 1, then IYRL will be the last year of study).
	11-20	F	TEMPL	Single discount rate (%/year) for domestic capital costs; valid until year IYRL.
	21-30	F	TEMPF	Like TEMPL except that it applies to foreign capital costs.

Table 8.1 (page 2) Types of data cards used in DYNPRO

Card type	Columns	Format[1]	Fortran name	Information
C2				Use if IOPW = 1; number of cards = NUM1.
	1-10	I	IYRL	Same meaning as given above for IYRL on type-C1 card. Each type-C2 card is followed by a set of type-C3 cards.
C3				Use if IOPW = 1; number of sets = NUM1; number of cards per set = NALTS, where NALTS is the total number of expansion candidates in VARSYS.
	1-8	F	RTINLC(IP)	Discount rate for domestic capital costs for expansion candidate IP (the number of the plant in the VARSYS list) during the period ending with the IYRL indicated on the preceding type-C2 card.
	9-16	F	RTINFC(IP)	Like RTINLS(IP) except that it applies to foreign capital costs.
1	1-4	I	INDEX	Index number: 1 indicates that all data for current year have been completed; 2 through 17 indicate that one or more cards follow of type equal to the INDEX number, except that INDEX = 5 and INDEX = 10 are not used in the DYNPRO Module of WASP-III Plus.
2[2]	1-8	F	COSTL(IP)	Depreciable domestic capital cost ($/kW) of plant number IP, where IP has the same meaning as in card type-C3 (see above). (leave blank for hydro.)
	9-16	F	COSTF(IP)	Depreciable foreign capital cost ($/kW). (leave blank for hydro.)
	17-24	F	PLIFE(IP)	Plant life (in years and fractions of years) to be used for salvage value calculation.
	25-32	F	COST2L(IP)	Non-depreciable domestic capital cost ($/kW). (leave blank for hydro.)
	33-40	F	COST2F(IP)	Non-depreciable foreign capital cost ($/kW). (leave blank for hydro.)
	41-48	F	ORC(IP)	Interest during construction included in COSTL and COSTF (in %). (leave blank for hydro.)
	49-56	F	TCON(IP)	Construction time (in years and fraction of years). (leave blank for hydro.)

Table 8.1 (page 3) Types of data cards used in DYNPRO

Card type	Columns	Format[1]	Fortran name	Information
2a[3]	1-8	F	HCOSTL(J)	Depreciable domestic capital cost ($/kW) of hydro project J, where J is the project number of this type in VARSYS.
	9-16	F	HCOSTF(J)	Depreciable foreign capital cost ($/kW) of hydro project J.
	41-48	F	ORC(J)	Same as ORC(IP) but for hydro project J.
	49-56	F	TCON(J)	Same as TCON(IP) but for hydro project J.
	73-76	A	NOMHY(J)	Name of hydro project J (must be equal to PNAME in card 2a of VARSYS).
3	1-8	F	FF	Factor by which all foreign costs will be multiplied (generally speaking FF should have values greater than 1.0) (default value 1.0)
4[4]	1-8	F	ESCLC(IP)	Annual escalation ratio of domestic capital cost of VARSYS plant IP (default value 1.0)
	9-16	F	ESCFC(IP)	Same as ESCLC(IP) except that it applies to foreign capital costs.
6	1-4, 5-8, 9-12, etc.	I I I	NLIMIT(IP)	Maximum number of units (sets) of the expansion candidate IP (plant number in the VARSYS list) which can be added per year (default value 50). One value per candidate. One card suffices since the maximum number of candidates is 14 (there should be NALTS numbers in the card).
7	1-4, 5-8, etc.	I I	NLOWLT(IP)	Like NLIMIT(IP) except that it defines the minimum number of units (sets) of each expansion candidate which must be added per year (default value is 0) (there should be NALTS numbers in the card).
8	1-6, 7-12, 13-18, . . . 73-78	F F F . . . F	RTINLO(I) RTINFO(I)	(1st card) On the first card the thirteen (2nd card) numbers are the respective discount rates (%/year) to be applied to the domestic operation costs of plants of "fuel" type (I); the corresponding numbers on the 2nd card apply to foreign operating costs respectively[6]. Thirteen numbers per card: the first number of each card in columns 1 to 6 and the last one in columns 73 to 78. These cards are not used if INDEX = 14 and INDEX = 15 are used (default values 0.0).

Table 8.1 (page 4) Types of data cards used in DYNPRO

Card type	Columns	Format[1]	Fortran name	Information
9	1-6, 7-12, 13-18, etc.	F F	RTESLO(I) RTESFO(I)	(1st card) Like the two type-8 cards (2nd card) except that the numbers are the annual escalation ratios to be applied to domestic (1st card) and foreign (2nd card) operating costs (default values 1.0) (thirteen numbers in each card.[5])
11	1-8, 9-16, 17-24	F F F	CF1, CF2, CF3	Coefficients of the 2nd order polynomial of the incremental cost of unserved energy ($/kWh) as a function of the unserved energy (expressed as a fraction of total annual energy) (default values 0.0).
12	1-8	F	CLOLP	Critical value of annual loss-of-load probability (in %) (default value 100).
13	3-4	I	NBEST	Number of best solutions to be reported; values from 1 to 10 (default value 1).
14	1-6	F	TEMP	A single discount rate (%/year) to be applied to all domestic operating costs (transferred to RTINLO(I) for all I) (see type-8 card description) (not used if INDEX=8 is used).
15	1-6	F	TEMP	Like 14 except that applies to all foreign operating costs (transferred to RTINFO(I)).
16	1-4	I	ISAL	Salvage value option; 0 (default value) calls for linear depreciation; 1 calls for sinking fund depreciation.
17	1-6, 7-12, 13-18, etc.	F F F	OPFACL(I) OPFACF(I)	(1st card) Multiplying factor by type of (2nd card) ("fuel") plant for domestic (1st card) and foreign (2nd card) fuel costs. (This allows sensitivity studies on fuel costs) (default values = 1.0) (thirteen numbers per card).[5]

<u>Notes to Table 4.1</u>

1 See Section 2.5 for Format description.

2 One card for each expansion candidate in the sequence listed in VARSYS, first all thermal candidates, then hydro type A (if any) followed by hydro type B (if any); each hydro type is followed by a set of cards type-2a (see [3] below).

3 One card for each hydro project in the sequence listed in VARSYS, first all projects type A (if any) preceded by the respective type-2 card, and then all projects of type B (if any) also preceded by a card type-2.

4 Same order and number of cards as explained in [2] above; one card for each hydro type existing in VARSYS.

5 Plant ("fuel") types in DYNPRO of WASP-III Plus go from 0 to 12 (total equal 13). Types 0, 1, 2,..., 9 are used for thermal plants; 10 and 11 for hydro type A and B respectively; and 12 is used for energy not served cost.

Card type-3 is used if a multiplying factor ($\neq$ 1.0) is to be applied to all foreign costs. Cards type-4 to give the annual escalation ratios (if $\neq$ 1.0) applicable to foreign and domestic capital costs of each expansion candidate. Cards type-6 and type-7 are used to impose additional constraints on the expansion schedule, and card type-12 on the reliability of the configurations (limit of the system's LOLP to be respected by the yearly configurations). A type-11 card will give the information required to evaluate the cost of the energy not served resulting from the simulation. A type-13 card specifies the number of best solutions to be included in the printout, and a type-16 card can be used to change (from default) the option for calculating salvage value of the plants added by each alternative expansion plan.

Cards type-8, -9, -14 and -15 apply to operating costs. Card type-9 gives the annual escalation ratios on local and foreign operating costs of each "fuel" type. Type-8 cards are used if *individual discount rates* are to be applied for each "fuel" type and the type-14 and type-15 cards if *single discount rates* are to be applied for all operating costs. Finally, type-17 cards define multiplying factors, by "fuel" type, for domestic (local) and foreign fuel costs.

It should be noted here that the use of the above mentioned data cards for different years of the study should be done with great care, since the program will carry out the optimization based on the instructions given in these cards. The user should be aware that by altering some of the economic parameters through the years of the study, the comparison between alternative expansion schedules is also altered. This is particularly valid for the various discount rates, escalation rates and the multiplying factors described in the DYNPRO data cards, which should be kept constant while searching for the optimal solution of the case study. All DYNPRO capabilities for handling various input data are particularly advantageous for carrying out sensitivity studies as it is described in Section 11.4.

The input data for a run of DYNPRO are arranged in the following sequence:

a) For the first year:

- First card: A type-X card (title of study and printing options).

- Second card: A type-A card (JHRPWB, JHRFUL, JAHR, and NJHRS).

- Third card: A type-B card with the option for discount rates on capital costs (IOPW) and the number (NUM1) of cards type-C1 or type-C2 which follow.

- Next cards: If IOPW = 0, NUM1 data cards type-C1 with the applicable single discount rates for each discounting period.

  If IOPW = 1, NUM1 groups of data cards; each group composed of one type-C2 card defining the cost discounting period and as many type-C3 cards as VARSYS plants (including hydro, if any) with the corresponding individual discount rates for each candidate.

- Next cards: One type-1 INDEX = 2 card followed by as many type-2 cards as thermal candidates are described in VARSYS.

- Next cards: Groups of type-2 and type-2a cards for each hydro plant type described in VARSYS; each group must be composed of one type-2 card with the economic plant life of the hydro type and as many type-2a cards as projects of this type are described in VARSYS.

- Following cards: Groups of one card type-1 INDEX = 3, = 4, = 6, = 7, = 9, = 11, = 12, = 13, = 16 or = 17, and one or more cards of type equal to the INDEX number, if it is required to change the default values of the corresponding variable (see Table 8.1). The information given on type-3, -6, -7, -11, -12, -13 or -16 cards requires only one card of the respective type, that of type-4 card requires one card per expansion candidate, and that of type-9 and -17 requires two cards of the type.

  Finally, one type-1 INDEX = 8 card followed by two type-8 cards to give *individual discount rates* (by fuel type) on operating costs or, alternatively, type-1 INDEX = 14 and type-1 INDEX = 15 cards are included to specify *single discount rates* for all operating costs in the card which follows in each case.

- Last card: One type- INDEX = 1 card (end of the year).

b) For the second and subsequent years:

- Groups of a card type-1 with INDEX equal to the type of card (or cards) which follow for each change of the respective variables. For example, the constraints on plant expansion schedule (card type-6 and type-7), the coefficients for evaluating the cost of unserved energy (type-11 card), and the reliability constraint (type-12) may be changed from year to year.

  As explained before, it is recommended not to use cards type-3, -4, -8, -9, or -14 through -17 for the remaining years of the study, while searching for the optimal solution which will serve as reference solution for the case under study. The use of these options to perform sensitivity studies is treated in Section 11.5.

- Last card: One card type-1 INDEX = 1 (end of the year).

8.3 Input Data for a Fixed Expansion Plan (DYNPRO Run-1)

Figure 8.1 represents the input data prepared for a fixed expansion plan for which DYNPRO is used only to evaluate the costs of a predetermined expansion schedule (see Section 8.0). This corresponds to the first DYNPRO run (identified as DYNPRO Run-1) for the sample problem, using the EXPANALT and SIMULNEW files created by CONGEN Run-1 and MERSIM Run-1 described in the Sections 6.3 and 7.3, respectively.

The first line in Fig. 8.1 is the usual type-X card with the title of study and the printout options for the run. The same remarks made in Section 6.3 for the title of study to be used in type-X card of CONGEN are also valid for DYNPRO. The "1" in column 64 of this card asks for printing of the information of the VARSYS file, while the "1" in col. 68 calls for printing the list of configurations considered in the run.

The second line of Fig. 8.2 is a type-A card which specifies in the two first (5-columns) fields the base years for present worth discounting of costs and cost escalation calculations (1995); in the 3rd field the first year of the study (1997); and in the last field the number of years (20) in the study (see Section 8.7).

```
   CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL          1    1
 1995 1995 1997   20
   0    1
      2016          8.0          8.0
  2
 291.0   779.0          30.     0.0      0.0    17.12       5.5                 1VCOA
 257.0   709.0          30.     0.0      0.0    14.19       4.5                 2VFOL
 370.0  1680.0          30.     0.0    250.0    22.72       7.5                 3VNUC
  80.0   320.0          20.     0.0      0.0     6.52       2.0                 4V-GT
                        50.                                                     5HYD1
1117.0   478.0                                  22.67       6.0                  VHY1
1218.0   522.0                                  22.67       6.0                  VHY3
1360.0   582.0                                  22.67       6.0                  VHY5
                        50.                                                     6HYD2
1015.0   435.0                                  29.22       8.0                  VHY2
1136.0   486.0                                  29.22       8.0                  VHY4
1320.0   565.0                                  29.22       8.0                  VHY6
1726.0   739.0                                  29.22       8.0                  VHY7
  6
 50   50   50   50   50   50
  7
  0    0    0    0    0    0
 11
   0.05    105.0      0.0
 12
  100.0
 13
  1
 14
  8.0
 15
  8.0
 16
  1
  1            (END OF 1997)
  1            (END OF 1998)
  1            (END OF 1999)
  1            (END OF 2000)
  1            (END OF 2001)
  1            (END OF 2002)
  1            (END OF 2003)
  1            (END OF 2004)
  1            (END OF 2005)
  1            (END OF 2006)
  1            (END OF 2007)
  1            (END OF 2008)
  1            (END OF 2009)
  1            (END OF 2010)
  1            (END OF 2011)
  1            (END OF 2012)
  1            (END OF 2013)
  1            (END OF 2014)
  1            (END OF 2015)
  1            (END OF 2016)
```

Figure 8.1 (page 1) DYNPRO Input Data for a Fixed Expansion Plan of the Sample Problem (CASE93). DYNPRO Run-1

The next line is a type-B card with a zero in column 5 indicating that single discount rates (one for local and one for foreign) on capital costs are to be used for all expansion candidates; the number on column 10 tells the computer that only one type-C1 card follows (i.e. only one discounting period). This type-C1 card indicates the last year for which the single discount rates will be used (2016), along with the respective single discount rates (in % per year) on local and foreign components of capital costs; both values are 8% per year for the sample problem.

Input line number 5 is a type-1 INDEX=2 card informing the program that capital cost data, plant life and construction times follow on type-2 cards. As explained earlier, this card must be followed by one type-2 card for each expansion candidate and one type-2a for each hydro project of each hydro plant type in the same order listed in VARSYS. Consequently, input lines number 6 to 9 of Fig. 8.1 give the data for the thermal expansion candidates in the same order of the listing for cards type-2 in Figure 5.1. In the sample problem, each card has been identified by the plant number and code name in cols. 72-76. This is for the convenience of the user and is not needed nor read by the program.

The type-2 card for each hydro plant type should contain only the plant life (in columns 17-24) and must be followed by the corresponding type-2a cards for the hydro projects of this type. Consequently, input line number 10 corresponds to the type-2 card for hydro plant A (HYD1), which contains the plant life (50. years) of the hydro projects of this type (note that the plant number and code name have also been added in cols. 72-76 for the convenience of the user). This is followed by three type-2a card to specify the cost information for these projects. Each type-2a card shows in cols. 73-76 the name of the project (NOMHY), information required by DYNPRO and REPROBAT for printing purposes. A similar sequence is used in the next five input lines: one type-2 card for hydro plant B (HYD2) and four type-2a cards with the cost data for hydro projects of this plant type.

The next line is a type-1 INDEX=6 card, followed by a type-6 card which specifies the maximum number of units or projects of each expansion candidate that can be added in the year[1]. Similarly, the type-1 INDEX=7 and type-7 cards that follow are used to specify the minimum number of units or projects of each expansion candidate that must be added in the year[1]. These cards allow the user to impose additional constraints on the optimization by controlling the pace of additions of each candidate. These are not recommended to be used while searching for the reference optimal solution for a WASP case study since they may distort the optimization procedure and reroute the area of optimality. Nevertheless, the type-6 and type-7 cards could be used to make adjustment to the reference optimal solution in order to determine a more practical and viable schedule of additions for the power system.

The next line in Fig. 8.1 is a type-1 INDEX=11 card and is followed by a type-11 card. This specifies the coefficients of the second order polynomial describing the incremental cost of unserved energy as a function of the amount of unserved energy. In the sample problem, the constant coefficient is 0.05; the coefficient of first order 105.0; and the 2nd order coefficient is 0.0. Thus, DYNPRO will evaluate the cost of the unserved energy (in thousand \$) as:

$$\text{Unserved Energy Cost} = [0.05 + \frac{1}{2} \times 105.0 \times \frac{ENS}{EA} + \frac{1}{3} \times 0.0 \times (\frac{ENS}{EA})^2] \times ENS \times 10^3$$

where ENS represents the amount of unserved energy calculated by MERSIM and EA the annual demand for the corresponding year, with ENS and EA expressed in GWh and the coefficients in \$/kWh. The above expression is calculated for each hydrocondition and the results weighted by the respective hydrocondition probability to give the expected cost of the energy not served.

---

1 Note that the specified value(s) is(are) equal to the default value(s) contained in the program (see Table 7.1). Therefore, these two cards may have been omitted altogether, but they have been included here for demonstration purposes.

The next input line is a type-1 INDEX-12 card, followed by a type-12 card giving the critical LOLP. For a predetermined expansion schedule, this is normally taken as 100% in order not to reject any configuration[1].

The subsequent lines are a type-1 INDEX = 13 card followed by a type-13 card which tells the computer the number of best, next best and so on (up to 10) solutions to be reported on; in this case only one solution can be reported[1].

Next lines are a type-1 INDEX = 14 card and a type-14 card. These are used to specify the single present worth discount rate (8%) to apply to all local operating costs. Similarly, the next line is of type-1 INDEX = 15 and is followed by a card type-15 with the single discount rate (8%) to be applied to all foreign operating costs. These are followed by a type-1 INDEX = 16 card calling for a type-16 card to indicate the salvage value option; the "1" shown in this card calls for sinking fund depreciation.

The remaining cards are all type-1 INDEX = 1 (all identified with the year for convenience of the user) informing the computer that all data have been read and that calculations should be carried out for each year of the study.

Concerning other data card types allowed by DYNPRO, cards type-1 INDEX = 8 were not used in the sample run since type-1 INDEX = 14 and 15, cards have already specified the desired discount rates to be applied to all local and foreign operating costs.

Similarly, cards type-1 INDEX = 3, 4, 9, 17 were not used in order not to alter the optimization process to be carried by DYNPRO. In fact, it is recommended to leave the respective variables controlled by these cards to the default values while searching for the reference optimal solution and concentrate on changes of these values while conducting sensitivity analyses.

Finally, cards type-1 INDEX = 5 and 10 are not permitted in DYNPRO; if used, they would lead to interruption of program execution and printing of an error message as explained in Appendix B, Section B.6, which describes the DYNPRO error messages.

8.4 Printout for a Fixed Expansion Plan (DYNPRO Run-1)

Figure 8.2 shows the (partial) DYNPRO printout for the fixed expansion plan of CASE93 using the input data of Figure 8.1 and the EXPANALT and SIMULNEW files created by CONGEN Run-1 and MERSIM Run-1. Since the file printing option (IOFILE) on card type-X of this run is "1", the program prints first the variable system description read from the VARPLANT file. This information, similar to the one on page 1 of Fig. 6.2, is not shown in Figure 8.2.

Page 1 of Fig 8.2 shows the cover page of the printout, which except for the module name, shows the same information as for the CONGEN runs (see page 6 of Fig. 6.2).

Page 2 summarizes the economic parameters and the capital costs given as input data; all type-1 INDEX cards are printed along with the data on the respective cards (or card) which follow. After printing of an INDEX = 1, the program reports the value of the objective function for each configuration (or state) in the year (in this case only one state) and the state in the preceding year included in the sub-optimum path to reach this year state. Page 3 shows this information for the first and last five years of the study.

Since only type-1 INDEX = 1 cards were used for the second and subsequent years, the printout for all these years includes an INDEX = 1 followed by the respective value of the objective function of the states and number of the previous year state included in the sub-optimum path[2].

Page 4 illustrates the results of the calculations carried out by DYNPRO for the sample problem. These are presented in a table that summarizes the most important results for the yearly configurations contained in the solution.

First the program reports the number of the solution (in this case only one) followed by a summary of each year's construction cost (*CONCST*), salvage value (*SALVAL*), operating cost (*OPCOST*) and cost of unserved energy (*ENSCST*). The objective function for each year is shown under *TOTAL* together with the cumulative value (*CUMM.*) of the objective function up to the corresponding year[3]. All values expressed in present worth and thousands of dollars (K$). The reliability of the configuration (LOLP with maintenance) is also shown (in %). Finally, each yearly configuration is identified by the plant name and the number of units or projects of each candidate plant.

Since no VARSYS plant was added in 1997, the configuration for this year (at the bottom of page 4) is identified by zero sets or projects for all expansion candidates, zero construction cost and salvage value[4], 427158 (K$) for operation cost and 13 (K$) for cost of unserved energy (or energy not served). The total costs (equal to the cumulative value of the objective function for this year) is simply the sum of the two values mentioned last. The configuration LOLP (0.067%) as read from the MERSIM file is also shown.

The configurations for the remaining years of the study are reported in a similar way as explained above for 1997.

The above described summary table with the DYNPRO results is very useful for having a glance at the best solutions reported by DYNPRO. Its usefulness for the process of finding the optimal solution is explained in Section 8.6.

Since for the present run of DYNPRO the print option IOPT is "1", after reporting the solution for the run the program prints the list of the states considered in the run. This list is shown on page 5 of Fig. 8.2. It should be noted that for variable expansion runs, with hundreds of configurations, this list can add several pages to the DYNPRO printout. Thus the convenience of setting IOPT to "0" for variable expansion runs.

---

2 For a fixed expansion plan there is only one state per year and only one solution. The use of the information on the optimization pattern will be explained in Section 8.6.

3 For each state, the total cumulative value of the objective function is identical to the one reported on page 3 of Fig. 8.2.

4 In some cases when there is no addition of new plants in the year, the respective construction cost are reported as zero but the salvage value of the configuration is reported with a non zero value. This is a result of the way the salvage value is calculated within DYNPRO and also depends on the computer system's ability of handling information. Since in DYNPRO runs, the information of interest comprehends mainly the states included in the best solutions and their corresponding cumulative values of objective function and, considering that in computer systems only a set of significant digits (five in this case) of a number are accurate, this anomalies can be disregarded.

```
                    WASP  COMPUTER  PROGRAM  PACKAGE

                            DYNPRO  MODULE

                             CASE  STUDY

          CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL



               ****************************************
               *                                      *
               *   LIST OF VAR. EXPAN. CANDIDATES     *
               *                                      *
               ****************************************
               *                                      *
               *          THERMAL    PLANTS           *
               *                                      *
               *      SEQU.NUMBER         NAME        *
               *                                      *
               *           1              VCOA        *
               *           2              VFOL        *
               *           3              VNUC        *
               *           4              V-GT        *
               *                                      *
               ****************************************
               *                                      *
               *       HYDROELECTRIC PLANTS           *
               *                                      *
               *                                      *
               *      SEQU.NUMBER         NAME        *
               *                                      *
               *           5              HYD1        *
               *           6              HYD2        *
               *                                      *
               ****************************************
```

Figure 8.2 (page 1) DYNPRO Printout for a Fixed Expansion Plan of the Sample Problem. DYNPRO Run-1. Cover Page

```
ALL COSTS WILL BE DISCOUNTED TO THE YEAR   1995
BASE YEAR FOR COST ESCALATION CALCULATION  1995
FIRST YEAR OF STUDY = 1997
DURATION  OF  STUDY =   20 YEARS
OPTION FOR DISCOUNTING OF CAPITAL COSTS, IOPW =  0
NUMBER OF DISCOUNTING PERIODS FOR CAPIT. COST =  1
LAST YEAR THAT FOLLOWING RATES ARE TO BE USED, IYRL =  2016
(IF IYRL = LAST YEAR OF STUDY, PROGRAM INCREASES IYRL BY ONE)
DISCOUNT RATE APPLIED TO ALL DOMESTIC CAPITAL COSTS - %/YR =    8.00
DISCOUNT RATE APPLIED TO ALL FOREIGN  CAPITAL COSTS - %/YR =    8.00
```

***** INPUT OF YEAR 1997 *****

INDEX = 2

PLANT	-- CAPITAL COSTS ($/KW) -- (DEPRECIABLE PART) DOMESTIC	FOREIGN	(NON-DEPREC. PART) DOMESTIC	FOREIGN	PLANT LIFE (YEARS)	I.D.C. (%)	CONSTR. TIME (YEARS)
VCOA	291.0	779.0	0.0	0.0	30.	17.12	5.5
VFOL	257.0	709.0	0.0	0.0	30.	14.19	4.5
VNUC	370.0	1680.0	0.0	250.0	30.	22.72	7.5
V-GT	80.0	320.0	0.0	0.0	20.	6.52	2.0
HYD1	HYDRO PROJECT(S) CAPITAL COSTS						
VHY1	1117.0	478.0			50.	22.67	6.0
VHY3	1218.0	522.0			50.	22.67	6.0
VHY5	1360.0	582.0			50.	22.67	6.0
HYD2	HYDRO PROJECT(S) CAPITAL COSTS						
VHY2	1015.0	435.0			50.	29.22	8.0
VHY4	1136.0	486.0			50.	29.22	8.0
VHY6	1320.0	565.0			50.	29.22	8.0
VHY7	1726.0	739.0			50.	29.22	8.0

```
INDEX =    6
UPPER LIMIT ON NUMBER OF UNITS THAT CAN BE ADDED FOR EACH CANDIDATE IN EACH YEAR
         VCOA  VFOL  VNUC  V-GT  HYD1  HYD2
          50    50    50    50    50    50

INDEX =    7
LOWER LIMIT ON NUMBER OF UNITS THAT MUST BE ADDED FOR EACH CANDIDATE IN EACH YEAR
         VCOA  VFOL  VNUC  V-GT  HYD1  HYD2
           0     0     0     0     0     0

INDEX =   11
COEFFICIENTS FOR CALCULATION OF COST OF ENERGY NOT SERVED - IN $/KWH :
          CF1 =    0.0500    CF2 = 105.0000    CF3 =    0.0000

INDEX =   12
CRITICAL LOSS-OF-LOAD PROBABILITY - IN (%) =    100.0000

INDEX =   13
NUMBER OF BEST SOLUTIONS REQUESTED IS    1

INDEX =   14
DISCOUNT RATE APPLIED TO ALL DOMESTIC OPERATING COSTS - %/YR =    8.00

INDEX =   15
DISCOUNT RATE APPLIED TO ALL FOREIGN  OPERATING COSTS - %/YR =    8.00

INDEX =   16
USE SINKING FUND DEPRECIATION METHOD FOR SALVAGE VALUE CALCULATION
```

Figure 8.2 (page 2) DYNPRO Printout for a Fixed Expansion Plan of the Sample Problem. DYNPRO Run-1. Input Data

```
INDEX =     1
OBJECTIVE FUNCTION STATE    1 TO   1
     427171.
           1

                                             *****  INPUT OF YEAR 1998  *****

INDEX =     1
OBJECTIVE FUNCTION STATE    2 TO   2
     881705.
           1

                                             *****  INPUT OF YEAR 1999  *****

INDEX =     1
OBJECTIVE FUNCTION STATE    3 TO   3
    1481478.
           2

                                             *****  INPUT OF YEAR 2000  *****

INDEX =     1
OBJECTIVE FUNCTION STATE    4 TO   4
    1965924.
           3

                                             *****  INPUT OF YEAR 2001  *****

INDEX =     1
OBJECTIVE FUNCTION STATE    5 TO   5
    2906137.
           4

                                             *****  INPUT OF YEAR 2002  *****

INDEX =     1
OBJECTIVE FUNCTION STATE    6 TO   6
    3496111.
           5

  .    .    .    .    .    .    .    .    .    .    .    .    .    .
  .    .    .    .    .    .    .    .    .    .    .    .    .    .
  .    .    .    .    .    .    .    .    .    .    .    .    .    .
  .    .    .    .    .    .    .    .    .    .    .    .    .    .
  .    .    .    .    .    .    .    .    .    .    .    .    .    .
  .    .    .    .    .    .    .    .    .    .    .    .    .    .
  .    .    .    .    .    .    .    .    .    .    .    .    .    .

                                             *****  INPUT OF YEAR 2012  *****

INDEX =     1
OBJECTIVE FUNCTION STATE   16 TO  16
    9678280.
          15

                                             *****  INPUT OF YEAR 2013  *****

INDEX =     1
OBJECTIVE FUNCTION STATE   17 TO  17
    9976100.
          16

                                             *****  INPUT OF YEAR 2014  *****

INDEX =     1
OBJECTIVE FUNCTION STATE   18 TO  18
   10308645.
          17

                                             *****  INPUT OF YEAR 2015  *****

INDEX =     1
OBJECTIVE FUNCTION STATE   19 TO  19
   10553453.
          18

                                             *****  INPUT OF YEAR 2016  *****

INDEX =     1
OBJECTIVE FUNCTION STATE   20 TO  20
   10786080.
          19
```

Figure 8.2 (page 3) DYNPRO Printout for a Fixed Expansion Plan of the Sample Problem. DYNPRO Run-1. Rest of Input Data and Dynamic Optimization Pattern

SOLUTION # 1 VARIABLE ALTERNATIVES BY YEAR

YEAR------	PRESENT WORTH COST OF THE YEAR (K$)------					OBJ.FUN.	LOLP	VCOA		VNUC		HYD1	
	CONCST	SALVAL	OPCOST	ENSCST	TOTAL	(CUMM.)	%		VFOL		V-GT		HYD2
2016	127537	117050	222124	16	232627	10786080	0.110	8	1	5	8	3	4
2015	137740	115923	222984	7	244808	10553453	0.079	7	1	5	8	3	4
2014	479644	371033	223930	4	332545	10308645	0.059	6	1	5	8	3	4
2013	200700	139926	237040	7	297820	9976100	0.062	6	1	4	8	3	4
2012	559456	363183	235232	21	431526	9678280	0.116	5	1	4	6	3	4
2011	187394	110444	250262	27	327239	9246754	0.134	5	1	3	6	3	4
2010	702989	377720	254502	6	579776	8919515	0.052	4	1	3	6	3	4
2009	218576	107004	274593	10	386174	8339739	0.073	4	1	2	4	3	4
2008	974252	438207	279735	2	815782	7953565	0.027	3	1	2	4	3	4
2007	286716	113048	283529	57	457254	7137783	0.141	3	0	1	4	3	4
2006	1522105	595047	285661	26	1212744	6680529	0.072	2	0	1	3	3	4
2005	298991	109192	334972	73	524844	5467784	0.184	2	0	0	3	3	3
2004	525171	167889	361749	12	719043	4942940	0.083	2	0	0	2	3	2
2003	525790	171457	373433	21	727786	4223897	0.105	1	0	0	2	2	2
2002	249734	66969	407166	43	589974	3496111	0.158	1	0	0	2	2	1
2001	678693	162265	423750	36	940213	2906137	0.135	1	0	0	1	1	1
2000	54447	3864	433684	179	484446	1965924	0.409	0	0	0	1	1	0
1999	211027	49363	437988	121	599773	1481478	0.289	0	0	0	0	1	0
1998	0	0	454492	42	454534	881705	0.159	0	0	0	0	0	0
1997	0	0	427158	13	427171	427171	0.067	0	0	0	0	0	0

Figure 8.2 (page 4) DYNPRO Printout for a Fixed Expansion Plan of the Sample Problem. DYNPRO Run-1. Results of the Economic Calculations.

1	STATE	0	0	0	0	0	0
2	STATE	0	0	0	0	0	0
3	STATE	0	0	0	0	1	0
4	STATE	0	0	0	1	1	0
5	STATE	1	0	0	1	1	1
6	STATE	1	0	0	2	2	1
7	STATE	1	0	0	2	2	2
8	STATE	2	0	0	2	3	2
9	STATE	2	0	0	3	3	3
10	STATE	2	0	1	3	3	4
11	STATE	3	0	1	4	3	4
12	STATE	3	1	2	4	3	4
13	STATE	4	1	2	4	3	4
14	STATE	4	1	3	6	3	4
15	STATE	5	1	3	6	3	4
16	STATE	5	1	4	6	3	4
17	STATE	6	1	4	8	3	4
18	STATE	6	1	5	8	3	4
19	STATE	7	1	5	8	3	4
20	STATE	8	1	5	8	3	4

Figure 8.2 (page 5) DYNPRO Printout for a Fixed Expansion Plan of the Sample Problem. DYNPRO Run-1. List of States Considered in the Run.

8.5 Input Data for Dynamic Expansion Plans

The execution of DYNPRO for a dynamic (or variable) expansion plan is essentially the same as for the fixed expansion schedule except for a few changes introduced in the data cards. Figure 8.3 shows the input data used for variable expansion runs of DYNPRO for the sample problem, which are very similar to those used for the fixed expansion plan (see Fig. 8.1) with a few changes. First, the type-X card in Fig. 8.3 has a zero for both printing options in order to reduce the output of the run.

```
  CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS MANUAL       0   0
1995 1995 1997   20
   0   1
     2016        8.0         8.0
  2
 291.0   779.0       30.     0.0     0.0  17.12     5.5              1VCOA
 257.0   709.0       30.     0.0     0.0  14.19     4.5              2VFOL
 370.0  1680.0       30.     0.0   250.0  22.72     7.5              3VNUC
  80.0   320.0       20.     0.0     0.0   6.52     2.0              4V-GT
                     50.                                             5HYD1
1117.0   478.0                            22.67     6.0               VHY1
1218.0   522.0                            22.67     6.0               VHY3
1360.0   582.0                            22.67     6.0               VHY5
                     50.                                             6HYD2
1015.0   435.0                            29.22     8.0               VHY2
1136.0   486.0                            29.22     8.0               VHY4
1320.0   565.0                            29.22     8.0               VHY6
1726.0   739.0                            29.22     8.0               VHY7
  11
   0.05    105.0     0.0
  12
  0.137
  13
  5
  14
  8.0
  15
  8.0
  16
  1
  1           (END OF 1997)
  1           (END OF 1998)
  1           (END OF 1999)
  1           (END OF 2000)
  1           (END OF 2001)
  1           (END OF 2002)
  1           (END OF 2003)
  1           (END OF 2004)
  1           (END OF 2005)
  1           (END OF 2006)
  1           (END OF 2007)
  1           (END OF 2008)
  1           (END OF 2009)
  1           (END OF 2010)
  1           (END OF 2011)
  1           (END OF 2012)
  1           (END OF 2013)
  1           (END OF 2014)
  1           (END OF 2015)
  1           (END OF 2016)
```

Figure 8.3 (page 1) DYNPRO Input Data for Variable Expansion Plans of the Sample Problem (CASE93)

Also, the value of the critical LOLP (0.137%, or 0.5 day/year in this case) is used for the variable expansion runs. In addition, 5 best solutions are requested to be included in the printout.

Since in the dynamic optimization phase for the sample problem, one is interested in finding the optimal solution which could be used later as "reference solution" for sensitivity studies, the plant addition schedule restrictions have been left to the respective default values in DYNPRO for the minimum and maximum number of sets or projects of the expansion candidates to be added each year; i.e. cards type-6 and type-7 are not used in variable expansion DYNPRO runs.

The rest of the data card types and values listed in Fig. 8.3 are the same as described for the DYNPRO run of the fixed expansion plan of CASE93 (see Section 8.3). The use of the various data card types for dynamic expansion runs of the DYNPRO module is left to the discretion of the user, according to the needs of the case study, It is however recommended to read carefully the remarks on this subject made in Sections 8.1 and 8.7.

8.6 Printouts for Dynamic Expansion Plans

The printout for variable expansion DYNPRO runs is basically the same as for the fixed expansion plan described in Section 8.4 but, since the printing options are both "0" for variable expansion runs, neither the data read from the VARSYS file nor the listing of states considered in the run are included in the printout for these runs. As mentioned earlier, this reduces considerably the size of the printout.

Figures 8.4 and 8.5 illustrate a sample of the DYNPRO printout for two dynamic expansion runs of the series made in the search for the reference optimal solution of CASE93. Figure 8.4 for the first of such runs (DYNPRO Run-2) which uses the EXPANALT and SIMULNEW files created by CONGEN Run-2 and MERSIM Run-2, respectively, and Figure 8.5 for the last run (DYNPRO Run-3) which uses the respective files created by CONGEN Run-3 and MERSIM Run-3. Only part of the printout is shown in each case.

The printout for DYNPRO Run-2 starts with the cover page identifying the run (not shown in Fig. 8.4), followed by the listing of input data for the run as shown in page 1 of Figure 8.4. Next, the program prints the so-called ***optimization pattern*** of the run, as illustrated on pages 2 and 3 of Fig. 8.4 for the first and last years of the study period.

The optimization pattern report produced by DYNPRO is very useful for tracing the optimal solution and the path of valid configurations (states) from any given year. In this part of the output, the objective function for each configuration considered by DYNPRO (10 per line) for each year of study are printed. The numbers below the objective function values show which state in the previous year preceded that particular state and are given in the same order as the values of the objective function.

For example, page 2 of Figure 8.4 shows that for the fifth year of study (year 2001), this DYNPRO run considered states: 43 to 117 (75 states in total). This is followed by the respective values of the objective function of these states, and the number of the state in the preceding year (2000) connected to the sub-optimum path. Therefore, state 117 has a value of the objective function of 3634809 (thousand $, or K$ in the printout), and is preceded by state 38 of year 2000, which in turn arises from state 6 of year 1999, and so on. The path for state 43 backward is: 15 - 5 - 3 - 1 (state 1 is the fixed system in 1997).

Similarly, the path for each of the states considered in this particular DYNPRO run (1166 states in total) can be traced by looking at the listing of the optimization pattern for the run (pages 2 and 3 of Fig. 8.4).

In this listing, those states which are given a zero for both, the objective function value and the number of the preceding year state, correspond to states not allowed by the constraints that were imposed by the user in DYNPRO. Thus, although 46 states were considered for year 2014 (see page 3 of Fig. 8.4), only 40 states met the constraints imposed in this case for the critical LOLP (6 states are represented by zeroes).

In some cases, the listing of objective function values may contain stars (*) for one or more states of some years and a number for the respective preceding year state. This can be explained as follows:

- If the preceding year state is shown as zero ("0"), this means that there is no possible transition from the previous year (i.e., this year state cannot be reached from any of the "accepted" states in the previous year) even if the current year state fulfills the DYNPRO constraints.

- If the preceding year state is marked with a number ($\neq$ 0), this simply means that the format for printing the objective function value has been overflown (i.e. this year state's objective function is greater than or equal to 10^{11} K$).

Page 4 of Fig. 8.4 shows the report for the best solution (#1) found in the DYNPRO Run-2 which is similar to the one shown in Fig. 8.2 for the fixed expansion run except that here some of the states contain a DYNPRO "message." This is represented by a sign (+) or (-) to the right of the number of sets or projects of each expansion candidate, to indicate what restriction used in CONGEN has acted as a constraint on the solution.

For example, the year 2005 state includes 3 sets of plant 2 (VFOL) followed by a sign (+) which means that more than 3 units of this plant may lead to a better solution (only up to 3 units of plant VFOL were permitted in this year in the CONGEN Run-2. Similarly, more than 4 units of plant 4 (V-GT) may lead to a better solution (only up to four such units were allowed).

On the other hand, the sign (-) indicates that the minimum number of sets or projects required in CONGEN for the respective plant in the year is too high. Therefore, the configuration for year 2005 shows 2- units (in this case projects) for both, plant 5 (HYD1) and plant 6 (HYD2) telling the user that less than 2 projects of these plant types may lead to a better solution (each of these values corresponds to the respective minimum number of projects of each plant which were specified this year in CONGEN Run-2).

Number of sets or projects not marked with a sign mean <u>either</u> that the solution was not constrained by the restrictions in CONGEN if the tunnel width for the respective plant in that year was not zero in CONGEN, or that DYNPRO did not have another choice (i.e. tunnel width for the plant is zero in the respective year).

In CONGEN Run-2, the tunnel width for all candidate plants were unequal zero in year 2005. Consequently, the zero with no "message" (sign) shown in the DYNPRO table for plant 1 (VCOA) and plant 3 (VNUC) can be interpreted as that the solution was not constrained in regards to these two candidate plants.

Unconstrained solutions for other years can be illustrated as follows. For example, in year 2007 in the CONGEN Run-2, the permitted number of units of plant 1 (VCOA) was 1, 2 and 3, and the configuration for this year in the optimum solution found by DYNPRO contains 2 sets of plant VCOA without any message. Likewise, in the same year, CONGEN Run-2 permitted 3, 4 and 5 sets of plant 4 (V-GT), and the configuration for this year in the DYNPRO solution contains 4 sets of plant V-GT without any message.

On the other hand, for years 2009 through 2016, CONGEN Run-2 considered zero tunnel width for both plant 5 and 6 (HYD1 and HYD2). Consequently, no "message" (sign) appears to the right of the respective number of projects of these plants included in the optimal solution for these years.

For variable expansion DYNPRO runs, a similar printout is produced by the program for as many best solutions as requested by the user on data card type-13 (if this card type is not used, DYNPRO reports 1 best solution). In DYNPRO Run-2, five best solutions were called for, so that the printout continues with the report for the 2nd, 3rd, 4th and 5th solution, similar to the one on page 4 of Fig. 8.4[5].

The messages in the DYNPRO printout for variable expansion plans help the user in finding the optimum solution for the case of study. Interpreting these messages, the user should proceed to execute new WASP iterations involving sequential runs of Modules 4 to 6, modifying each time the restrictions in CONGEN accordingly[6]. The process should be repeated until the best solution reported by DYNPRO is free of messages or, eventually, until the restrictions in CONGEN can no longer be relaxed. At each iteration, the value of the objective function for the best solution of DYNPRO is to be compared with the respective value for the best solution found in the previous iteration in order to determine that in fact a better solution has been achieved with the new iteration. This is particularly important when option "2" for LOLP calculation in CONGEN is selected for the case under study, since in this case "non overexpansion" is permitted by CONGEN while generating the yearly configurations of the system.

---

[5] In some cases, a fewer number of best solutions than the number requested in the type-13 card can be reported by the program, simply because there are no more solutions to report. This is identified in the DYNPRO output by a message printed at the bottom of the last possible solution: "ALL POSSIBLE PATHS TRACED".

[6] Iterations of CONGEN-MERSIM-DYNPRO should be made using the "merge" mode of operation for MERSIM. For the process to be effective, RENAME must be run after the current DYNPRO run and before proceeding to a new iteration. This will allow CONGEN to identify which are the actual "new" configurations generated in the run, so that the execution time of the subsequent MERSIM run can be adequately estimated. Likewise, this will permit saving computational time in MERSIM since simulation of system operation will be carried out only for the new configurations.

```
ALL COSTS WILL BE DISCOUNTED TO THE YEAR   1995
BASE YEAR FOR COST ESCALATION CALCULATION  1995
FIRST YEAR OF STUDY = 1997
DURATION  OF  STUDY =   20 YEARS
OPTION FOR DISCOUNTING OF CAPITAL COSTS, IOPW =  0
NUMBER OF DISCOUNTING PERIODS FOR CAPIT. COST =  1
LAST YEAR THAT FOLLOWING RATES ARE TO BE USED, IYRL =  2016
(IF IYRL = LAST YEAR OF STUDY, PROGRAM INCREASES IYRL BY ONE)
DISCOUNT RATE APPLIED TO ALL DOMESTIC CAPITAL COSTS - %/YR =   8.00
DISCOUNT RATE APPLIED TO ALL FOREIGN  CAPITAL COSTS - %/YR =   8.00

                                             *****  INPUT OF YEAR 1997  *****

INDEX =    2
```

PLANT	-- C A P I T A L (DEPRECIABLE PART) DOMESTIC	FOREIGN	C O S T S ($/KW) -- (NON-DEPREC. PART) DOMESTIC	FOREIGN	PLANT LIFE (YEARS)	I.D.C. (%)	CONSTR. TIME (YEARS)
VCOA	291.0	779.0	0.0	0.0	30.	17.12	5.5
VFOL	257.0	709.0	0.0	0.0	30.	14.19	4.5
VNUC	370.0	1680.0	0.0	250.0	30.	22.72	7.5
V-GT	80.0	320.0	0.0	0.0	20.	6.52	2.0
HYD1	HYDRO PROJECT(S) CAPITAL COSTS						
VHY1	1117.0	478.0			50.	22.67	6.0
VHY3	1218.0	522.0			50.	22.67	6.0
VHY5	1360.0	582.0			50.	22.67	6.0
HYD2	HYDRO PROJECT(S) CAPITAL COSTS						
VHY2	1015.0	435.0			50.	29.22	8.0
VHY4	1136.0	486.0			50.	29.22	8.0
VHY6	1320.0	565.0			50.	29.22	8.0
VHY7	1726.0	739.0			50.	29.22	8.0

```
INDEX =    11
COEFFICIENTS FOR CALCULATION OF COST OF ENERGY NOT SERVED - IN $/KWH :
          CF1 =    0.0500     CF2 = 105.0000     CF3 =    0.0000

INDEX =    12
CRITICAL LOSS-OF-LOAD PROBABILITY - IN (%) =       0.1370

INDEX =    13
NUMBER OF BEST SOLUTIONS REQUESTED IS     5

INDEX =    14
DISCOUNT RATE APPLIED TO ALL DOMESTIC OPERATING COSTS - %/YR =   8.00

INDEX =    15
DISCOUNT RATE APPLIED TO ALL FOREIGN  OPERATING COSTS - %/YR =   8.00

INDEX =    16
USE SINKING FUND DEPRECIATION METHOD FOR SALVAGE VALUE CALCULATION

INDEX =    1
OBJECTIVE FUNCTION STATE     1 TO   2
     427171.     497158.
          1            1

                                             *****  INPUT OF YEAR 1998  *****

INDEX =    1
OBJECTIVE FUNCTION STATE     3 TO   4
     945115.    1008512.
          1            1
```

Figure 8.4 (page 1) DYNPRO Printout (partial) for the First Variable Expansion Plan of the Sample Problem (DYNPRO Run-2). Input Data for the Run and List of Objective Functions.

***** INPUT OF YEAR 1999 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 5 TO 14

1764428.	1453363.	1821834.	1510688.	1879305.	1914304.	1603448.	1971598.	1660790.	2028866.
3	3	3	3	3	3	3	3	3	3

***** INPUT OF YEAR 2000 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 15 TO 42

2221559.	2599743.	2551353.	2936985.	2270975.	2231334.	2609447.	2560929.	2946405.	2322490.
2283093.	2660949.	2612359.	2998090.	2355601.	2735055.	2684692.	3071924.	2406216.	2365146.
2744558.	2694572.	3080917.	2085711.	2457910.	2416840.	2796276.	2746352.		
5	5	5	5	6	6	6	6	6	6
6	6	6	6	5	5	5	5	6	6
6	6	6	6	6	6	6	6		

***** INPUT OF YEAR 2001 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 43 TO 117

3007105.	3340278.	2964892.	3310844.	3642289.	3055848.	3017938.	3350718.	2975746.	3321290.
3653053.	2769133.	3102155.	2727234.	3064248.	3397197.	3022411.	3367768.	3128654.	3461724.
3084971.	3431089.	3762046.	3177399.	3139305.	3472235.	3095798.	3441658.	3772756.	2846787.
3180354.	2812538.	3150985.	3483878.	3107471.	3453301.	3188552.	3520736.	3142458.	3490827.
3820728.	2903541.	3237639.	2856567.	3199367.	3531549.	3153270.	3501642.	2950035.	3284127.
2903052.	3245857.	3577980.	3199817.	3548074.	2965758.	3309921.	3642000.	3262629.	3611971.
3941623.	3025034.	3359234.	2976573.	3320794.	3653119.	3273247.	3623140.	3027990.	3362206.
2988226.	3332491.	3664789.	3284949.	3634809.					
15	15	15	15	15	19	20	20	20	20
20	19	19	20	20	20	20	20	15	15
15	15	15	19	20	20	20	20	20	38
38	38	38	38	38	38	15	15	15	15
15	19	19	20	20	20	20	20	19	19
20	20	20	20	20	15	15	15	15	15
15	19	19	20	20	20	20	20	38	38
38	38	38	38	38					

***** INPUT OF YEAR 2002 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 118 TO 217

3761640.	3720606.	4018051.	0.	0.	3773505.	0.	3732424.	4029886.	3510220.
3470430.	3768581.	3436533.	3742005.	4039435.	3869990.	3829099.	4126408.	0.	0.
3881876.	0.	3840945.	4138122.	3579111.	3546725.	3845121.	3510624.	3818647.	4115777.
0.	4002385.	0.	3961410.	4257868.	3752209.	3715883.	4013828.	3662399.	3972884.
4269749.	3711717.	3679052.	3977151.	3640072.	3950710.	4247506.	0.	3923202.	0.
3882409.	4179630.	3627685.	3582321.	3880956.	3543671.	3854719.	4151754.	3669330.	3623959.
3922644.	3585214.	3896435.	4193504.	3681450.	3979893.	3640847.	3953502.	4250002.	3735892.
3690357.	3989067.	3649849.	3962679.	4259016.	3740534.	3705826.	4004352.	3665221.	3977981.
4274408.	3813850.	4112675.	3771771.	4085958.	4380956.	3868542.	3822837.	4121621.	3780916.
4094923.	4389920.	3574625.	3873134.	3530781.	3838253.	4136959.	3796321.	4110283.	4405426.
43	45	45	0	0	49	0	51	51	54
56	56	56	56	56	43	45	45	0	0
49	0	51	51	72	74	74	74	74	74
0	43	0	45	45	48	49	49	51	51
51	72	74	74	74	74	74	0	43	0
81	81	84	86	86	86	86	86	84	86
86	86	86	86	98	98	98	98	98	84
86	86	86	86	86	72	113	113	113	113
113	98	98	98	98	98	84	86	86	86
86	86	72	72	113	113	113	113	113	113

***** INPUT OF YEAR 2003 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 218 TO 313

0.	0.	4555859.	4253850.	4219431.	4484260.	0.	0.	4291032.	0.
4256650.	4521400.	4412558.	4360897.	4626324.	4370936.	4336650.	4602048.	4172979.	4142684.
4408160.	4100980.	4373867.	4639227.	4377654.	4340698.	4605560.	0.	0.	4396801.
4083680.	4358630.	4623398.	4198872.	4168391.	4433968.	4120852.	4395800.	4660516.	0.
0.	4495394.	0.	4458188.	4723151.	4243959.	4201749.	4467504.	4166066.	4444260.
4708969.	4281134.	4238920.	4504645.	4203257.	4481405.	4746044.	4481101.	4436791.	4703011.
4382977.	4664286.	4928965.	4487262.	4455932.	4722042.	4400968.	4682056.	4946738.	4524473.
4493148.	4759066.	4438066.	4719152.	4983829.	4598509.	4554073.	4819599.	4498320.	4781227.
5044290.	4303308.	4569108.	4247744.	4526193.	4791823.	4484394.	4767290.	5030351.	4340497.
4606286.	4284735.	4563371.	4829083.	4521546.	4804447.				
0	0	125	143	145	145	0	0	143	0
145	145	154	156	156	143	145	145	142	143
143	145	145	145	171	173	173	0	0	143
196	196	196	142	143	143	196	196	196	0
0	171	0	173	173	210	212	212	212	212
212	210	212	212	212	212	212	170	171	171
173	173	173	142	143	143	196	196	196	142
143	143	196	196	196	170	171	171	173	173
173	210	210	212	212	212	212	212	212	210
210	212	212	212	212	212				

***** INPUT OF YEAR 2004 *****

INDEX = 1
OBJECTIVE FUNCTION STATE 314 TO 381

4994586.	0.	0.	4963826.	4812747.	4761986.	4996850.	5098435.	4836238.	4802267.
5037613.	4869300.	4835314.	5070511.	5022750.	4987247.	5223016.	4960667.	4926437.	5162064.
4993696.	4959466.	5195058.	5051771.	4999057.	5232601.	5071723.	5015082.	5248627.	4892147.

Figure 8.4 (page 2) DYNPRO Printout (partial) for the First Variable Expansion Plan of the Sample Problem (DYNPRO Run-2). List of Objective Functions.

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                                    *****  INPUT OF YEAR 2010  *****

INDEX =     1
OBJECTIVE FUNCTION STATE  887 TO  925
         0.    8549590.    8541235.    8642599.          0.    8749143.          0.    8732739.    8834253.    8724203.
   8825633.    8926827.    8351374.    8550205.    8540777.    8642138.    8661035.    8756361.    8644794.    8733349.
   8834865.    8723741.    8825173.    8925759.    8365060.    8485055.    8462374.    8564088.    8453339.    8554661.
   8656022.    8674926.    8770245.    8658685.    8747233.    8848756.    8737625.    8839064.    8939643.
         0         832         832         832           0         849           0         832         832         832
       832         832         868         866         868         868         849         865         832         866
       866         868         868         868         868         865         866         866         868         868
       868         849         865         832         866         866         868         868         868

                                    *****  INPUT OF YEAR 2011  *****

INDEX =     1
OBJECTIVE FUNCTION STATE  926 TO  958
   8925583.    8895913.    8980385.    9092605.    9073817.    9157845.    9064986.    9127955.    9211696.          0.
   8915179.    8906823.    8991291.          0.    9085582.          0.    9063412.    9147440.    9054974.    9138863.
   9222605.    8765286.    8926651.    8918294.    9002760.    9012412.    9097049.    8990386.    9074879.    9158908.
   9066441.    9150331.    9234075.
       900         899         899         903         900         900         901         899         899           0
       913         915         915           0         912           0         913         913         915         915
       915         899         913         915         915         912         912         913         913         913
       915         915         915

                                    *****  INPUT OF YEAR 2012  *****

INDEX =     1
OBJECTIVE FUNCTION STATE  959 TO  993
   9264106.    9258933.    9326443.    9388994.    9379068.    9446786.    9389297.    9441310.    9508940.    9132683.
   9259863.    9268166.    9322199.    9323731.    9391443.    9318527.    9386010.    9442541.    9380706.    9448249.
   9504696.    9141917.          0.          0.    9269096.    9277401.    9331429.    9332968.    9400673.    9327762.
   9395240.    9451770.    9389937.    9457479.    9513927.
       927         927         927         936         927         927         944         927         927         947
       947         927         947         953         953         953         953         947         953         953
       947         947           0           0         947         927         947         953         953         953
       953         947         953         953         947

                                    *****  INPUT OF YEAR 2013  *****

INDEX =     1
OBJECTIVE FUNCTION STATE  994 TO 1032
         0.    9602703.    9579724.    9632429.          0.    9695188.          0.    9688049.    9741000.    9686491.
   9717778.    9769989.    9494615.    9609864.    9586885.    9639587.    9649619.    9702349.    9645086.    9695209.
   9748158.    9693650.    9724938.    9777148.    9501777.************    9564421.    9617025.    9571242.    9594047.
   9646747.    9656782.    9709551.    9652250.    9702408.    9755317.    9700849.    9732096.    9784309.
         0         969         968         968           0         972           0         969         969         974
       968         968         968         969         968         968         972         972         974         969
       969         974         968         968         968           0         969         969         960         968
       968         972         972         974         969         969         974         968         968

                                    *****  INPUT OF YEAR 2014  *****

INDEX =     1
OBJECTIVE FUNCTION STATE 1033 TO 1079
   9896041.          0.          0.    9988510.          0.    9969050.    9992310.   10011107.   10050370.   10007083.
  10046142.   10085052.   10043309.   10065327.   10087457.    9901284.    9958792.    9943880.    9982782.    9951439.
   9974293.    9997550.   10016350.   10055612.   10012326.   10040412.   10079321.   10047710.   10070568.   10092699.
   9891657.    9883498.    9906527.    9964047.    9949136.    9988024.    9956697.    9979536.   10002792.   10021595.
  10060787.   10017570.   10045587.   10084561.   10052884.   10075809.   10097942.
      1006           0           0        1012           0         996        1006        1010        1010        1012
      1012        1012        1012         996        1006        1006        1010        1020        1020        1022
       996        1006        1010        1010        1012        1020        1020        1022         996        1006
      1020         996        1006        1010        1020        1020        1022         996        1006        1010
      1010        1012        1020        1020        1022         996        1006

                                    *****  INPUT OF YEAR 2015  *****

INDEX =     1
OBJECTIVE FUNCTION STATE 1080 TO 1130
  10209995.          0.          0.   10259885.          0.   10241532.   10267579.   10280445.   10306834.   10265945.
  10292188.   10317630.   10290450.   10299106.   10324572.          0.          0.   10213462.   10251726.   10229699.
  10255782.   10222194.   10244999.   10271044.          0.   10283920.   10310299.   10269419.   10288085.   10313526.
  10280309.   10302572.   10328038.   10201574.   10191151.   10217004.   10255193.   10233165.   10259248.   10225661.
  10248465.   10274509.   10268853.   10287383.   10313753.   10272881.   10291111.   10316990.   10283299.   10306035.
  10331505.
      1033           0           0        1050           0        1033        1033        1049        1049        1050
      1050        1050        1050        1033        1033           0           0        1033        1049        1063
      1063        1064        1033        1033           0        1049        1049        1050        1063        1063
      1064        1033        1033        1063        1033        1033        1049        1063        1063        1064
      1033        1033        1040        1049        1049        1050        1063        1063        1064        1033
      1033

                                    *****  INPUT OF YEAR 2016  *****

INDEX =     1
OBJECTIVE FUNCTION STATE 1131 TO 1166
         0.   10498316.   10512290.   10535232.   10513520.   10527768.   10506495.   10520541.   10534305.          0.
  10500371.   10490563.   10504538.          0.   10537016.          0.   10515305.   10522932.   10508282.   10512786.
  10526552.   10484594.          0.          0.   10502194.          0.   10492387.   10506357.   10527658.   10538839.
  10517762.   10517128.   10524753.   10510105.   10514608.   10528372.
         0        1101        1101        1098        1099        1099        1101        1101        1101           0
      1113        1114        1114           0        1098           0        1099        1113        1101        1114
      1114        1114           0           0        1113           0        1114        1114        1122        1098
      1089        1099        1113        1101        1114        1114
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Figure 8.4 (page 3) DYNPRO Printout (partial) for the First Variable Expansion Plan of the Sample Problem (DYNPRO Run-2). List of Objective Functions (cont.).

SOLUTION # 1 VARIABLE ALTERNATIVES BY YEAR

YEAR	CONCST	SALVAL	OPCOST	ENSCST	TOTAL	OBJ.FUN. (CUMM.)	LOLP %	VCOA	VFOL	VNUC	V-GT	HYD1	HYD2
	------ PRESENT WORTH COST OF THE YEAR (K$) ------												
2016	143429	131442	281443	13	293443	10484594	0.100	8+	5+	1-	13+	3	4
2015	51492	42142	285746	15	295110	10191151	0.105	7	5+	1-	12+	3	4
2014	479644	371033	292800	16	401426	9896041	0.105	7+	5+	1-	9-	3	4
2013	180680	126661	307895	18	361932	9494615	0.110	7+	5+	0	9	3	4
2012	156648	101093	311816	26	367397	9132683	0.136	6+	5+	0	8	3	4
2011	234096	135157	314960	13	413912	8765286	0.089	6+	4+	0	8+	3	4
2010	404770	217578	321188	12	508393	8351374	0.089	5+	4+	0	6	3	4
2009	251805	119194	319220	9	451839	7842981	0.074	3-	4+	0	6+	3	4
2008	236062	105074	322961	15	453964	7391142	0.083	3	3+	0	4	3	4+
2007	842278	368168	320873	14	794997	6937178	0.065	2	3+	0	4	3+	4+
2006	692783	274579	346741	18	764963	6142181	0.098	1	3+	0	4	3+	3
2005	305522	97367	358954	18	567127	5377218	0.104	0	3+	0	4+	2-	2-
2004	289944	86384	358774	12	562347	4810091	0.077	0	2+	0	3	2	2+
2003	525790	171458	362625	6	716963	4247744	0.046	0	1	0	3	2+	2+
2002	203055	60985	400472	13	542555	3530781	0.072	0	1	0	3+	2+	1+
2001	639370	153861	417005	1	902515	2988226	0.027	0	1	0	3+	1+	1+
2000	249842	53567	436058	16	632348	2085711	0.090	0	0	0	3+	1+	0
1999	58802	2674	452105	15	508248	1453363	0.094	0	0	0	2	0	0
1998	63507	1388	455816	9	517944	945115	0.066	0	0	0	1	0	0
1997	0	0	427158	13	427171	427171	0.067	0	0	0	0	0	0

Figure 8.4 (page 4) DYNPRO Printout (partial) for the First Variable Expansion Plan of the Sample Problem (DYNPRO Run-2). "Best" Solution for the Run.

SOLUTION # 1 VARIABLE ALTERNATIVES BY YEAR

YEAR	PRESENT WORTH COST OF THE YEAR (K$)					OBJ.FUN.	LOLP	VCOA		VNUC		HYD1	
	CONCST	SALVAL	OPCOST	ENSCST	TOTAL	(CUMM.)	%		VFOL		V-GT		HYD2
2016	411217	377763	261337	16	294807	10170170	0.113	9	2+	2	14+	3+	4+
2015	137740	115924	280115	21	301953	9875363	0.132	9	2+	1	14+	3+	4+
2014	479644	371034	283261	12	391883	9573410	0.096	8	2+	1	14+	3+	4+
2013	160660	113395	302550	14	349829	9181527	0.099	8	2+	0	14+	3+	4+
2012	195134	124804	305787	9	376126	8831698	0.074	7	2+	0	14+	3+	4+
2011	210745	122801	308494	10	396448	8455572	0.075	6	2+	0	13	3+	4+
2010	385099	207005	313639	5	491738	8059124	0.042	5	2+	0	12	3+	4+
2009	273050	129594	308711	3	452170	7567386	0.032	4	1	0	12	3+	4+
2008	236062	105074	311759	3	442749	7115216	0.033	3	1	0	10	3+	4+
2007	842278	368169	307537	3	781649	6672467	0.023	2	1	0	10	3+	4+
2006	484560	182940	336007	3	637630	5890818	0.034	1	1	0	10	3+	3
2005	373102	126418	336006	3	582693	5253188	0.023	0	1	0	9	2	3+
2004	254126	77221	355571	6	532483	4670495	0.042	0	1	0	6	2	2+
2003	525790	171458	374471	6	728809	4138012	0.041	0	1	0	4	1	2+
2002	338191	81061	413013	8	670150	3409203	0.064	0	1	0	4	1	1+
2001	324537	80752	409546	11	653342	2739053	0.064	0	0	0	4	1+	1+
2000	249842	53567	436058	16	632348	2085711	0.090	0	0	0	3	1+	0
1999	58802	2674	452105	15	508248	1453363	0.094	0	0	0	2	0	0
1998	63507	1388	455816	9	517944	945115	0.066	0	0	0	1	0	0
1997	0	0	427158	13	427171	427171	0.067	0	0	0	0	0	0

Figure 8.5 DYNPRO Printout (partial) for the Last Variable Expansion Plan of the Sample Problem (DYNPRO Run-3). Optimum Solution

Ten CONGEN, MERSIM, DYNPRO (RENAME) runs were required to achieve a limit free (optimum) solution for the sample problem. Figure 8.5 shows part of the printout for the last DYNPRO run (DYNPRO Run-3) of this series. In this run, the five "best" solutions were called for but only the report on the optimal solution (solution #1) for the sample problem is shown in this figure.

Table 8.2 summarizes the configurations for year 2016 of the five best solutions, as well as for the fixed expansion schedule (DYNPRO Run-1) and for the first variable expansion schedule (DYNPRO Run-2) described previously. Table 8.2 also compares the objective functions of each solution. It is seen that the fifth best solution (DYNPRO Run-3) increased the value of the objective function by only about 0.21% whereas the fixed expansion schedule resulted in an objective function 6.06% higher than that of the optimal solution. Also, comparing the objective function of the best solution for each of the variable expansion DYNPRO runs illustrated in this manual, it can be seen that the dynamic optimization process reduced this value by 3.09%. [Note: The objective function stands for present-worth of total values expansion costs. Thus, these apparently small differences in the objective function values can represent a large difference in terms of the annual expenditures associated to each solution.]

Table 8.2

Variation of Objective Function for the Various DYNPRO Runs of CASE93

DYNPRO Run	Solution	Configuration for Year 2016: Number of Units or Projects of Each Expansion Candidate						O.F. Cum. Value $x10^6	Change %
		VCOA	VFOL	VNUC	V-GT	HYD1	HYD2		
3	1	9	2+	2	14+	3+	4+	10170.17	-
	2	10+	1	1	14+	3+	3+	10174.67	0.0442
	3	10+	2+	2	14+	3+	4+	10184.92	0.1450
	4	8-	2+	3+	14+	3+	4+	10187.62	0.1716
	5	9	1	3+	14+	3+	4+	10191.96	0.2143
2[1]	1	8+	5+	1-	13+	3	4	10484.59	3.092
1[2]	1	8	1	5	8	3	4	10786.08	6.056

[1] Only the first solution for this run is reported here.
[2] Only one solution was obtained for this run.

Regarding the report of the optimal solution in Fig. 8.5, it can be seen that this still contains some messages concerning the constraints used in the respective CONGEN run (CONGEN Run-3). Some messages apply to the number of projects of the hydro plant types A and B; for hydro plant type A (HYD1) in years 2000 and 2001, and from 2006 up to 2016, and for type B (HYD2) in years 2001 to 2016 (except 2006). In 2001, for example, DYNPRO Run-3 reports that more than 1 project of each hydro plant type may lead to a better solution so that a new CONGEN, MERSIM, DYNPRO iteration should be carried out opening the respective tunnel widths in the CONGEN run. However, the constraints used in CONGEN Run-3 (only 0 and 1 project of plants HYD1 and HYD2 were permitted this year) cannot be relaxed any longer since the second project of each plant type is only available for expansion in subsequent years of the study period (2002 for HYD1 and 2003 for HYD2).

A similar situation may arise for the number of sets of the thermal candidates included in the optimum solution. This will be the case when the number of units of a certain candidate cannot exceed a given limit even if the DYNPRO reports (+) messages for this plant type. For example, due to constraints in the total exploitable resources of the associated fuel, or because of energy policies of the country or other considerations. This is the case for expansion candidate number 2 (VFOL) and number 4 (V-GT) for which additional constraints were set at the beginning of the optimization runs. In this case, the optimal solution for DYNPRO Run-3 reports both plants with a plus signs. However, relaxing these constraints is no longer possible in view of the rules described in Section 6.5.2.

Messages for the minimum number of sets or projects (-) may also appear in the optimal solution but the dynamic optimization process can be stopped. This occurs when the minimum number of sets or projects of the respective plant cannot be reduced any further owing to commitments of plant additions for the particular system.

Alternatively, the above messages can be eliminated from the DYNPRO printout by simply executing a new WASP iteration (executing Modules 4 to 6 in the same order). In the new CONGEN run, the expansion schedule is made "fixed" for the plants which are still acting as a constraint on the optimum solution. This is achieved by specifying in type-2 cards of the CONGEN run, the same number of sets or projects contained in the optimal solution for the respective plants in each applicable year and setting the corresponding tunnel widths (cards type-3) to zero. For example, if the messages for the optimal solution of the sample problem (Fig. 8.5) were to be eliminated from the DYNPRO report, a new CONGEN, MERSIM, DYNPRO (RENAME) iteration should be executed. In this case, the new CONGEN run would be carried out using card types 2 and 3 in the applicable years. For plants HYD1 and HYD2, the card type-2 for the year would include the respective number shown on Fig. 8.5, and the card type-3 would give zero tunnel widths for these two plants. This iteration, however, was not executed. This feature of WASP to reproduce an optimal solution without messages is very similar to the execution of a fixed expansion plan as described for Run-1 of CONGEN, MERSIM and DYNPRO of the sample problem.

It should be stressed that regardless of the expansion rules and energy policies provided by the regulating authorities, it is always convenient to run an overall optimization of WASP for the case study, where only the physical constraints imposed by the construction periods of thermal and hydro expansion candidates, or the total amount of domestic fuel available for expansion, are respected. In such a run, additional constraints related to the availability of imported fuels should be waived. This will permit to provide a feedback as to how expensive the chosen "reference" optimal solution is when compared to the overall "unconstrained" optimal solution.

This "unconstrained" optimal solution was carried out for the sample problem and took four additional iterations of Modules 4 to 6 (including RENAME). The results of this solution are illustrated in Table 8.3.

Table 8.3

Comparison of Objective Function for Reference and Unconstrained Solutions

DYNPRO Run	Solution	Configuration for Year 2016: Number of Units or Projects of Each Expansion Candidate						O.F. Cum. Value $\$ x10^6$	Change %
		VCOA	VFOL	VNUC	V-GT	HYD1	HYD2		
3	1	9	2+	2	14+	3+	4+	10170.17	-
4[1]	1	9	1	1	21	3+	4+	10043.95	-1.2411

8.7 Special Remarks on the DYNPRO Capabilities

As mentioned in the introduction of this Chapter, DYNPRO is designed to cost each alternative policy for system expansion based on a performance criterion or an objective function. This objective function is evaluated as the algebraic sum of the present-worth values of all costs associated with each configuration integrating a given expansion policy through the study period. Present-worth (discounting) calculations are carried out using the appropriate discount rates given by the user and certain assumptions for the cash flows on the various expenditures. Escalation of costs can be also applied as the study progresses and using the appropriate escalation ratios specified by the user. These calculations also require the definition by the user of base years for present-worth (JHRPWB) and escalation (JHRFUL). These concepts were discussed briefly in Section 1.2, and are treated in more detail in Section D.12 of Appendix D which describes the dynamic programming algorithm.

It should be noted that the main assumptions behind the definitions of the reference years (JHRPWB, JHRFUL) to be used as input data for a DYNPRO run are the following:

- All cost information (capital or operating) is supposed to be given in monetary units of the base year for escalation (JHRFUL). Thus, no escalation effect is applied for the years up to JHRFUL (even if erroneously specified by the user) and the escalation effect in any year after JHRFUL takes into account the effect of any escalation in the preceding years combined with that of the year being considered.

- The base year simply represents a reference year to which all cash flows associated with an expansion policy are discounted supposing a certain occurrence of the expenditure flow and using appropriate discount factors. The discount factor for a given expenditure combines the effect of all discount rates specified for the period of time from JHRPWB up to the moment the expenditure is assumed to occur.

Based on the above assumptions, if discount rates and escalation ratios are kept constant for all years of the study, all calculations performed by DYNPRO are correct for all possible cases of definition of JHRPWB and JHRFUL (see Appendix D Section D.12).

On the other hand, and according to the WASP capabilities to handle input information summarized in Table 1.1, DYNPRO can handle different discount rates for type of cost component (local or foreign), for type of expenditure (capital or operating), and for type of plant (for capital costs for each expansion candidate or for operating costs for each "fuel" type, including the cost of energy not served as on "fuel" type). Similarly, different escalation ratios can be specified for type of cost component, for type of expenditure and for type of plant. Additionally, these discount rates and escalation ratios can be varied from one year to another over the study period. The idea behind these dimensions is to permit the user executing a broad range of sensitivity studies for his/her case, once the optimal solution has been found. Appendix D discusses how the escalation and discounting effects are calculated by DYNPRO for the case of varying escalation ratios and discount rates over the study period, depending on the possible cases of definition of the relative positions of the base years (JHRPWB and JHRFUL) with respect to the first year of study.

According to the description in Appendix D, it can be concluded that accuracy of the DYNPRO results in the case of varying discount rates over the study period is only guaranteed if JHRPWB is defined less than or equal to the first year of study and the input data on discount rates for the respective operating costs are determined by the user from:

$$1 + do_i' = (1 + do_{i-1})^{-0.5} \cdot (1 + do_i)^{-0.5}$$

where:

do_i' = discount rate to be used as input data for year i in DYNPRO,
do_i = actual discount rate applicable to year i,
do_{i-1} = actual discount rate applicable to year i-1.

No restriction exists for the cost escalation calculations performed by DYNPRO for the case of varying escalation ratios over the study period. The user is referred to the description of the dynamic programming algorithm in Section D.12 of Appendix D for further details.

CHAPTER 9

EXECUTION OF REPROBAT

REPROBAT is Module 7 of WASP-III Plus and has the purpose of presenting either total or partial results of an electric power system planning study in a concise and easily read form. Partial results for the first three WASP modules can also be obtained as soon as any of them has been run successfully without the need of having run CONGEN, MERSIM, and DYNPRO (see Chapter 11). Once all previous six modules of WASP have been run successfully, a full REPROBAT report can be obtained. Partial reports can also be obtained by deleting the portions not required. For example, data on cash flow of construction costs may be requested for only a part of the study period. Also one complete module of WASP could be dropped from the report as explained in Section 9.2.

If a complete report of the optimal solution (or eventually of the best solution found by the latest DYNPRO run) is to be printed by REPROBAT, it is necessary to execute first a resimulation (REMERSIM) of this solution as described in Section 7.6. REPROBAT can also be used to produce a report on a fixed expansion schedule and in this case there is no need to execute the resimulation run, provided that the SIMULNEW file created by the respective MERSIM run contains only the same configurations (one per year) as the fixed expansion plan. In this case, however, optional reports on fuel stock and consumption by thermal plant type, etc., could not be produced by REPROBAT (see type-4 card in Table 9.1)

The format of the report printed by REPROBAT is such that the printout can be cut to suit a European and American Standard report size.

9.1 Control Cards

The control cards for running REPROBAT are listed in Fig. 2.3. The first three cards identify the module and its location in the computer system, and the input data file to be used in the run. The next card specifies the normal printout file. The 5th card is the second printout file which is used only for debugging purposes and is therefore dummied in normal runs.

Control cards 6 to 11 define in sequence the files created by other WASP modules, i.e.: OSDYNDAT, FIXPLANT, VARPLANT, LOADDUCU, EXPANALT and SIMULRSM. In the case of a complete report of a fixed expansion plan, SIMULNEW would be used in place of SIMULRSM. Control cards 12 to 19 define four temporary auxiliary files which store information to be called for by the data cards. Each of these files is defined in two cards (the comma in the first card means that the next one is a continuation card). Card 20 specifies the SIMULREP file (produced by the last REMERSIM run and which will be used to store some results from the present run) and card 21 identifies the SIMGRAPH file (used by REMERSIM and REPROBAT to store some results for graphical display of the results).

9.2 Data Cards

REPROBAT can use up to 10 types of data cards as shown and described in Table 9.1. In normal runs when the entire printout option is desired, cards type-2 and type-3 are omitted.

The first data card is the type-X card giving the title of the study (centered to columns 30-31 of the card) and in column 63 a symbol which will be used by REPROBAT to fill the empty spaces of the matrices in some of the Tables included in the report. This is to be selected by the user for his/her convenience from symbols such as: star (*); hyphen (-); apostrophe ('); etc. A dot (.) is recommended. If no symbol appears in card type-X, the empty spaces in the Tables are simply left blank (default value).

A type-A data card gives, in the first two fields, the initial and last year of the study, which should be the same values used in FIXSYS. The next two fields of this card are used to specify the first and last year of the planning period, which must be embedded within the study period. This permits specifying a planning period covering only a few important years fewer than the total number of years of the study period.

Cards type-1 with INDEX = 1 to 8 are used to control the input data flow depending on the INDEX number. A type-1 INDEX = 1 card tells the computer that all input data have been completed and that execution of REPROBAT can begin. A type-1 INDEX = 2 (3 or 4) indicates that a card type-2 (-3 or -4) must be read next. Similarly, a type-1 INDEX = 5 tells the computer that data cards type-5a and -5b follow, and a type-1 INDEX = 6 that cards type-6 (up to 50) are to be read next. Finally groups of one type-1 INDEX = 7 (or 8) card and the respective type-7a to -7g (or -8a to -8d) cards are used following the sequence described in Table 9.1. Similar to all other WASP modules, it is important to use the proper sequence for the module to run, otherwise it may lead to wrong calculations for the run or stop of its execution (see Section B.7 of Appendix B).

A type-2 card is used if a partial report is asked for, i.e. if one or more modules are to be dropped from the report or if only reports on cash flows of operating and/or construction costs are needed. This type-2 card specifies eight output options controlling the logic of execution and the output. All options are set to "1" by default. If reset to "0", no output for the corresponding part is produced. For the convenience of the user, it is recommended to set the value equal to the number of the option as indicated below. The eight output options are:

Option #1: 0 (i.e. "1") load system description (LOADSY)

2: 0 (i.e. "2") fixed system description (FIXSYS)

3: 0 (i.e. "3") variable system description (VARSYS)

4: 0 (i.e. "4") constraints in the configurations generator module (CONGEN)

5: 0 (i.e. "5") optimum solution (DYNPRO)

6: 0 (i.e. "6") economic parameters and constraints (DYNPRO)

7: 0 (i.e. "7") expected costs of operation (MERSIM)

8: 0 (i.e. "8") cash flow of construction and fuel inventory costs

It should be noted that <u>all eight options have to be defined</u> if a card type-2 is used (blanks in the corresponding field are interpreted by the computer as zeroes, thus no output is produced). For example, if a partial report of the three first modules of WASP is required before executing modules 4 to 6 of WASP, the type-2 card for the REPROBAT run should contain a "1" in column 4, "2" in column 8 and "3" in column 12; columns 16, 20, 24, 28 and 32 being "0" (or left blank).

Table 9.1 (page 1) Types of data cards used in REPROBAT

Card type	Columns	Format[1]	Fortran name	Information
X	1-60	A	IDENT (COUNTR)	Title of the study which has to be centered in the given space (columns 30-31 are the center columns of the field).
	63	A	LATICE	One character to pre-format empty spaces of matrices in the tables of the report. (Default value is blank; recommended value a dot [.]).
A	1-5	I	IYSTUD	Initial year of study (same as in FIXSYS).
	6-10	I	LYSTUD	Last year of study (same as in FIXSYS).
	11-15	I	IYPLAN	First year of planning period.
	16-20	I	LYPLAN	Last year of planning period. Note:The planning period must be embedded in the study period or be equal to it (default value). If YPLAN = 0 or blank, the planning period is made equal to the study period.
1	1-4	I	INDEX	Index number from 1 to 8 telling the computer what to do next. An INDEX = 1 means that input data have been completed and that the program can start execution. Other INDEX values indicate that cards of type equal to the INDEX number follows; i.e.: INDEX = 2, Card type-2 follows. INDEX = 3, Card type-3 follows. INDEX = 4, Card type-4 follows[2]. INDEX = 5, Card type-5a and card type-5b follow, etc.
2	1-4, 5-8, 9-12, 13-16, 17-20, etc.	I I I I I	IOPLST	Eight printout options. Default value is "1" in all cases. To suppress printout of any part of the report, set to zero ("0") the corresponding field. In sequence, the eight options are: (1) load system description (LOADSY) (2) fixed system description (FIXSYS) (3) variable system description (VARSYS) (4) constraints in configuration generator module (CONGEN) (5)[3] optimum solution[4] (DYNPRO) (6) economic parameters and additional constraints (DYNPRO) (7) expected cost of operation (MERSIM) (8)[3] cash flow of construction and fuel inventory costs Note: All eight options must be specified if data card type-2 is used.

Table 9.1 (page 2) Types of data cards used in REPROBAT

Card type	Columns	Format[1]	Fortran name	Information
3	1-4, 5-8, 9-12, etc.	I I I	IOPCON	Three sub-options to option #8 (see type-2 card above). Default value = 1 in all cases. By setting it to zero ("0"), the following parts of the printout will be suppressed: (1) Detailed output of cash flows by year and plant (2) Calculation and output of IDC (3) Listing of capital and IDC costs combined <u>Note</u>: All three sub-options must be specified if data card type-3 is used.
4[2]	1-4	I	IOPSIM	Sub-option to option #5 (see type-2 card above) for reports on fuel stock and consumption of thermal plants by fuel type, generation by plant type, by hydro condition and weighted by the probability of the hydro conditions. If: = 0 no report (default) = 1 only weighted values are reported (and not by hydro condition) = 2 maximum output
5a	1	A	NAM	An "N" indicating the type of card used to specify the contents of the footnote of the cover page of the report (one card type-5b must be used as well).
	5-24	A	NDAT	Date of the report (any set of 20 characters).
	25-60	A	NAME	Text 1 (name of the author(s) or any other text. Up to 36 characters to be written after the header "STUDY CARRIED BY:").
5b	1	A	NAM	An "N" (see card type-5a).
	5-64	A	COUNTR	Text 2 (up to 60 characters to be written on the report below Text 1 of card type-5a). Start in column 29 if this text is to be aligned with Text 1.
6	1	A	LEG	An "L" indicating the type of card.
	5-64	A	COUNTR	Text 3 (up to 60 characters per card). Up to 50 type-6 cards may be used to provide additional explanatory information by the author.

Table 9.1 (page 3) Types of data cards used in REPROBAT

Card type	Columns	Format[1]	Fortran name	Information
7a[5]	1-4	A	NAMAD	Name of thermal plant unit or hydro project of the FIXSYS plant to be considered in the REPROBAT report.
	6-7	I	NTYP	Plant Fuel type (thermal: 0-9, hydro: 10,11).
	10	I	IFC	Key to control input of fuel inventory data for this plant. If = 1 the fuel inventory must be provided in the type-7d and -7e cards. If = 0 (or blank) these two cards will not be required. Leave blank for hydro.
	12-15	I	IY	First year of service of the plant.
	16-20	I	NY	Number of years of construction (maximum = 10).
7b[6]	1-10	F	TCTRL	Domestic total pure construction cost (million $).
	11-16 17-22 . 65-70	F F F	X1	Annual distribution of domestic pure construction cost (%) (As many entries as years of construction - NY).
7c[6]	1-10	F	TCTRF	Foreign total pure construction cost (million $).
	11-16 17-22 . 65-70	F F F	X2	Annual distribution of foreign pure construction cost (%) (As many entries as years of construction - NY).
7d[7]	1-10	F	TSTKL	Domestic total fuel inventory cost (million $).
	11-16 17-22	F F	X3	Annual distribution of domestic fuel inventory cost (%). (Only two entries).
7e[7]	1-10	F	TSTKF	Foreign total fuel inventory cost (million $).
	11-16 17-22	F F	X4	Annual distribution of foreign fuel inventory cost (%). (Only two entries).
7f[6]	1-10	F	TXIDL	Domestic total interest during construction (million $).
	11-16 . 65-70	F . F	X5	Annual distribution of domestic interest during construction (%) (As many entries as years of construction - NY).

Table 9.1 (Page 4) Types of data cards used in REPROBAT

Card type	Columns	Format[1]	Fortran name	Information
7g[8]	1-10	F	TXIDF	Foreign total interest during construction (million $).
	11-16 . 65-70	F . F	X6	Annual distribution of foreign interest during construction (%) (As many entries as years of construction - NY).
8a[8]	1-4	A	NAMP	Thermal plant name or hydro plant type name (has to be equal to VARSYS name).
	6-9	A	NAMH	Hydro project name (must be equal to VARSYS name). Leave blank for thermal.
	10	I	IFC	Key to control input of fuel inventory data for this plant. If = 1 the fuel inventory must be provided in the type-8c and -8d cards. If = 0 (or blank) these two cards will not be required. Leave blank for hydro.
	11-16 . 65-70	F . F	PERCCL	Annual distribution of domestic pure construction costs (%) (as many entries as years of construction of the plant or project)
8b[8]	11-16 . 65-70	F . F	PERCCF	Annual distribution of foreign pure construction costs (%) (as many entries as years of construction of the plant or project).
8c[9]	11-16 17-22	F F	PERCFL	Annual distribution of domestic fuel inventory cost (%) (only 2 entries).
8d[9]	11-16 17-22	F F	PERCFF	Annual distribution of foreign fuel inventory cost (%) (only 2 entries).

Notes to Table 9.1

1 See Section 2.5 for Format description.

2 A type-1 INDEX = 4 and a type-4 cards can be used only after a REMERSIM run has been made for the best solution being reported by DYNPRO. For the related output tables to be correct, the preceding run of REMERSIM must be executed using printout option ≥ 1 for all years of study. See Fig. 9.2 and description.

3 Sub-options are also allowed (see card type 3 and 4).

4 If the user is running Fixed Expansion plans and a REPROBAT of the solution reported by DYNPRO is required, it is necessary either to run REMERSIM first, or to change the REPROBAT JCL shown in Figure 2.3 in order to replace specification of file 15 (SIMULNEW replaces SIMULRSM).

5 The set of data cards type-7 can be repeated up to 20 times. These are used to include in the REPROBAT report the annual investment of some committed units specified in FIXSYS.

6 Each card type-7b, 7c, 7f and 7g has as many entries as years of construction of the plant (NY).

7 Data card types 7d and 7e require only two entries. They are used only if IFC = 1 in the preceding type-7a card. No cards 7d or 7e required for hydro!

8 This set of cards is repeated for each thermal candidate and/or hydro project for which a distribution of investment costs (different from the S-curve approach) is defined by the user.

9 Data card types 8c and 8d require only two entries. They are used only if IFC = 1 in the preceding type-8a card. No cards 8c or 8d required for hydro!

A type-3 card specifies three sub-options to option #8 (see type-2 card above) controlling the output of cash flows. They are all set to a value =1 by default (If type-7 cards are used, option #8 > 0 and its suboptions must be greater than 0). For the convenience of the user it is recommended to set the values equal to the number of the option (see below). All three sub-options have to be defined if a type-3 card is used. The logic and output of the program for these three sub-options is as follows:

- Cash flow of Construction Costs:

IOPCON(1) > 0 (i.e. "1") cash flow calculated and printed.

= 0 --------> no report.

- Cash flow of Interest During Construction (IDC)

IOPCON(2) > 0 (i.e. "2") and IOPCON(1) > 0

--------> cash flow calculated & printed and summary report on investment costs is printed with IDC columns.

= 0 --------> no report and if IOPCON(1)>0, summary report of investment costs is printed without IDC columns.

- Cash flow of Construction + IDC Costs

IOPCON(3) > 0 (i.e. "3") and IOPCON(1) & (2) > 0 report printed.

= 0 --------> no report.

- Cash flow of Fuel Inventory (investment) Cost

IOPCON(1) > 0 --------> cash flow calculated and printed.

= 0 --------> no report.

A type-1 INDEX=4 card followed by a type-4 card are used to specify the option for reporting detailed information about the simulation of system operation for the optimal solution. This option can only be used if a resimulation (REMERSIM) of the best solution found by DYNPRO (or eventually the optimal solution) has been carried out prior to the REPROBAT run. The following alternatives are available, depending on the value of this sub-option, which if:

Sub-option: = 2 Maximum output: the report includes summary tables of the fuel stock and consumption by thermal fuel type, and of the generation by plant type both by hydrocondition and weighted by the probabilities of the hydroconditions.

= 1 Same as =2 above, but no reports per hydrocondition.

= 0 No report printed (default value).

The type-5a and -5b data cards are all identified by one "N" in column 1 of the card. The information given in these data cards is used by REPROBAT to produce the cover page of the report. If a card type-1 INDEX=5 is used, one card type-5a and one card type-5b must also be used, even if the titles in any of these two cards are to be left blank. If no card type-1 INDEX=5 is used, REPROBAT will set these titles to blank (default values).

Data cards type-6 (identified by one "L" in column 1 of the card) are used if additional information is to be printed in the report. A maximum of 50 cards type-6 can be used in a REPROBAT run. All this additional information is printed in a separate page of the report (see Figure 9.2).

The remaining data card types (7 and 8) in the REPROBAT input data can be used as follows. Groups of type-7 cards are included in the input data to specify which FIXSYS plants must be considered in the cash flow tables of capital costs of the REPROBAT report. The necessary data for these plants are also specified in these card types. Up to 20 sets of type-7 cards can be used in a run of the module. The first card in each set must be a type-1 INDEX=7 accompanied by the following sequence of data cards:

Card type-7a: to specify plant name, fuel type, the control key for fuel inventory cost data (IFC), first year of service and construction period.

Card type-7b: total domestic component of the "pure" construction costs and the annual distribution (%) of this total for as many years as the length of the construction period, including fraction of years (e.g. if the plant takes 52 months to be built, the annual distribution data must cover 5 years).

Card type-7c: same as type-7b above, but for the foreign component of these costs.

Card type-7d: total domestic component of the fuel inventory costs and the annual distribution (%) of these costs. Only two entries are required since the program assumes that these costs are always distributed over 18 months. This card is not needed for hydro projects. In addition, this card is not needed if IFC=0 in the type-7a card of this set for any of the FIXSYS thermal plants.

Card type-7e: same as type-7e above, but for foreign component of these costs.

Card type-7f: total domestic component of interest during construction (IDC) and the annual distribution (%) of this total for as many years as the length of the construction period, including fraction of years.

Card type-7g: same as type-7f above, but for the foreign component of these costs.

Similarly, a type-1 INDEX=8 card can be used to specify for which expansion candidates (VARSYS plants) a distribution of capital investment cost versus time (different from the standard "S" curve used as default) will be defined in subsequent cards (type-8a through -8d). The sequence of these data card types is as follows:

Card type-8a: to specify plant name and plant type (for hydro projects), the control key for fuel inventory cost data (IFC), and the annual distribution (%) of domestic portion of pure construction cost (for as many years, including fractions, as the length of the construction period specified in DYNPRO for this expansion candidate or project).

Card type-8b: annual distribution (%) of the foreign portion of pure construction cost (as many entries as years of construction).

Card type-8c: annual distribution (%) of domestic fuel inventory cost (two entries are required since the program assumes that these costs are always distributed over 18 months). This card is not required for hydro projects, or if IFC=0 in the type-8a card for thermal expansion candidates.

Card type-8d: same as type-8c above but for the foreign component of these costs.

9.3 Input Data for the Sample Problem

After having found the optimum solution (in DYNPRO Run-3) of the sample problem and having executed the resimulation run described in Section 7.6, module REPROBAT was run in order to obtain a complete report on this optimum solution. Figure 9.1 shows the input data used for this run.

The first data line in Fig. 9.1 is a type-X card with the title of the study (kept the same for all runs of the sample problem), and the symbol to be used for filling the empty spaces of the matrices in all tables of the report. A dot (.) has been selected as symbol for this particular run.

Card number 2 is a type-A card specifying in the two first fields the length of the study period (1997-2016), and in the last two fields, that of the planning period. In this case, these fields have been left blank so that the program sets it equal to the study period.

The next input line is a type-1 INDEX=2 card followed by a type-2 card to specify which part of the output are required to be printed. In this case, all options have been given values greater than zero so that the full REPROBAT report is requested[1]. These are followed by a type-1 INDEX=3 and a type-3 cards to give the sub-option values for printing option #8 of the type-2 card. Again, all three suboptions have been given values greater than zero, asking for complete report[1].

The next type of input is a type-1 INDEX=5 card and is followed by the two type-5 (5a and 5b) cards giving the date and author(s) of the study.

The next input line is a type-1 INDEX=6 card and is followed by twenty six type-6 cards providing information supplied by the user. Up to 50 lines of a text can be used here. In this case, they are used to summarize the principal improvements incorporated in the WASP-III Plus program.

Next type of data in Fig. 9.1 correspond to two groups of one type-1 INDEX=7 card followed by several type-7 cards to specify for which committed plants (i.e., included as part of the FIXSYS description) the REPROBAT report must contain capital investment information in a tabular form. The respective cost information is provided in the type-7 cards of each group.

---

[1] Note that the specified value(s) is(are) equal to the default value(s) contained in the program (see Table 9.1); therefore, these two cards may have been omitted altogether, but they have been included here for demonstration purposes.

```
   CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL
 1997 2016
   2
   1   2   3   4   5   6   7   8
   3
   1   2   3
   4
   2
   5
N   DECEMBER 1993        NENP/PESS/IAEA
N                            CASE93 FOR WASP-3 PLUS
   6
L   **********************************************
L   *          NEW VERSION OF WASP III           *
L   *                 IAEA                       *
L   *                                            *
L   *                    DECEMBER 1993           *
L   **********************************************
L
L   STUDY PERIOD                1997 - 2016
L   PLANNING PERIOD             1997 - 2016
L
L
L   INCLUDES FOLLOWING IMPROVEMENTS WITH RESPECT TO WASP-3
L
L   - INCREASED NUMBER OF THERMAL FUEL TYPES (UP TO 10)
L
L   - TREATMENT OF FUEL LIMITATIONS FOR CERTAIN FUEL TYPES
L
L   - PRODUCTION OF A FILE FOR GRAPHICAL DISPLAY OF RESULTS
L
L   - STUDY WITH ESCALATION IN CONSTRUCTION COSTS
L
L   - NEW PROCESS TO DEFINE ANNUAL DISTRIBUTION OF CAPITAL COSTS
L
L   - NEW PROCESS TO CALCULATE ANNUAL IDC VALUES.
L
L   - REPORT OF CASH FLOW OF FIXSYS PLANTS CAPITAL COSTS
   7
FCO2  2  0 1999     6
    241.20     10     25     35     15     10      5
    645.60     10     25     35     15     10      5
     49.80     15     25     30     20      5      5
    133.40     15     25     30     20      5      5
   7
FHY5 11    1997     8
    784.40      3      4     10     15     30     19     15      4
    336.20      3      4     10     15     30     19     15      4
    230.60      4      5     13     15     25     20     15      3
     98.80      4      5     13     15     25     20     15      3
   8
VFOL       01.685 8.052 29.58844.75715.918
            1.687 8.113 29.55844.81915.823
   8
HYD2 VHY4 1.935 3.27549.709816.48229.68918.47516.3894.0448
          1.92153.27429.715816.48229.68918.48416.4014.0325
   1
```

Figure 9.1 Input Data for REPROBAT Run of the Optimal Solution for the Sample problem (CASE93)

The first of such groups specifies in the corresponding type-7a card that the REPROBAT report has to include the cash flows for one unit of coal 400 MW. (FCO2 in the first field) of fuel type 2 (second field). The zero in the third field of this card tells the computer that no fuel inventory cost information needs to be reported for this plant (and thus that no type-7d or 7e cards are expected to be read). The last two fields in this card identify the year of start of operation (1999) and the construction period (6 years) of this plant. The next line is one type-7b card to specify the total domestic pure construction cost of this plant and the percent annual distribution of these costs over the construction period.

This is followed by a corresponding type-7c card specifying similar information but concerning the foreign component of pure construction costs. The last two lines are a type-7f and a type-7g cards giving similar information to the two last previous ones but for the interest during construction cost. [Note: all annual distribution of costs must add up to 100%]

The second group is identified in the type-7a card as hydro project FHY5 (first field) of type code 11 (HYD2 in second field). The third field in the card is left blank since this (fuel inventory cost) is not applicable to hydro. The fourth field indicates that the plant started operation in year 1997 and the last one a total of 8 years of construction period. The type-7b, 7c, -7f and -7g cards that follow give cost information for this project in the same sequence as explained above for the FCO2 thermal unit.

Two groups of one type-1 INDEX=8 and two type-8 cards follow in sequence to specify expansion candidate plants or projects for which the distribution of investment expenditures against time are different to the standard "S" curve function used as default by the program. The first group corresponds to a thermal expansion candidate and is identified in the type-8a card as VFOL (first field of the card). The second field of the card is left blank since this applies only to hydro projects. The third field shows a 0 indicating that no information on fuel inventory costs are to be reported for this plant (and thus the type-8c and -8d cards are not used). The last ten fields in the card are used to give the annual percentage distribution of domestic pure construction costs of this plant. Since the construction period for this plant specified in DYNPRO is 4.5 years, five entries must be included in this card. The annual distribution of foreign pure construction costs is given in the subsequent type-8b card. Note that in each case, the annual distribution of costs must add up to 100%. In addition, it is not necessary to specify the total costs of the plant since this information is already available to the program (read from DYNPRO).

The group of type-8 cards for hydro project VHY4 of plant type HYD2 follow a similar sequence as indicated above.

The last data card is a type-1 INDEX=1 card indicating that all input data have been completed and that the module should be executed.

9.4 Printout of REPROBAT of the Optimal Solution

Figure 9.2 illustrates the REPROBAT printout for the sample problem obtained from executing this module using the data cards shown in Fig. 9.1. Except for the cover page of the report, all pages are automatically numbered by REPROBAT[2] as can be seen in Fig. 9.2. Page 1 of the figure is the *Cover Page* showing the title of study, the study and planning periods (specified in the type-A card), and the date and authors of the study (input data on type-5a and -5b cards). This page bears a message telling the user that cash flows on construction cost and fuel inventory cost are reported only for plants added during the defined planning period. Thus if the user requires cash flows over the entire study period, the planning period to be specified (on the type-A card) must be equal to the study period (alternatively the corresponding fields are left blank and the planning period is set to default).

[2] The report presented in Fig. 9.2 has been compressed as much as possible by deleting some empty lines with the view of reducing the size of this document. For the same reason, whenever possible, the pages of the figure contain more than one printout page.

Page 2 is the *Table of Contents*, which is actually printed last by REPROBAT since the numbering of pages depends on the size of the problem and which REPROBAT output options are selected for the run. Page 3 of Fig. 9.2 contains the additional *Information Supplied by the User* on data cards type-6.

Page 4 identifies the *Code Numbers and Code Names* associated with the twelve types of generating plant ("fuel" type) used in the study. Although the WASP modules 5 (MERSIM) and 6 (DYNPRO) automatically assign the code number of hydro plant type A (HYD1 in this case) to 5 and of hydro plant type B (HYD2 in this case) to 7, these numbers are not shown on this page since all information included here is simply retrieved by REPROBAT from the FIXPLANT file (see Section 4.3 for description of the fuel types used for CASE93). Fuel type limitations (if any) are also identified in this page of the report.

Page 5 gives a *Summary of the Annual Loads*, adding to the information read from the LOADDUCU file, the growth rates for the annual peak and minimum loads and for the annual energy demand.

Pages 6 to 10 give a *Summary Description of the Fixed System* for all years of the study period. Page 6 corresponds to the description of *Thermal Plants* in the original fixed system, i.e. those thermal plants in FIXSYS for the first year of study (1997). This information is the same as shown on the table of thermal plants of the FIXSYS printout for the respective year (see page 4 of Fig. 4.2), except for the last columns of the table which are not reproduced in the REPROBAT printout.

Page 7 summarizes the *Characteristics of the Composite Hydroelectric Plant Type A* (HYD1) in FIXSYS and page 8 those of the FIXSYS *Composite Hydro Plant Type B* (HYD2). These characteristics are given (for each period and hydrocondition) each time a change (addition or retirement) is made to the respective hydro plant. In the case of the HYD1 hydro plant, for example, the characteristics are given for years 1997, 2003 and 2008, i.e. for years when a change was made to this plant type in FIXSYS. It should be noted that the number of projects of this plant in years 2003 and 2008 is increased by one in spite of the fact that an actual retirement was made from this plant in each of these years (see discussion of the FIXSYS printout for out sample problem in Section 4.4). Similarly, the characteristics of the composite hydro plant type B (HYD2) are given for 1997 only since no addition to or retirement from this plant was made in FIXSYS after this year.

Page 9 of the printout shows the *Thermal Additions and Retirements* of the original fixed system. In this case one 200-MW coal-fired unit is retired from plant FC01 in years 1998, 2000, 2002 and 2006 respectively, and two such units are retired in 2010. Similarly, one 400-MW oil-fired unit is retired from plant FOIL in years 2005, 2007, 2009 and 2011; and two 100-MW gas turbine sets are retired from plant F-GT in year 1999 and one set is retired in each of the years 2002, 2004, 2007, 2010, 2012 and 2014.

Page 10 provides a *Summary of Installed Capacities of the Fixed System* (thermal + hydro) for each year of the study in which a change is made. When a year does not appear in the table or when the entries for thermal or hydro plant ("fuel") types are left blank, this means that the respective values for the year are the same as for the last previous year.

Pages 11 to 13 give a *Description of the Expansion Candidates* provided in the variable system: Page 11 for thermal candidates (same information as in page 4 of Fig. 5.2) and Pages 12 and 13 for the two composite hydro plant types. Here again only the characteristics of the respective composite hydro plant type (per period and hydrocondition) are given combining up to the first, the second, ... up to the last VARSYS hydro project of each type. Thus, Page 12 gives the characteristics of the composite hydro plant HYD1 in VARSYS up to 1 project, up to 2 and 3 projects, and Page 13 those of the HYD2 hydro plant up to 1, 2, 3 and 4 projects, composed. In each case the year reported shows the year of availability of the last project added.

Pages 14 and 15 give the *Constraints on Configurations Generated* that were imposed on the solution in Module 4 (CONGEN Run-3) for each year of study, showing also how many configurations were generated for each year and the total for all years (2157 in this case).

Page 16 summarizes the *Optimum Solution* found by Module 6 for this expansion problem. In this table, the configuration and the LOLP (as calculated by Modules 4 and 5 in this case) along with the capacity additions (from VARSYS) are given for year of the study[3]. Examining this optimal solution, it can be seen that nine 600-MW coal-fired units (VCOA) were added in the study period, two 600-MW oil-fired units (VFOL) were also chosen by DYNPRO as well as two 900-MW nuclear units (VNUC), fourteen 200-MW gas turbines sets (V-GT), three projects of the HYD1 hydro type and four of the HYD2 type. The annual average LOLP with maintenance (from Module 5) is shown to vary from 0.066% (in year 1997), down to 0.023% (2005, 2007), up to 0.132% in 2015.

For this optimal solution, page 17 gives a *Summary of Total Installed Capacities* for each year of the study and for each thermal fuel type combining all plants in FIXSYS plus the plants from VARSYS which are added by the optimal solution. Page 18 reports a similar information but focusing on a breakdown of the capacity by hydro plant type, while the thermal capacity is presented as total. This table also shows the system reserve capacity (% of installed capacity exceeding the annual peak demand) and the annual average LOLP with maintenance (from Module 5). The last three columns correspond to the amount of energy not served calculated by MERSIM for each hydrocondition defined (3 in this case).

Pages 19-20 report the *Fuel Stock of Thermal Plants* for the FIXSYS and Optimum Solution for each year of study. Two pages are needed to cover the ten thermal fuel types allowed by WASP-III Plus (even if less fuel types are used in the study). Note that these tables assume that fuel stocks are accumulated one year prior to start of operation of the associated thermal power plants and therefore, the table begins one year before the study period. Also, all years appear in this table even if the corresponding information is zero. Thus, entries in this table are given for all years from 1996 through 2015. Non-zero entries correspond to the year before the associated plant is added to the system (either in FIXSYS or from the candidate plants).

Pages 21 to 23 summarize the *Generation by Plant Type* for all FIXSYS plus Optimum Solution plants for each year of study and for each hydrocondition specified, while Page 24 lists the expected generation values (annual averages calculated from the values for each hydrocondition weighted by the hydrocondition probability). (Note: the output tables regarding Generation by fuel type illustrated here will show the appropriate entries only if the preceding REMERSIM run was executed specifying printout option ≥ 1 for all years of study. If IOPT in REMERSIM is set to zero for some years, these years will show zero entries in the tables. This is also applicable to the output tables on Fuel Consumption by type described below).

---

[3] The CONGEN runs executed for the case example did not request LOLP calculation (IOPTN=0). Consequently, the respective columns of the table in Page 16 are left blank.

The annual *Fuel Consumption of Thermal Plants by Fuel Type* of the combined FIXSYS plus Optimal Solution are reported in the subsequent pages, including in Pages 25-26 those for hydrocondition 1, Pages 27-28 for hydrocondition 2 and 29-30 for hydrocondition 3. Pages 31-32 report the annual expected values (weighted by the hydrocondition probabilities).

Text continues in page 194

```
                         SUMMARY REPORT
               ON A GENERATION EXPANSION PLAN FOR

         CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL

           PROCESSED BY THE WASP-III COMPUTER PROGRAM PACKAGE
                          OF THE IAEA

                          STUDY  PERIOD

                          1997 - 2016

                        PLANNING PERIOD

                          1997 - 2016

                       CONSTRUCTION COSTS
                         IN MILLION $
                    ARE REPORTED ONLY FOR
                     PLANTS COMMISSIONED
                  DURING THE PLANNING PERIOD.
                ALL OTHER INFORMATION IS GIVEN
                  FOR THE WHOLE STUDY PERIOD.




   DATE OF REPORT       :  DECEMBER 1993
   STUDY CARRIED OUT BY :  NENP/PESS/IAEA
                           CASE93 FOR WASP-3 PLUS
```

Figure 9.2 (page 1) REPROBAT Printout for the Optimal Solution of the Sample Problem. Cover Page

TABLE OF CONTENTS

Figure 9.2 (page 2) REPROBAT Printout for the Optimal Solution of the Sample Problem. Table of Contents

PAGE 3

INFORMATION SUPPLIED BY USER :

```
**********************************************
*          NEW VERSION OF WASP III           *
*                  IAEA                      *
*                                            *
*                      DECEMBER 1993         *
**********************************************
```

STUDY PERIOD 1997 - 2016
PLANNING PERIOD 1997 - 2016

INCLUDES FOLLOWING IMPROVEMENTS WITH RESPECT TO WASP-3

- INCREASED NUMBER OF THERMAL FUEL TYPES (UP TO 10)
- TREATMENT OF FUEL LIMITATIONS FOR CERTAIN FUEL TYPES
- PRODUCTION OF A FILE FOR GRAPHICAL DISPLAY OF RESULTS
- STUDY WITH ESCALATION IN CONSTRUCTION COSTS
- NEW PROCESS TO DEFINE ANNUAL DISTRIBUTION OF CAPITAL COSTS
- NEW PROCESS TO CALCULATE ANNUAL IDC VALUES.
- REPORT OF CASH FLOW OF FIXSYS PLANTS CAPITAL COSTS

PAGE 4

THIS IS A LIST OF THE DIFFERENT TYPES OF ELECTRIC POWER PLANTS
USED IN THE STUDY.
THE NUMERIC CODES ARE USED BY THE COMPUTER PROGRAMS

0	NUCL	NUCLEAR PLANTS
1	CO-1	COAL PLANTS DOM-FUEL
2	CO-2	COAL PLANTS IMP-FUEL
3	FOIL	OIL PLANTS IMP-FUEL
4	GTGO	GAS TURBINES GAS-OIL
5	LIGN	LIGNITE PLANT (LIM.)
6	IMPO	IMPORTS (FUEL SUBS.)
7	****	NOT APPLICABLE
8	****	NOT APPLICABLE
9	****	NOT APPLICABLE
	HYD1	HYDRO PLANTS GROUP 1
	HYD2	HYDRO PLANTS GROUP 2

		ENERGY LIMIT MILLION KCAL/DAY	SUBST. PL#
5	LIGN	13000.00	8

Figure 9.2 (page 3) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

ANNUAL LOAD DESCRIPTION

PERIOD(S) PER YEAR : 4

YEAR	PEAKLOAD MW	GR.RATE %	MIN.LOAD MW	GR.RATE %	ENERGY GWH	GR.RATE %	LOADFACTOR %
1997	6000.0	-	2160.0	-	30353.4	-	57.75
1998	6333.0	5.5	2279.9	5.6	32038.0	5.5	57.75
1999	6725.6	6.2	2421.2	6.2	34024.4	6.2	57.75
2000	7109.0	5.7	2559.2	5.7	35963.8	5.7	57.75
2001	7496.4	5.4	2698.7	5.4	37923.8	5.4	57.75
2002	7897.5	5.4	2843.1	5.4	39952.7	5.4	57.75
2003	8304.2	5.1	2989.5	5.1	42010.3	5.1	57.75
2004	8702.8	4.8	3133.0	4.8	44026.7	4.8	57.75
2005	9120.6	4.8	3283.4	4.8	46141.7	4.8	57.75
2006	9558.4	4.8	3441.0	4.8	48356.5	4.8	57.75
2007	10017.2	4.8	3606.2	4.8	50677.9	4.8	57.75
2008	10488.0	4.7	3775.7	4.7	53059.7	4.7	57.75
2009	10980.9	4.7	3953.1	4.7	55553.3	4.7	57.75
2010	11497.0	4.7	4138.9	4.7	58164.3	4.7	57.75
2011	12025.9	4.6	4329.3	4.6	60840.0	4.6	57.75
2012	12579.1	4.6	4528.5	4.6	63638.7	4.6	57.75
2013	13157.7	4.6	4736.8	4.6	66565.9	4.6	57.75
2014	13749.8	4.5	4949.9	4.5	69561.4	4.5	57.75
2015	14368.5	4.5	5172.7	4.5	72691.4	4.5	57.75
2016	15015.1	4.5	5405.4	4.5	75962.6	4.5	57.75

PAGE 5

FIXED SYSTEM
SUMMARY DESCRIPTION OF THERMAL PLANTS IN YEAR 1997

NO.	NAME	NO. OF SETS	MIN. LOAD MW	CAPA CITY MW	HEAT RATES KCAL/KWH BASE LOAD	AVGE INCR	FUEL COSTS CENTS/ MILLION KCAL DMSTC	FORGN	FUEL TYPE	FAST SPIN RES %	FOR %	DAYS SCHL MAIN	MAIN CLAS MW	O&M (FIX) $/KWM	O&M (VAR) $/MWH
3	FCO1	6	67.	200.	2490.	2190.	665.0	0.0	1	10	6.0	35	200.	3.85	0.00
4	FCO2	3	133.	400.	2470.	2170.	80.0	730.0	2	10	9.0	42	400.	2.95	0.00
5	FOIL	4	133.	400.	2450.	2150.	60.0	1190.0	3	10	7.0	42	400.	1.95	0.00
6	F-GT	8	100.	100.	3480.	3480.	50.0	1750.0	4	0	1.2	14	100.	0.75	0.00
7	FLIG	1	120.	294.	2560.	2250.	635.0	0.0	5	10	8.0	42	400.	3.05	0.00
8	IMPT	1	1.	1.	2560.	2560.	0.0	3000.0	6	0	3.0	0	100.	3.10	1.55

PAGE 6

Figure 9.2 (page 4) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

FIXED SYSTEM
SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
*** CAPACITY IN MW * ENERGY IN GWH ***
FIXED O&M COSTS : 0.700 $/KW-MONTH

YEAR	PROJ	PER	HYDROCONDITION 1 PROB.: 0.75 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 2 PROB.: 0.15 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 3 PROB.: 0.10 CAPACITY BASE	PEAK	ENERGY
1997	3	1	242.	137.	614.	266.	142.	695.	210.	109.	485.
		2	251.	148.	636.	299.	148.	770.	219.	110.	507.
		3	267.	153.	677.	325.	146.	844.	229.	119.	556.
		4	250.	149.	648.	298.	156.	789.	217.	118.	535.
		INST.CAP.		500.							
		TOTAL ENERGY			2575.			3098.			2083.
2003	4	1	203.	137.	529.	223.	142.	600.	181.	109.	420.
		2	207.	148.	541.	237.	148.	635.	185.	110.	432.
		3	217.	153.	567.	259.	146.	699.	191.	119.	471.
		4	216.	149.	573.	259.	156.	704.	187.	118.	470.
		INST.CAP.		425.							
		TOTAL ENERGY			2210.			2638.			1793.
2008	5	1	173.	117.	445.	187.	123.	500.	160.	90.	355.
		2	175.	125.	455.	194.	126.	525.	160.	90.	360.
		3	177.	133.	465.	203.	127.	555.	160.	100.	385.
		4	183.	127.	485.	206.	144.	570.	161.	99.	395.
		INST.CAP.		350.							
		TOTAL ENERGY			1850.			2150.			1495.

PAGE 7

FIXED SYSTEM
SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD2
*** CAPACITY IN MW * ENERGY IN GWH ***
FIXED O&M COSTS : 0.550 $/KW-MONTH

YEAR	PROJ	PER	HYDROCONDITION 1 PROB.: 0.75 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 2 PROB.: 0.15 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 3 PROB.: 0.10 CAPACITY BASE	PEAK	ENERGY
1997	2	1	210.	1240.	1800.	201.	1299.	2200.	215.	1085.	1330.
		2	210.	1250.	1900.	201.	1349.	2300.	215.	1105.	1450.
		3	210.	1280.	2100.	201.	1369.	2550.	215.	1125.	1650.
		4	210.	1310.	2200.	201.	1399.	2700.	215.	1165.	1800.
		INST.CAP.		1600.							
		TOTAL ENERGY			8000.			9750.			6230.

PAGE 8

FIXED SYSTEM
THERMAL ADDITIONS AND RETIREMENTS

NUMBER OF SETS ADDED AND RETIRED(-)
1997 TO 2016

YEAR: 19.. (200./20..)

NO.	NAME	98	99	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
3	FCO1	-1	.	-1	.	-1	.	.	.	-1	.	.	.	-2	.	.	.	.
4	FCO2	1	1	.	.	.	.	-1	.	-1	.	.	.	.	.	.	.	.
5	FOIL	.	.	.	.	.	.	.	-1	.	-1	.	-1	.	-1	.	.	.
6	F-GT	.	-2	.	.	-1	.	-1	.	.	-1	.	.	-1	.	-1	.	-1
7	FLIG	.	.	1	.	1	.	1	.	.	.	.	.	.	.	.	.	.

PAGE 9

Figure 9.2 (page 5) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

FIXED SYSTEM
SUMMARY OF INSTALLED CAPACITIES
(NOMINAL CAPACITIES (MW))

YEAR	HYDROELECTRIC HYD1 PR.	CAP	HYD2 PR.	CAP	THERMAL FUEL TYPE 0 NUCL	1 CO-1	2 CO-2	3 FOIL	4 GTGO	5 LIGN	6 IMPO	7 ****	8 ****	9 ****	TOTAL
1997	3	500.	2	1600.	0.	1200.	1200.	1600.	800.	294.	1.	0.	0.	0.	7195.
1998					0.	1000.	1600.	1600.	800.	294.	1.	0.	0.	0.	7395.
1999					0.	1000.	2000.	1600.	600.	294.	1.	0.	0.	0.	7595.
2000					0.	800.	2000.	1600.	600.	588.	1.	0.	0.	0.	7689.
2002					0.	600.	2000.	1600.	500.	882.	1.	0.	0.	0.	7683.
2003	4	425.	2	1600.											7608.
2004					0.	600.	1600.	1600.	400.	1176.	1.	0.	0.	0.	7402.
2005					0.	600.	1600.	1200.	400.	1176.	1.	0.	0.	0.	7002.
2006					0.	400.	1200.	1200.	400.	1176.	1.	0.	0.	0.	6402.
2007					0.	400.	1200.	800.	300.	1176.	1.	0.	0.	0.	5902.
2008	5	350.	2	1600.											5827.
2009					0.	400.	1200.	400.	300.	1176.	1.	0.	0.	0.	5427.
2010					0.	0.	1200.	400.	200.	1176.	1.	0.	0.	0.	4927.
2011					0.	0.	1200.	0.	200.	1176.	1.	0.	0.	0.	4527.
2012					0.	0.	1200.	0.	100.	1176.	1.	0.	0.	0.	4427.
2014					0.	0.	1200.	0.	0.	1176.	1.	0.	0.	0.	4327.

PAGE 10

VARIABLE SYSTEM
SUMMARY DESCRIPTION OF THERMAL PLANTS

NO.	NAME	NO. OF SETS	MIN. LOAD MW	CAPA CITY MW	HEAT RATES KCAL/KWH BASE LOAD	AVGE INCR	FUEL COSTS CENTS/ MILLION KCAL DMSTC	FORGN	FUEL TYPE	FAST SPIN RES %	FOR %	DAYS SCHL MAIN	MAIN CLAS MW	O&M (FIX) $/KWM	O&M (VAR) $/MWH
1	VCOA	0	200.	600.	2460.	2160.	80.0	730.0	2	10	12.0	42	600.	3.85	0.00
2	VFOL	0	200.	600.	2440.	2140.	60.0	1190.0	3	10	10.0	42	600.	1.95	0.00
3	VNUC	0	600.	900.	2566.	2361.	0.0	246.0	0	10	8.0	42	900.	3.05	0.00
4	V-GT	0	200.	200.	3470.	3470.	50.0	1750.0	4	0	1.2	14	200.	0.70	0.00

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VARIABLE SYSTEM
SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD1
*** CAPACITY IN MW * ENERGY IN GWH ***
FIXED O&M COSTS : 0.700 $/KW-MONTH

YEAR	PROJ	PER	HYDROCONDITION 1 PROB.: 0.75 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 2 PROB.: 0.15 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 3 PROB.: 0.10 CAPACITY BASE	PEAK	ENERGY
1999	1	1	91.	0.	200.	105.	65.	240.	64.	0.	140.
		2	100.	0.	220.	115.	65.	260.	73.	0.	160.
		3	105.	65.	240.	133.	47.	300.	80.	0.	175.
		4	91.	0.	200.	105.	65.	240.	64.	0.	140.
		INST.CAP.	180.								
		TOTAL ENERGY			860.			1040.			615.
2002	2	1	120.	121.	435.	134.	206.	480.	66.	137.	295.
		2	131.	139.	465.	153.	217.	530.	77.	136.	320.
		3	139.	221.	495.	182.	198.	600.	86.	134.	345.
		4	120.	121.	435.	138.	202.	490.	66.	137.	295.
		INST.CAP.	380.								
		TOTAL ENERGY			1830.			2100.			1255.
2004	3	1	196.	255.	635.	229.	321.	720.	122.	291.	450.
		2	208.	273.	665.	247.	333.	770.	133.	290.	475.
		3	215.	355.	695.	276.	314.	840.	142.	288.	500.
		4	196.	255.	635.	232.	318.	730.	122.	291.	450.
		INST.CAP.	590.								
		TOTAL ENERGY			2630.			3060.			1875.

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Figure 9.2 (page 6) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

VARIABLE SYSTEM
SUMMARY DESCRIPTION OF COMPOSITE HYDROELECTRIC PLANT TYPE HYD2
*** CAPACITY IN MW * ENERGY IN GWH ***
FIXED O&M COSTS : 0.550 $/KW-MONTH

YEAR	PROJ	PER	HYDROCONDITION 1 PROB.: 0.75 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 2 PROB.: 0.15 CAPACITY BASE	PEAK	ENERGY	HYDROCONDITION 3 PROB.: 0.10 CAPACITY BASE	PEAK	ENERGY
2001	1	1	91.	149.	350.	68.	212.	400.	114.	86.	300.
		2	68.	192.	380.	46.	254.	420.	91.	139.	310.
		3	46.	234.	400.	37.	263.	450.	68.	172.	340.
		4	68.	192.	380.	46.	254.	420.	91.	139.	300.
		INST.CAP.	300.								
		TOTAL ENERGY			1510.			1690.			1250.
2003	2	1	228.	502.	970.	160.	670.	1100.	297.	393.	860.
		2	160.	620.	1100.	91.	769.	1210.	228.	517.	910.
		3	114.	716.	1220.	59.	841.	1400.	114.	656.	1000.
		4	160.	640.	1140.	91.	779.	1270.	228.	527.	920.
		INST.CAP.	900.								
		TOTAL ENERGY			4430.			4980.			3690.
2005	3	1	228.	782.	1280.	160.	970.	1460.	297.	643.	1125.
		2	160.	900.	1430.	91.	1069.	1590.	228.	767.	1185.
		3	114.	996.	1570.	59.	1141.	1800.	114.	906.	1290.
		4	160.	920.	1460.	91.	1079.	1650.	228.	777.	1195.
		INST.CAP.	1200.								
		TOTAL ENERGY			5740.			6500.			4795.
2006	4	1	228.	1332.	1780.	160.	1570.	2060.	297.	1183.	1545.
		2	160.	1450.	2030.	91.	1669.	2290.	228.	1307.	1655.
		3	114.	1546.	2270.	59.	1741.	2700.	114.	1446.	1810.
		4	160.	1470.	2100.	91.	1679.	2400.	228.	1317.	1685.
		INST.CAP.	1800.								
		TOTAL ENERGY			8180.			9450.			6695.

PAGE 13

C O N G E N
CONSTRAINTS ON CONFIGURATIONS GENERATED
CON: NUMBER OF CONFIGURATIONS
MINIMUM
MAXIMUM

YEAR	CON	RES. MAR-GIN	VCOA	VFOL	VNUC	V-GT	HYD1	HYD2
1997	2	15	0	0	0	0	0	0
		40	0	0	0	1	0	0
1998	2	15	0	0	0	0	0	0
		40	0	0	0	2	0	0
1999	10	15	0	0	0	1	0	0
		40	0	1	0	3	1	0
2000	19	15	0	0	0	2	0	0
		30	1	2	0	4	1	0
2001	41	15	0	0	0	3	0	0
		30	1	2	0	5	1	1
2002	90	15	0	0	0	3	0	0
		30	2	2	0	5	2	1
2003	199	15	0	0	0	3	0	0
		30	2	2	1	5	2	2
2004	154	15	0	0	0	5	1	1
		30	2	2	1	7	3	2
2005	238	15	0	0	0	8	1	1
		30	2	2	1	10	3	3
2006	165	15	0	0	0	9	2	2
		30	2	2	1	11	3	4

(PERMITTED EXTREME CONFIGURATIONS OF ALTERNATIVES)

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Figure 9.2 (page 7) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

C O N G E N (CONTD.)
CONSTRAINTS ON CONFIGURATIONS GENERATED
CON: NUMBER OF CONFIGURATIONS
MINIMUM
MAXIMUM

RES. PERMITTED EXTREME CONFIGURATIONS OF ALTERNATIVES

YEAR	CON	RES. MAR- GIN	VCOA	VFOL	VNUC	V-GT	HYD1	HYD2
2007	156	15	1	0	0	9	2	3
		30	3	2	2	11	3	4
2008	164	15	2	0	0	9	2	3
		30	4	2	2	11	3	4
2009	173	15	3	0	0	11	2	3
		30	5	2	2	13	3	4
2010	161	15	4	0	0	11	2	3
		30	6	2	2	13	3	4
2011	145	15	5	0	0	12	2	3
		30	7	2	2	14	3	4
2012	136	15	6	0	0	12	2	3
		30	8	2	2	14	3	4
2013	132	15	7	0	0	12	2	3
		30	9	2	2	14	3	4
2014	60	15	7	0	0	12	2	3
		30	9	2	2	14	3	4
2015	52	15	8	0	0	12	2	3
		30	10	2	2	14	3	4
2016	58	15	8	0	1	12	2	3
		30	10	2	3	14	3	4

2157 TOTAL NUMBER OF CONFIGURATIONS GENERATED

OPTIMUM SOLUTION
ANNUAL ADDITIONS: CAPACITY(MW) AND NUMBER OF UNITS OR PROJECTS
FOR DETAILS OF INDIVIDUAL UNITS OR PROJECTS SEE VARIABLE SYSTEM REPORT
SEE ALSO FIXED SYSTEM REPORT FOR OTHER ADDITIONS OR RETIREMENTS

NAME:				VCOA	VFOL	VNUC	V-GT	HYD1	HYD2
SIZE (MW):				600.	600.	900.	200.	0.	0.
	%LOLP								
YEAR	MAINT	NOMNT	CAP						
1997	0.067		0.	.	.	.	.	.	.
1998	0.066		200.	.	.	.	1	.	.
1999	0.094		200.	.	.	.	1	.	.
2000	0.090		380.	.	.	.	1	1	.
2001	0.064		500.	.	.	.	1	.	1
2002	0.064		600.	.	1	.	.	.	.
2003	0.041		600.	.	.	.	.	.	1
2004	0.042		600.	.	.	.	2	1	.
2005	0.023		900.	.	.	.	3	.	1
2006	0.034		1010.	1	.	.	1	1	.
2007	0.023		1200.	1	.	.	.	.	1
2008	0.033		600.	1	.	.	.	.	.
2009	0.032		1000.	1	.	.	2	.	.
2010	0.042		1200.	1	1	.	.	.	.
2011	0.075		800.	1	.	.	1	.	.
2012	0.074		800.	1	.	.	1	.	.
2013	0.099		600.	1	.	.	.	.	.
2014	0.096		900.	.	.	1	.	.	.
2015	0.132		600.	1	.	.	.	.	.
2016	0.113		900.	.	.	1	.	.	.
TOTALS			13590.	9	2	2	14	3	4

Figure 9.2 (page 8) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
(NOMINAL CAPACITY (MW))

YEAR	THERMAL FUEL TYPE CAPACITIES 0	1	2	3	4	5	6	7	8	9	TOTAL CAP
	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	
1997	0	1200	1200	1600	800	294	1	0	0	0	5095
1998	0	1000	1600	1600	1000	294	1	0	0	0	5495
1999	0	1000	2000	1600	1000	294	1	0	0	0	5895
2000	0	800	2000	1600	1200	588	1	0	0	0	6189
2001	0	800	2000	1600	1400	588	1	0	0	0	6389
2002	0	600	2000	2200	1300	882	1	0	0	0	6983
2003	0	600	2000	2200	1300	882	1	0	0	0	6983
2004	0	600	1600	2200	1600	1176	1	0	0	0	7177
2005	0	600	1600	1800	2200	1176	1	0	0	0	7377
2006	0	400	1800	1800	2400	1176	1	0	0	0	7577
2007	0	400	2400	1400	2300	1176	1	0	0	0	7677
2008	0	400	3000	1400	2300	1176	1	0	0	0	8277
2009	0	400	3600	1000	2700	1176	1	0	0	0	8877
2010	0	0	4200	1600	2600	1176	1	0	0	0	9577
2011	0	0	4800	1200	2800	1176	1	0	0	0	9977
2012	0	0	5400	1200	2900	1176	1	0	0	0	10677
2013	0	0	6000	1200	2900	1176	1	0	0	0	11277
2014	900	0	6000	1200	2800	1176	1	0	0	0	12077
2015	900	0	6600	1200	2800	1176	1	0	0	0	12677
2016	1800	0	6600	1200	2800	1176	1	0	0	0	13577

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
(NOMINAL CAPACITY IN MW, ENERGY IN GWH)

YEAR	HYDROELECTRIC HYD1 PR.	HYD1 CAP	HYD2 PR.	HYD2 CAP	TOTAL THERMAL CAPACITY	TOTAL CAP	SYSTEM RES. %	SYSTEM LOLP. %	ENERGY NOT SERVED HYDROCONDITION 1	2	3
1997	3	500	2	1600	5095	7195	19.9	0.067	0.2	0.1	1.2
1998	3	500	2	1600	5495	7595	19.9	0.066	0.2	0.0	0.9
1999	3	500	2	1600	5895	7995	18.9	0.094	0.3	0.1	1.9
2000	4	680	2	1600	6189	8469	19.1	0.090	0.3	0.1	2.2
2001	4	680	3	1900	6389	8969	19.6	0.064	0.2	0.1	1.6
2002	4	680	3	1900	6983	9563	21.1	0.064	0.2	0.0	1.5
2003	5	605	4	2500	6983	10088	21.5	0.041	0.2	0.1	0.7
2004	6	805	4	2500	7177	10482	20.4	0.042	0.2	0.1	0.9
2005	6	805	5	2800	7377	10982	20.4	0.023	0.1	0.0	0.4
2006	7	1015	5	2800	7577	11392	19.2	0.034	0.1	0.0	0.7
2007	7	1015	6	3400	7677	12092	20.7	0.023	0.0	0.2	1.3
2008	8	940	6	3400	8277	12617	20.3	0.033	0.1	0.0	0.9
2009	8	940	6	3400	8877	13217	20.4	0.032	0.1	0.0	0.8
2010	8	940	6	3400	9577	13917	21.0	0.042	0.3	0.0	1.1
2011	8	940	6	3400	9977	14317	19.1	0.075	0.5	0.1	2.5
2012	8	940	6	3400	10677	15017	19.4	0.074	0.6	0.1	2.4
2013	8	940	6	3400	11277	15617	18.7	0.099	1.0	0.2	3.4
2014	8	940	6	3400	12077	16417	19.4	0.096	0.9	0.2	3.5
2015	8	940	6	3400	12677	17017	18.4	0.132	1.9	0.4	5.1
2016	8	940	6	3400	13577	17917	19.3	0.113	1.6	0.3	4.3

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Figure 9.2 (page 9) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL STOCK OF THERMAL PLANTS BY FUEL TYPE (KTON)

THERMAL FUEL TYPES

YEAR	0 NUCL DOM.	FOR	1 CO-1 DOM.	FOR	2 CO-2 DOM.	FOR	3 FOIL DOM.	FOR	4 GTGO DOM.	FOR
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00	16.34	147.08	0.00	0.00	1.20	22.88
1998	0.00	0.00	0.00	0.00	16.34	147.08	0.00	0.00	1.20	22.88
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	22.88
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	22.88
2001	0.00	0.00	0.00	0.00	0.00	0.00	4.61	87.55	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.41	45.76
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.61	68.64
2005	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	1.20	22.88
2006	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	2.41	45.76
2009	0.00	0.00	0.00	0.00	24.41	219.67	4.61	87.55	0.00	0.00
2010	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	1.20	22.88
2011	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	1.20	22.88
2012	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	0.00	0.00
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	24.41	219.67	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL STOCK OF THERMAL PLANTS BY FUEL TYPE (KTON)

THERMAL FUEL TYPES

YEAR	5 LIGN DOM.	FOR	6 IMPO DOM.	FOR	7 **** DOM.	FOR	8 **** DOM.	FOR	9 **** DOM.	FOR
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Figure 9.2 (page 10) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
GENERATION BY PLANT TYPE (GWH)

HYDROCONDITION 1

	HYDROELECTRIC			THERMAL FUEL TYPES											
				0	1	2	3	4	5	6	7	8	9		GR.
YEAR	HYD1	HYD2	TOTAL	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	TOTAL	TOTAL
1997	2575	8000	10575	0	8930	7866	1410	30	1536	0	0	0	0	19772	30347
1998	2575	8000	10575	0	7443	8174	4247	57	1536	0	0	0	0	21457	32032
1999	2575	8000	10575	0	7443	10129	3846	54	1970	0	0	0	0	23442	34017
2000	3435	8000	11435	0	5954	10512	4032	90	3932	0	0	0	0	24520	35955
2001	3435	9510	12945	0	5954	10740	3981	104	4192	0	0	0	0	24971	37916
2002	3435	9510	12945	0	4465	11721	4826	74	5915	0	0	0	0	27001	39946
2003	3070	12430	15500	0	4465	11978	4094	51	5915	0	0	0	0	26503	42003
2004	4040	12430	16470	0	4466	9915	4690	94	8384	0	0	0	0	27549	44019
2005	4040	13740	17780	0	4465	10733	4546	227	8384	0	0	0	0	28355	46135
2006	4840	13740	18580	0	2977	11865	6223	320	8384	0	0	0	0	29769	48349
2007	4840	16180	21020	0	2977	14348	3747	195	8384	0	0	0	0	29651	50671
2008	4480	16180	20660	0	2977	17122	3709	200	8384	0	0	0	0	32392	53052
2009	4480	16180	20660	0	2977	20537	2663	324	8384	0	0	0	0	34885	55545
2010	4480	16180	20660	0	0	24852	3995	266	8384	0	0	0	0	37497	58157
2011	4480	16180	20660	0	0	28370	3009	410	8384	0	0	0	0	40173	60833
2012	4480	16180	20660	0	0	31353	2819	416	8384	0	0	0	0	42972	63632
2013	4480	16180	20660	0	0	34350	2735	429	8384	0	0	0	0	45898	66558
2014	4480	16180	20660	6417	0	30638	3118	335	8384	0	0	0	0	48892	69552
2015	4480	16180	20660	6417	0	33748	3108	364	8384	0	0	0	0	52021	72681
2016	4480	16180	20660	12832	0	31017	2756	301	8384	0	0	0	0	55290	75950

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
GENERATION BY PLANT TYPE (GWH)

HYDROCONDITION 2

	HYDROELECTRIC			THERMAL FUEL TYPES											
				0	1	2	3	4	5	6	7	8	9		GR.
YEAR	HYD1	HYD2	TOTAL	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	TOTAL	TOTAL
1997	3098	9750	12848	0	8930	6275	741	18	1536	0	0	0	0	17500	30348
1998	3098	9750	12848	0	7443	6260	3909	36	1536	0	0	0	0	19184	32032
1999	3098	9750	12848	0	7443	8448	3274	35	1970	0	0	0	0	21170	34018
2000	4138	9750	13888	0	5954	8707	3424	52	3932	0	0	0	0	22069	35957
2001	4138	11440	15578	0	5954	8973	3165	55	4192	0	0	0	0	22339	37917
2002	4138	11440	15578	0	4465	10173	3777	38	5915	0	0	0	0	24368	39946
2003	3678	14730	18408	0	4465	10195	2998	22	5915	0	0	0	0	23595	42003
2004	4738	14730	19468	0	4466	8424	3233	45	8384	0	0	0	0	24552	44020
2005	4738	16250	20988	0	4465	9154	3018	126	8384	0	0	0	0	25147	46135
2006	5698	16250	21948	0	2977	9942	4906	191	8384	0	0	0	0	26400	48348
2007	5698	19200	24898	0	2977	10906	3407	99	8384	0	0	0	0	25773	50671
2008	5210	19200	24410	0	2977	14090	3084	108	8384	0	0	0	0	28643	53053
2009	5210	19200	24410	0	2977	17228	2357	189	8384	0	0	0	0	31135	55545
2010	5210	19200	24410	0	0	21905	3303	155	8384	0	0	0	0	33747	58157
2011	5210	19200	24410	0	0	25448	2330	262	8384	0	0	0	0	36424	60834
2012	5210	19200	24410	0	0	28448	2122	269	8384	0	0	0	0	39223	63633
2013	5210	19200	24410	0	0	31818	1657	291	8384	0	0	0	0	42150	66560
2014	5210	19200	24410	6417	0	27090	3035	217	8384	0	0	0	0	45143	69553
2015	5210	19200	24410	6417	0	30447	2782	242	8384	0	0	0	0	48272	72682
2016	5210	19200	24410	12832	0	27670	2454	202	8384	0	0	0	0	51542	75952

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Figure 9.2 (page 11) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
GENERATION BY PLANT TYPE (GWH)

HYDROCONDITION 3

	HYDROELECTRIC			0	1	2	THERMAL 3	FUEL 4	TYPES 5	6	7	8	9		GR.
YEAR	HYD1	HYD2	TOTAL	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	TOTAL	TOTAL
1997	2083	6230	8313	0	8930	8203	3296	67	1536	1	0	0	0	22033	30346
1998	2083	6230	8313	0	7443	9639	4989	111	1536	1	0	0	0	23719	32032
1999	2083	6230	8313	0	7443	11643	4542	104	1970	0	0	0	0	25702	34015
2000	2698	6230	8928	0	5954	12110	4854	176	3932	0	0	0	0	27026	35954
2001	2698	7480	10178	0	5954	12272	5108	210	4192	0	0	0	0	27736	37914
2002	2698	7480	10178	0	4465	12782	6450	153	5915	1	0	0	0	29766	39944
2003	2408	9920	12328	0	4465	13260	5922	111	5915	0	0	0	0	29673	42001
2004	3048	9920	12968	0	4466	10804	7202	193	8384	0	0	0	0	31049	44017
2005	3048	11025	14073	0	4465	11091	7705	415	8384	0	0	0	0	32060	46133
2006	3668	11025	14693	0	2977	12295	9301	697	8384	0	0	0	0	33654	48347
2007	3668	12925	16593	0	2977	16061	6080	574	8384	0	0	0	0	34076	50669
2008	3370	12925	16295	0	2977	19526	5518	350	8384	0	0	0	0	36755	53050
2009	3370	12925	16295	0	2977	23210	4106	572	8384	0	0	0	0	39249	55544
2010	3370	12925	16295	0	0	27169	5875	433	8384	0	0	0	0	41861	58156
2011	3370	12925	16295	0	0	30851	4501	800	8384	0	0	0	0	44536	60831
2012	3370	12925	16295	0	0	34255	4066	629	8384	0	0	0	0	47334	63629
2013	3370	12925	16295	0	0	37657	3580	640	8384	0	0	0	0	50261	66556
2014	3370	12925	16295	6417	0	34552	3397	504	8384	0	0	0	0	53254	69549
2015	3370	12925	16295	6417	0	37722	3323	537	8384	0	0	0	0	56383	72678
2016	3370	12925	16295	12832	0	34920	3067	449	8384	0	0	0	0	59652	75947

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED GENERATION BY PLANT TYPE (GWH),
WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

	HYDROELECTRIC			0	1	2	THERMAL 3	FUEL 4	TYPES 5	6	7	8	9		GR.
YEAR	HYD1	HYD2	TOTAL	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	TOTAL	TOTAL
1997	2604	8085	10689	0	8930	7661	1498	32	1536	0	0	0	0	19657	30346
1998	2604	8085	10689	0	7443	8033	4270	59	1536	0	0	0	0	21341	32030
1999	2604	8085	10689	0	7443	10028	3830	56	1970	0	0	0	0	23327	34016
2000	3467	8085	11552	0	5954	10401	4023	93	3932	0	0	0	0	24403	35955
2001	3467	9596	13063	0	5954	10629	3972	107	4192	0	0	0	0	24854	37917
2002	3467	9596	13063	0	4465	11595	4831	77	5915	0	0	0	0	26883	39946
2003	3095	12524	15619	0	4465	11839	4112	53	5915	0	0	0	0	26384	42003
2004	4045	12524	16569	0	4466	9780	4723	96	8384	0	0	0	0	27449	44018
2005	4045	13845	17890	0	4465	10532	4633	230	8384	0	0	0	0	28244	46134
2006	4851	13845	18696	0	2977	11619	6333	338	8384	0	0	0	0	29651	48347
2007	4851	16307	21158	0	2977	14003	3929	219	8384	0	0	0	0	29512	50670
2008	4478	16307	20785	0	2977	16908	3796	201	8384	0	0	0	0	32266	53051
2009	4478	16307	20785	0	2977	20308	2761	329	8384	0	0	0	0	34759	55544
2010	4478	16307	20785	0	0	24641	4079	266	8384	0	0	0	0	37370	58155
2011	4478	16307	20785	0	0	28180	3056	427	8384	0	0	0	0	40047	60832
2012	4478	16307	20785	0	0	31207	2839	415	8384	0	0	0	0	42845	63630
2013	4478	16307	20785	0	0	34301	2658	430	8384	0	0	0	0	45773	66558
2014	4478	16307	20785	6417	0	30497	3133	334	8384	0	0	0	0	48765	69550
2015	4478	16307	20785	6417	0	33650	3080	363	8384	0	0	0	0	51894	72679
2016	4478	16307	20785	12832	0	30905	2742	301	8384	0	0	0	0	55164	75949

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Figure 9.2 (page 12) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 1

THERMAL FUEL TYPES

YEAR	0 NUCL DOM.	0 NUCL FOR	1 CO-1 DOM.	1 CO-1 FOR	2 CO-2 DOM.	2 CO-2 FOR	3 FOIL DOM.	3 FOIL FOR	4 GTGO DOM.	4 GTGO FOR
1997	0.00	0.00	3714.96	0.00	0.00	2973.33	0.00	328.47	0.00	10.19
1998	0.00	0.00	3096.44	0.00	0.00	3089.71	0.00	989.45	0.00	19.14
1999	0.00	0.00	3096.24	0.00	0.00	3828.74	0.00	896.15	0.00	18.14
2000	0.00	0.00	2476.90	0.00	0.00	3973.64	0.00	939.52	0.00	30.29
2001	0.00	0.00	2476.76	0.00	0.00	4059.91	0.00	927.65	0.00	34.77
2002	0.00	0.00	1857.59	0.00	0.00	4430.36	0.00	1090.74	0.00	24.86
2003	0.00	0.00	1857.59	0.00	0.00	4527.61	0.00	921.43	0.00	17.18
2004	0.00	0.00	1857.86	0.00	0.00	3747.89	0.00	1059.42	0.00	31.41
2005	0.00	0.00	1857.56	0.00	0.00	4056.89	0.00	1020.29	0.00	75.93
2006	0.00	0.00	1238.32	0.00	0.00	4480.83	0.00	1397.12	0.00	107.04
2007	0.00	0.00	1238.32	0.00	0.00	5415.21	0.00	840.45	0.00	65.38
2008	0.00	0.00	1238.32	0.00	0.00	6460.32	0.00	832.07	0.00	67.09
2009	0.00	0.00	1238.48	0.00	0.00	7747.41	0.00	588.21	0.00	108.63
2010	0.00	0.00	0.00	0.00	0.00	9374.10	0.00	867.07	0.00	89.21
2011	0.00	0.00	0.00	0.00	0.00	10700.16	0.00	640.94	0.00	137.30
2012	0.00	0.00	0.00	0.00	0.00	11824.15	0.00	600.50	0.00	139.21
2013	0.00	0.00	0.00	0.00	0.00	12953.71	0.00	582.47	0.00	143.87
2014	0.00	0.14	0.00	0.00	0.00	11553.81	0.00	664.10	0.00	112.24
2015	0.00	0.14	0.00	0.00	0.00	12726.25	0.00	661.93	0.00	122.11
2016	0.00	0.28	0.00	0.00	0.00	11696.65	0.00	587.13	0.00	100.83

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 1

THERMAL FUEL TYPES

YEAR	5 LIGN DOM.	5 LIGN FOR	6 IMPO DOM.	6 IMPO FOR	7 **** DOM.	7 **** FOR	8 **** DOM.	8 **** FOR	9 **** DOM.	9 **** FOR
1997	0.00	1216.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	1216.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	1560.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	3114.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	3320.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	6640.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	6640.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	6640.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.00	6640.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.00	6640.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Figure 9.2 (page 13) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 2

THERMAL FUEL TYPES

YEAR	0 NUCL DOM.	0 NUCL FOR	1 CO-1 DOM.	1 CO-1 FOR	2 CO-2 DOM.	2 CO-2 FOR	3 FOIL DOM.	3 FOIL FOR	4 GTGO DOM.	4 GTGO FOR
1997	0.00	0.00	3714.96	0.00	0.00	2371.83	0.00	172.56	0.00	6.11
1998	0.00	0.00	3096.45	0.00	0.00	2366.18	0.00	910.71	0.00	12.21
1999	0.00	0.00	3096.24	0.00	0.00	3193.24	0.00	762.80	0.00	11.75
2000	0.00	0.00	2476.90	0.00	0.00	3291.20	0.00	797.80	0.00	17.34
2001	0.00	0.00	2476.76	0.00	0.00	3391.69	0.00	737.50	0.00	18.46
2002	0.00	0.00	1857.59	0.00	0.00	3845.25	0.00	847.79	0.00	12.78
2003	0.00	0.00	1857.60	0.00	0.00	3853.83	0.00	668.77	0.00	7.47
2004	0.00	0.00	1857.86	0.00	0.00	3184.23	0.00	721.27	0.00	15.08
2005	0.00	0.00	1857.56	0.00	0.00	3460.21	0.00	673.43	0.00	42.11
2006	0.00	0.00	1238.32	0.00	0.00	3754.22	0.00	1109.75	0.00	64.08
2007	0.00	0.00	1238.32	0.00	0.00	4115.47	0.00	762.86	0.00	33.16
2008	0.00	0.00	1238.32	0.00	0.00	5315.78	0.00	687.66	0.00	36.07
2009	0.00	0.00	1238.48	0.00	0.00	6498.58	0.00	518.24	0.00	63.45
2010	0.00	0.00	0.00	0.00	0.00	8262.13	0.00	714.28	0.00	51.81
2011	0.00	0.00	0.00	0.00	0.00	9597.54	0.00	496.31	0.00	87.63
2012	0.00	0.00	0.00	0.00	0.00	10728.12	0.00	451.95	0.00	89.96
2013	0.00	0.00	0.00	0.00	0.00	11998.47	0.00	352.97	0.00	97.35
2014	0.00	0.14	0.00	0.00	0.00	10216.20	0.00	646.46	0.00	72.65
2015	0.00	0.14	0.00	0.00	0.00	11481.91	0.00	592.63	0.00	81.03
2016	0.00	0.28	0.00	0.00	0.00	10434.88	0.00	522.71	0.00	67.59

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 2

THERMAL FUEL TYPES

YEAR	5 LIGN DOM.	5 LIGN FOR	6 IMPO DOM.	6 IMPO FOR	7 **** DOM.	7 **** FOR	8 **** DOM.	8 **** FOR	9 **** DOM.	9 **** FOR
1997	0.00	1216.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	1216.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	1560.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	3114.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	3320.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	6640.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	6640.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	6640.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.00	6640.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.00	6640.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	6639.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Figure 9.2 (page 14) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 3

THERMAL FUEL TYPES

YEAR	0 NUCL DOM.	0 NUCL FOR	1 CO-1 DOM.	1 CO-1 FOR	2 CO-2 DOM.	2 CO-2 FOR	3 FOIL DOM.	3 FOIL FOR	4 GTGO DOM.	4 GTGO FOR
1997	0.00	0.00	3714.96	0.00	0.00	3100.60	0.00	768.05	0.00	22.46
1998	0.00	0.00	3096.12	0.00	0.00	3643.53	0.00	1162.38	0.00	37.07
1999	0.00	0.00	3096.24	0.00	0.00	4401.23	0.00	1058.20	0.00	34.92
2000	0.00	0.00	2476.90	0.00	0.00	4577.61	0.00	1130.94	0.00	58.87
2001	0.00	0.00	2476.76	0.00	0.00	4638.93	0.00	1190.25	0.00	70.40
2002	0.00	0.00	1857.59	0.00	0.00	4831.74	0.00	1455.46	0.00	51.23
2003	0.00	0.00	1857.59	0.00	0.00	5012.24	0.00	1334.08	0.00	37.23
2004	0.00	0.00	1857.86	0.00	0.00	4084.00	0.00	1621.65	0.00	64.67
2005	0.00	0.00	1857.56	0.00	0.00	4192.27	0.00	1730.28	0.00	138.93
2006	0.00	0.00	1238.32	0.00	0.00	4643.30	0.00	2093.45	0.00	233.56
2007	0.00	0.00	1238.32	0.00	0.00	6062.87	0.00	1353.81	0.00	192.31
2008	0.00	0.00	1238.32	0.00	0.00	7368.81	0.00	1229.77	0.00	117.41
2009	0.00	0.00	1238.47	0.00	0.00	8757.11	0.00	903.25	0.00	191.72
2010	0.00	0.00	0.00	0.00	0.00	10249.59	0.00	1277.11	0.00	144.93
2011	0.00	0.00	0.00	0.00	0.00	11637.52	0.00	958.61	0.00	268.11
2012	0.00	0.00	0.00	0.00	0.00	12920.52	0.00	866.07	0.00	210.85
2013	0.00	0.00	0.00	0.00	0.00	14202.61	0.00	762.51	0.00	214.47
2014	0.00	0.14	0.00	0.00	0.00	13030.95	0.00	723.55	0.00	168.87
2015	0.00	0.14	0.00	0.00	0.00	14225.60	0.00	707.87	0.00	179.80
2016	0.00	0.28	0.00	0.00	0.00	13168.82	0.00	653.37	0.00	150.39

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION
FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON)

HYDROCONDITION 3

THERMAL FUEL TYPES

YEAR	5 LIGN DOM.	5 LIGN FOR	6 IMPO DOM.	6 IMPO FOR	7 **** DOM.	7 **** FOR	8 **** DOM.	8 **** FOR	9 **** DOM.	9 **** FOR
1997	0.00	1216.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	1216.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	1560.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	3114.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	3320.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	6640.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	6640.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	6640.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.00	6640.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.00	6640.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Figure 9.2 (page 15) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON),
WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

THERMAL FUEL TYPES

YEAR	0 NUCL DOM.	0 NUCL FOR	1 CO-1 DOM.	1 CO-1 FOR	2 CO-2 DOM.	2 CO-2 FOR	3 FOIL DOM.	3 FOIL FOR	4 GTGO DOM.	4 GTGO FOR
1997	0.00	0.00	3714.96	0.00	0.00	2895.83	0.00	349.04	0.00	10.80
1998	0.00	0.00	3096.41	0.00	0.00	3036.56	0.00	994.93	0.00	19.90
1999	0.00	0.00	3096.24	0.00	0.00	3790.66	0.00	892.35	0.00	18.86
2000	0.00	0.00	2476.90	0.00	0.00	3931.67	0.00	937.40	0.00	31.20
2001	0.00	0.00	2476.76	0.00	0.00	4017.57	0.00	925.39	0.00	35.89
2002	0.00	0.00	1857.59	0.00	0.00	4382.73	0.00	1090.77	0.00	25.68
2003	0.00	0.00	1857.59	0.00	0.00	4475.00	0.00	924.80	0.00	17.72
2004	0.00	0.00	1857.86	0.00	0.00	3696.95	0.00	1064.92	0.00	32.29
2005	0.00	0.00	1857.56	0.00	0.00	3980.93	0.00	1039.26	0.00	77.16
2006	0.00	0.00	1238.32	0.00	0.00	4388.09	0.00	1423.65	0.00	113.25
2007	0.00	0.00	1238.32	0.00	0.00	5285.02	0.00	880.14	0.00	73.24
2008	0.00	0.00	1238.32	0.00	0.00	6379.49	0.00	850.18	0.00	67.47
2009	0.00	0.00	1238.47	0.00	0.00	7661.06	0.00	609.22	0.00	110.16
2010	0.00	0.00	0.00	0.00	0.00	9294.86	0.00	885.16	0.00	89.17
2011	0.00	0.00	0.00	0.00	0.00	10628.50	0.00	651.01	0.00	142.93
2012	0.00	0.00	0.00	0.00	0.00	11769.39	0.00	604.78	0.00	138.99
2013	0.00	0.00	0.00	0.00	0.00	12935.31	0.00	566.05	0.00	143.95
2014	0.00	0.14	0.00	0.00	0.00	11500.88	0.00	667.40	0.00	111.97
2015	0.00	0.14	0.00	0.00	0.00	12689.54	0.00	656.13	0.00	121.71
2016	0.00	0.28	0.00	0.00	0.00	11654.60	0.00	584.09	0.00	100.80

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SUMMARY OF
FIXED SYSTEM PLUS OPTIMUM SOLUTION

EXPECTED FUEL CONSUMPTION OF THERMAL PLANTS BY FUEL TYPE (KTON),
WEIGHTED BY PROBABILITIES OF HYDRO CONDITIONS

THERMAL FUEL TYPES

YEAR	5 LIGN DOM.	5 LIGN FOR	6 IMPO DOM.	6 IMPO FOR	7 **** DOM.	7 **** FOR	8 **** DOM.	8 **** FOR	9 **** DOM.	9 **** FOR
1997	0.00	1216.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	0.00	1216.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	0.00	1560.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	3114.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.00	3320.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2003	0.00	4684.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	0.00	6640.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	6640.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2006	0.00	6640.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2007	0.00	6640.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.00	6640.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	0.00	6640.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2013	0.00	6639.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2015	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016	0.00	6639.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Figure 9.2 (page 16) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

D Y N P R O

SUMMARY OF CAPITAL COSTS OF ALTERNATIVES IN $/KW

PLANT	CAPITAL COSTS (DEPRECIABLE PART) DOMESTIC	FOREIGN	INCLUSIVE IDC %	CONSTR. TIME (YEARS)	PLANT LIFE (YEARS)	CAPITAL COSTS (NON-DEPREC. PART) DOMESTIC	FOREIGN
THERMAL PLANT CAPITAL COSTS							
VCOA	291.0	779.0	17.12	5.50	30.	0.0	0.0
VFOL	257.0	709.0	14.19	4.50	30.	0.0	0.0
VNUC	370.0	1680.0	22.72	7.50	30.	0.0	250.0
V-GT	80.0	320.0	6.52	2.00	20.	0.0	0.0
HYD1 - HYDRO PROJECT CAPITAL COSTS, PROJECT LIFE: 50.							
1	1117.0	478.0	22.67	6.00			
2	1218.0	522.0	22.67	6.00			
3	1360.0	582.0	22.67	6.00			
HYD2 - HYDRO PROJECT CAPITAL COSTS, PROJECT LIFE: 50.							
1	1015.0	435.0	29.22	8.00			
2	1136.0	486.0	29.22	8.00			
3	1320.0	565.0	29.22	8.00			
4	1726.0	739.0	29.22	8.00			

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D Y N P R O

ECONOMIC PARAMETERS AND CONSTRAINTS

ALL COSTS WILL BE DISCOUNTED TO YEAR : 1995
BASE YEAR FOR ESCALATION CALCULATION IS : 1995

1997 INITIAL VALUES : (XX) = INDEX NUMBER; (0) = NO INDEX READ
****

NAME OF ALTERNATIVES :

VCOA VFOL VNUC V-GT HYD1 HYD2

DISCOUNT RATE APPLIED TO ALL DOMESTIC CAPITAL COSTS - %/YR 8.0
DISCOUNT RATE APPLIED TO ALL FOREIGN CAPITAL COSTS - %/YR 8.0

ESCALATION RATIOS FOR CAPITAL COSTS (0)

DOMESTIC	1.00	1.00	1.00	1.00	1.00	1.00
FOREIGN	1.00	1.00	1.00	1.00	1.00	1.00

MAXIMUM NUMBER OF UNITS WHICH CAN BE ADDED (0)

50 50 50 50 50 50

MINIMUM NUMBER OF UNITS WHICH MUST BE ADDED (0)

0 0 0 0 0 0

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Figure 9.2 (page 17) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

D Y N P R O (CONTD.)

ECONOMIC PARAMETERS AND CONSTRAINTS

1997 INITIAL VALUES : (XX) = INDEX NUMBER; (0) = NO INDEX READ
****

FUEL TYPE:	THERMAL										HYDRO		ENERGY
	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	HYD1	HYD2	NOT SERVED

DISCOUNT RATE APPLIED TO ALL DOMESTIC OPERATION COSTS - %/YR (14) 8.0
DISCOUNT RATE APPLIED TO ALL FOREIGN OPERATION COSTS - %/YR (15) 8.0

ESCALATION RATIOS FOR OPERATING COSTS (0)

	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	HYD1	HYD2	NOT SERVED
DOMESTIC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOREIGN	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

MULTIPLYING FACTOR FOR FUEL COSTS (0)

	NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	HYD1	HYD2	NOT SERVED
DOMESTIC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FOREIGN	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

COEFFICIENTS OF ENERGY NOT SERVED COST FUNCTION (11)		CF1	CF2	CF3
	($/KWH)	0.0500	105.0000	0.0000

PENALTY FACTOR ON FOREIGN EXPENDITURE (0) 1.0000

CRITICAL LOSS OF LOAD PROBABILITY IN % (12) 0.1370

DEPRECIATION OPTION (16) : 1 = SINKING FUND

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EXPECTED COST OF OPERATION
FUEL COST
DOMESTIC

TYPE OF PLANT:		NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****
YEAR	TOTAL	COST BY PLANT TYPE (MILLION $)									
1997	175.4	0.0	136.0	14.0	2.1	0.1	23.2	0.0	0.0	0.0	0.0
1998	157.7	0.0	113.4	14.8	6.2	0.1	23.2	0.0	0.0	0.0	0.0
1999	167.3	0.0	113.4	18.5	5.5	0.1	29.7	0.0	0.0	0.0	0.0
2000	175.2	0.0	90.7	19.2	5.8	0.2	59.3	0.0	0.0	0.0	0.0
2001	179.4	0.0	90.7	19.6	5.7	0.2	63.3	0.0	0.0	0.0	0.0
2002	185.6	0.0	68.0	21.3	7.0	0.1	89.3	0.0	0.0	0.0	0.0
2003	185.0	0.0	68.0	21.7	5.9	0.1	89.3	0.0	0.0	0.0	0.0
2004	219.4	0.0	68.0	17.9	6.8	0.2	126.5	0.0	0.0	0.0	0.0
2005	220.7	0.0	68.0	19.2	6.6	0.4	126.5	0.0	0.0	0.0	0.0
2006	202.5	0.0	45.3	21.1	8.9	0.6	126.5	0.0	0.0	0.0	0.0
2007	203.5	0.0	45.3	25.6	5.6	0.4	126.5	0.0	0.0	0.0	0.0
2008	208.6	0.0	45.3	30.9	5.5	0.3	126.5	0.0	0.0	0.0	0.0
2009	213.5	0.0	45.3	37.1	4.0	0.6	126.5	0.0	0.0	0.0	0.0
2010	177.8	0.0	0.0	44.9	5.9	0.5	126.5	0.0	0.0	0.0	0.0
2011	183.0	0.0	0.0	51.4	4.4	0.7	126.5	0.0	0.0	0.0	0.0
2012	188.2	0.0	0.0	56.9	4.1	0.7	126.5	0.0	0.0	0.0	0.0
2013	193.7	0.0	0.0	62.6	3.8	0.7	126.5	0.0	0.0	0.0	0.0
2014	187.6	0.0	0.0	56.0	4.5	0.6	126.5	0.0	0.0	0.0	0.0
2015	193.4	0.0	0.0	61.8	4.4	0.6	126.5	0.0	0.0	0.0	0.0
2016	188.1	0.0	0.0	57.0	4.0	0.5	126.5	0.0	0.0	0.0	0.0
TOTALS	3805.5	0.0	997.6	671.5	106.7	7.7	2022.0	0.0	0.0	0.0	0.0

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Figure 9.2 (page 18) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

EXPECTED COST OF OPERATION
FUEL COST
FOREIGN

TYPE OF PLANT:		NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****
YEAR	TOTAL	COST BY PLANT TYPE (MILLION $)									
1997	171.8	0.0	0.0	127.5	42.2	2.0	0.0	0.0	0.0	0.0	0.0
1998	261.8	0.0	0.0	135.5	122.7	3.6	0.0	0.0	0.0	0.0	0.0
1999	282.6	0.0	0.0	169.1	110.1	3.4	0.0	0.0	0.0	0.0	0.0
2000	296.0	0.0	0.0	175.0	115.3	5.7	0.0	0.0	0.0	0.0	0.0
2001	298.9	0.0	0.0	178.6	113.7	6.5	0.0	0.0	0.0	0.0	0.0
2002	336.5	0.0	0.0	193.9	137.9	4.7	0.0	0.0	0.0	0.0	0.0
2003	318.5	0.0	0.0	197.8	117.5	3.2	0.0	0.0	0.0	0.0	0.0
2004	303.5	0.0	0.0	163.1	134.5	5.9	0.0	0.0	0.0	0.0	0.0
2005	319.7	0.0	0.0	175.0	130.6	14.0	0.0	0.0	0.0	0.0	0.0
2006	390.4	0.0	0.0	192.9	177.0	20.5	0.0	0.0	0.0	0.0	0.0
2007	358.7	0.0	0.0	233.4	112.0	13.3	0.0	0.0	0.0	0.0	0.0
2008	402.8	0.0	0.0	282.1	108.4	12.2	0.0	0.0	0.0	0.0	0.0
2009	437.3	0.0	0.0	338.7	78.7	20.0	0.0	0.0	0.0	0.0	0.0
2010	542.3	0.0	0.0	410.0	116.1	16.2	0.0	0.0	0.0	0.0	0.0
2011	581.4	0.0	0.0	468.8	86.8	25.9	0.0	0.0	0.0	0.0	0.0
2012	625.2	0.0	0.0	519.4	80.6	25.2	0.0	0.0	0.0	0.0	0.0
2013	672.7	0.0	0.0	571.1	75.5	26.1	0.0	0.0	0.0	0.0	0.0
2014	660.6	39.4	0.0	511.2	89.7	20.3	0.0	0.0	0.0	0.0	0.0
2015	713.6	39.4	0.0	563.9	88.2	22.1	0.0	0.0	0.0	0.0	0.0
2016	696.3	78.8	0.0	520.6	78.6	18.3	0.0	0.0	0.0	0.0	0.0
TOTALS	8670.5	157.7	0.0	6127.6	2116.2	268.9	0.0	0.1	0.0	0.0	0.0

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EXPECTED COST OF OPERATION
OPERATION & MAINTENANCE AND ENERGY NOT SERVED (ENS)
DOMESTIC

TYPE OF PLANT:		NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	HYD1	HYD2	ENS
YEAR	TOTAL	COST BY PLANT TYPE (MILLION $)												
1997	170.7	0.0	55.4	42.5	37.4	7.2	10.8	2.6	0.0	0.0	0.0	4.2	10.6	0.0
1998	177.3	0.0	46.2	56.6	37.4	8.9	10.8	2.6	0.0	0.0	0.0	4.2	10.6	0.0
1999	189.3	0.0	46.2	70.8	37.4	8.8	10.8	0.6	0.0	0.0	0.0	4.2	10.6	0.0
2000	194.7	0.0	37.0	70.8	37.4	10.4	21.5	1.2	0.0	0.0	0.0	5.7	10.6	0.0
2001	197.1	0.0	37.0	70.8	37.4	12.1	21.5	0.0	0.0	0.0	0.0	5.7	12.5	0.0
2002	213.5	0.0	27.7	70.8	51.5	11.2	32.3	1.7	0.0	0.0	0.0	5.7	12.5	0.0
2003	216.8	0.0	27.7	70.8	51.5	11.2	32.3	1.7	0.0	0.0	0.0	5.1	16.5	0.0
2004	215.8	0.0	27.7	56.6	51.5	13.7	43.0	0.0	0.0	0.0	0.0	6.8	16.5	0.0
2005	213.5	0.0	27.7	56.6	42.1	18.7	43.0	0.0	0.0	0.0	0.0	6.8	18.5	0.0
2006	221.3	0.0	18.5	70.2	42.1	20.4	43.0	0.0	0.0	0.0	0.0	8.5	18.5	0.0
2007	242.7	0.0	18.5	97.9	32.8	19.5	43.0	0.0	0.0	0.0	0.0	8.5	22.4	0.0
2008	269.8	0.0	18.5	125.6	32.8	19.5	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2009	291.5	0.0	18.5	153.4	23.4	22.9	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2010	313.9	0.0	0.0	181.1	37.4	22.0	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2011	333.9	0.0	0.0	208.8	28.1	23.6	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2012	362.4	0.0	0.0	236.5	28.1	24.4	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2013	390.2	0.0	0.0	264.2	28.1	24.4	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.1
2014	422.2	32.9	0.0	264.2	28.1	23.5	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.1
2015	450.0	32.9	0.0	292.0	28.1	23.5	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.1
2016	482.9	65.9	0.0	292.0	28.1	23.5	43.0	0.0	0.0	0.0	0.0	7.9	22.4	0.1
TOTALS	5569.4	131.8	406.6	2752.3	720.7	349.5	699.4	10.4	0.0	0.0	0.0	136.5	361.7	0.6

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Figure 9.2 (page 19) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

EXPECTED COST OF OPERATION
TOTAL COST
DOMESTIC AND FOREIGN

TYPE OF PLANT:		NUCL	CO-1	CO-2	FOIL	GTGO	LIGN	IMPO	****	****	****	HYD1	HYD2	ENS
YEAR	TOTAL	COST BY PLANT TYPE (MILLION $)												
1997	517.8	0.0	191.5	184.0	81.8	9.2	33.9	2.6	0.0	0.0	0.0	4.2	10.6	0.0
1998	596.7	0.0	159.6	207.0	166.3	12.6	33.9	2.6	0.0	0.0	0.0	4.2	10.6	0.0
1999	639.2	0.0	159.6	258.5	153.1	12.3	40.5	0.6	0.0	0.0	0.0	4.2	10.6	0.0
2000	665.9	0.0	127.7	265.0	158.6	16.3	80.9	1.2	0.0	0.0	0.0	5.7	10.6	0.0
2001	675.4	0.0	127.6	269.0	156.9	18.8	84.8	0.0	0.0	0.0	0.0	5.7	12.5	0.0
2002	735.6	0.0	95.7	286.0	196.3	16.0	121.5	1.7	0.0	0.0	0.0	5.7	12.5	0.0
2003	720.3	0.0	95.7	290.3	174.9	14.5	121.5	1.7	0.0	0.0	0.0	5.1	16.5	0.0
2004	738.7	0.0	95.7	237.7	192.7	19.7	169.6	0.0	0.0	0.0	0.0	6.8	16.5	0.0
2005	753.9	0.0	95.7	250.9	179.4	33.1	169.6	0.0	0.0	0.0	0.0	6.8	18.5	0.0
2006	814.2	0.0	63.8	284.3	228.0	41.5	169.6	0.0	0.0	0.0	0.0	8.5	18.5	0.0
2007	804.8	0.0	63.8	356.9	150.4	33.2	169.6	0.0	0.0	0.0	0.0	8.5	22.4	0.0
2008	881.1	0.0	63.8	438.7	146.7	32.1	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2009	942.3	0.0	63.8	529.2	106.0	43.4	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2010	1034.0	0.0	0.0	636.0	159.4	38.6	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2011	1098.4	0.0	0.0	728.9	119.2	50.3	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2012	1175.8	0.0	0.0	812.8	112.8	50.3	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.0
2013	1256.5	0.0	0.0	897.9	107.4	51.3	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.1
2014	1270.5	72.4	0.0	831.4	122.3	44.4	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.1
2015	1356.9	72.4	0.0	917.6	120.7	46.2	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.1
2016	1367.2	144.7	0.0	869.6	110.6	42.3	169.6	0.0	0.0	0.0	0.0	7.9	22.4	0.1
TOTALS	18045.3	289.5	1404.1	9551.5	2943.6	626.0	2721.4	10.5	0.0	0.0	0.0	136.5	361.7	0.6

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DOMESTIC CONSTRUCTION COSTS (MILLION $)

YEAR	#	PLANT	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	SUM
1998	1	V-GT	.	.	.	4.7	10.3	.	.	.	.	.	.	.	15.0
1999	1	V-GT	.	.	.	.	4.7	10.3	.	.	.	.	.	.	15.0
2000	1	V-GT	.	.	.	.	.	4.7	10.3	.	.	.	.	.	15.0
2000	1	VHY1	.	4.4	10.9	33.6	57.5	38.4	10.7	.	.	.	.	.	155.5
2001	1	V-GT	.	.	.	.	.	.	4.7	10.3	.	.	.	.	15.0
2001	1	VHY2	4.2	7.1	20.9	35.5	64.0	39.8	35.3	8.7	.	.	.	.	215.5
2002	1	VFOL	.	.	.	.	2.2	10.7	39.2	59.2	21.1	.	.	.	132.3
2003	1	VHY4	.	.	9.3	15.8	46.8	79.5	143.2	89.1	79.1	19.5	.	.	482.4
2004	2	V-GT	.	.	.	.	.	.	.	.	.	9.4	20.5	.	29.9
2004	1	VHY3	.	.	.	.	.	5.3	13.2	40.7	69.7	46.5	13.0	.	188.4
2005	3	V-GT	.	.	.	.	.	.	.	.	.	.	14.1	30.8	44.9
2005	1	VHY6	.	.	.	.	5.4	9.2	27.2	46.2	83.2	51.8	46.0	11.3	280.3
END		TOTAL	4.2	11.5	41.1	89.6	191.0	197.8	297.9	286.3	348.5	333.3	484.8	369.1	

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Figure 9.2 (page 20) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

DOMESTIC CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR	#	PLANT	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	SUM
2006	1	VCOA	.	1.9	7.0	28.8	54.2	40.4	12.4	.	.	.	.	.	144.7
2006	1	V-GT	.	.	.	.	.	4.7	10.3	.	.	.	.	.	15.0
2006	1	VHY5	.	6.2	15.4	47.7	81.7	54.5	15.3	.	.	.	.	.	220.9
2007	1	VCOA	.	.	1.9	7.0	28.8	54.2	40.4	12.4	.	.	.	.	144.7
2007	1	VHY7	14.2	24.0	71.1	120.8	217.6	135.5	120.2	29.6	.	.	.	.	733.0
2008	1	VCOA	.	.	.	1.9	7.0	28.8	54.2	40.4	12.4	.	.	.	144.7
2009	1	VCOA	.	.	.	.	1.9	7.0	28.8	54.2	40.4	12.4	.	.	144.7
2009	2	V-GT	.	.	.	.	.	.	.	.	9.4	20.5	.	.	29.9
2010	1	VCOA	.	.	.	.	.	1.9	7.0	28.8	54.2	40.4	12.4	.	144.7
2010	1	VPOL	.	.	.	.	.	.	2.2	10.7	39.2	59.2	21.1	.	132.3
2011	1	VCOA	.	.	.	.	.	.	1.9	7.0	28.8	54.2	40.4	12.4	144.7
2011	1	V-GT	.	.	.	.	.	.	.	.	.	.	4.7	10.3	15.0
END TOTAL			297.9	286.3	348.5	333.3	484.8	369.1	292.6	187.3	200.3	240.7	216.0	210.7	

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DOMESTIC CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR	#	PLANT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2012	1	VCOA	1.9	7.0	28.8	54.2	40.4	12.4	.	.	.	.	144.7
2012	1	V-GT	.	.	.	.	4.7	10.3	.	.	.	.	15.0
2013	1	VCOA	.	1.9	7.0	28.8	54.2	40.4	12.4	.	.	.	144.7
2014	1	VNUC	2.3	7.1	15.9	45.4	65.8	62.3	47.1	11.5	.	.	257.3
2015	1	VCOA	.	.	.	1.9	7.0	28.8	54.2	40.4	12.4	.	144.7
2016	1	VNUC	.	.	2.3	7.1	15.9	45.4	65.8	62.3	47.1	11.5	257.3
END TOTAL			187.3	200.3	240.7	216.0	210.7	199.5	179.6	114.2	59.5	11.5	4567.0

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Figure 9.2 (page 21) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

FOREIGN CONSTRUCTION COSTS (MILLION $)

YEAR	#	PLANT	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	SUM
1998	1	V-GT	.	.	.	18.8	41.0	.	.	.	.	.	.	.	59.8
1999	1	V-GT	.	.	.	.	18.8	41.0	.	.	.	.	.	.	59.8
2000	1	V-GT	.	.	.	.	.	18.8	41.0	.	.	.	.	.	59.8
2000	1	VHY1	.	1.9	4.7	14.4	24.6	16.4	4.6	.	.	.	.	.	66.5
2001	1	V-GT	.	.	.	.	.	.	18.8	41.0	.	.	.	.	59.8
2001	1	VHY2	1.8	3.0	9.0	15.2	27.4	17.1	15.1	3.7	.	.	.	.	92.4
2002	1	VFOL	.	.	.	.	6.2	29.6	107.9	163.6	57.8	.	.	.	365.0
2003	1	VHY4	.	.	4.0	6.8	20.1	34.0	61.3	38.1	33.9	8.3	.	.	206.4
2004	2	V-GT	.	.	.	.	.	.	.	.	.	37.6	82.1	.	119.7
2004	1	VHY3	.	.	.	.	.	2.3	5.6	17.4	29.9	19.9	5.6	.	80.7
2005	3	V-GT	.	.	.	.	.	.	.	.	.	.	56.4	123.1	179.5
2005	1	VHY6	.	.	.	.	2.3	3.9	11.6	19.8	35.6	22.2	19.7	4.8	120.0
END		TOTAL	1.8	4.9	17.6	55.1	140.4	163.2	272.1	301.7	217.9	260.8	537.7	582.2	

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FOREIGN CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR	#	PLANT	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	SUM
2006	1	VCOA	.	5.0	18.7	77.0	145.2	108.2	33.3	.	.	.	.	.	387.4
2006	1	V-GT	.	.	.	.	.	18.8	41.0	.	.	.	.	.	59.8
2006	1	VHY5	.	2.7	6.6	20.4	35.0	23.3	6.5	.	.	.	.	.	94.5
2007	1	VCOA	.	.	5.0	18.7	77.0	145.2	108.2	33.3	.	.	.	.	387.4
2007	1	VHY7	6.1	10.3	30.5	51.7	93.2	58.0	51.5	12.7	.	.	.	.	313.8
2008	1	VCOA	.	.	.	5.0	18.7	77.0	145.2	108.2	33.3	.	.	.	387.4
2009	1	VCOA	.	.	.	.	5.0	18.7	77.0	145.2	108.2	33.3	.	.	387.4
2009	2	V-GT	.	.	.	.	.	.	.	.	37.6	82.1	.	.	119.7
2010	1	VCOA	.	.	.	.	.	5.0	18.7	77.0	145.2	108.2	33.3	.	387.4
2010	1	VFOL	.	.	.	.	.	.	6.2	29.6	107.9	163.6	57.8	.	365.0
2011	1	VCOA	.	.	.	.	.	.	5.0	18.7	77.0	145.2	108.2	33.3	387.4
2011	1	V-GT	.	.	.	.	.	.	.	.	.	.	18.8	41.0	59.8
END		TOTAL	272.1	301.7	217.9	260.8	537.7	582.2	492.6	440.1	565.0	710.5	683.4	736.1	

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FOREIGN CONSTRUCTION COSTS (MILLION $) (CONTD.)

YEAR	#	PLANT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2012	1	VCOA	5.0	18.7	77.0	145.2	108.2	33.3	.	.	.	.	387.4
2012	1	V-GT	.	.	.	.	18.8	41.0	.	.	.	.	59.8
2013	1	VCOA	.	5.0	18.7	77.0	145.2	108.2	33.3	.	.	.	387.4
2014	1	VNUC	10.4	32.2	72.0	206.0	299.0	282.7	213.7	52.4	.	.	1168.5
2015	1	VCOA	.	.	.	5.0	18.7	77.0	145.2	108.2	33.3	.	387.4
2016	1	VNUC	.	.	10.4	32.2	72.0	206.0	299.0	282.7	213.7	52.4	1168.5
END		TOTAL	440.1	565.0	710.5	683.4	736.1	748.2	691.2	443.3	247.0	52.4	8365.3

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Figure 9.2 (page 22) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

DOMESTIC INT. DURING CONSTR. (MILLION $)

YEAR	#	PLANT	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	SUM
1998	1	V-GT	.	.	.	0.2	0.8	.	.	.	.	.	.	.	1.0
1999	1	V-GT	.	.	.	.	0.2	0.8	.	.	.	.	.	.	1.0
2000	1	V-GT	.	.	.	.	.	0.2	0.8	.	.	.	.	.	1.0
2000	1	VHY1	.	0.2	0.8	2.6	6.5	10.8	13.7	.	.	.	.	.	34.6
2001	1	V-GT	.	.	.	.	.	.	0.2	0.8	.	.	.	.	1.0
2001	1	VHY2	0.2	0.6	1.8	4.2	8.5	13.3	17.4	20.6	.	.	.	.	66.5
2002	1	VFOL	.	.	.	.	0.1	0.6	2.6	6.8	10.5	.	.	.	20.6
2003	1	VHY4	.	.	0.4	1.4	4.0	9.4	19.0	29.8	38.9	46.0	.	.	148.9
2004	2	V-GT	.	.	.	.	.	.	.	.	.	0.4	1.6	.	2.0
2004	1	VHY3	.	.	.	.	.	0.2	1.0	3.2	7.8	13.1	16.6	.	41.9
2005	3	V-GT	.	.	.	.	.	.	.	.	.	.	0.6	2.4	2.9
2005	1	VHY6	.	.	.	.	0.2	0.8	2.3	5.4	11.0	17.3	22.6	26.7	86.5
END		TOTAL	0.2	0.8	2.9	8.4	20.2	36.1	57.5	69.0	76.1	97.2	87.1	107.3	

DOMESTIC INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR	#	PLANT	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	SUM
2006	1	VCOA	.	0.1	0.4	1.9	5.3	9.6	12.5	.	.	.	.	.	29.7
2006	1	V-GT	.	.	.	.	.	0.2	0.8	.	.	.	.	.	1.0
2006	1	VHY5	.	0.2	1.1	3.7	9.2	15.4	19.4	.	.	.	.	.	49.1
2007	1	VCOA	.	.	0.1	0.4	1.9	5.3	9.6	12.5	.	.	.	.	29.7
2007	1	VHY7	0.6	2.1	6.1	14.2	28.8	45.3	59.2	69.9	.	.	.	.	226.2
2008	1	VCOA	.	.	.	0.1	0.4	1.9	5.3	9.6	12.5	.	.	.	29.7
2009	1	VCOA	.	.	.	.	0.1	0.4	1.9	5.3	9.6	12.5	.	.	29.7
2009	2	V-GT	.	.	.	.	.	.	.	.	0.4	1.6	.	.	2.0
2010	1	VCOA	.	.	.	.	.	0.1	0.4	1.9	5.3	9.6	12.5	.	29.7
2010	1	VFOL	.	.	.	.	.	.	0.1	0.6	2.6	6.8	10.5	.	20.6
2011	1	VCOA	.	.	.	.	.	.	0.1	0.4	1.9	5.3	9.6	12.5	29.7
2011	1	V-GT	.	.	.	.	.	.	.	.	.	.	0.2	0.8	1.0
END		TOTAL	57.5	69.0	76.1	97.2	87.1	107.3	109.2	100.4	33.2	39.5	44.5	38.9	

DOMESTIC INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR	#	PLANT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2012	1	VCOA	0.1	0.4	1.9	5.3	9.6	12.5	.	.	.	.	29.7
2012	1	V-GT	.	.	.	.	0.2	0.8	.	.	.	.	1.0
2013	1	VCOA	.	0.1	0.4	1.9	5.3	9.6	12.5	.	.	.	29.7
2014	1	VNUC	0.1	0.5	1.4	4.0	8.7	14.5	20.1	24.1	.	.	73.4
2015	1	VCOA	.	.	.	0.1	0.4	1.9	5.3	9.6	12.5	.	29.7
2016	1	VNUC	.	.	0.1	0.5	1.4	4.0	8.7	14.5	20.1	24.1	73.4
END		TOTAL	100.4	33.2	39.5	44.5	38.9	43.2	46.6	48.2	32.5	24.1	1123.2

Figure 9.2 (page 23) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

FOREIGN INT. DURING CONSTR. (MILLION $)

YEAR	#	PLANT	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	SUM
1998	1	V-GT	.	.	.	0.7	3.2	.	.	.	.	.	.	.	3.9
1999	1	V-GT	.	.	.	.	0.7	3.2	.	.	.	.	.	.	3.9
2000	1	V-GT	.	.	.	.	.	0.7	3.2	.	.	.	.	.	3.9
2000	1	VHY1	.	0.1	0.3	1.1	2.8	4.6	5.9	.	.	.	.	.	14.8
2001	1	V-GT	.	.	.	.	.	.	0.7	3.2	.	.	.	.	3.9
2001	1	VHY2	0.1	0.3	0.8	1.8	3.6	5.7	7.5	8.8	.	.	.	.	28.5
2002	1	VPOL	.	.	.	.	0.2	1.7	7.3	18.7	29.1	.	.	.	57.0
2003	1	VHY4	.	.	0.2	0.6	1.7	4.0	8.1	12.8	16.7	19.7	.	.	63.7
2004	2	V-GT	.	.	.	.	.	.	.	.	.	1.5	6.4	.	7.8
2004	1	VHY3	.	.	.	.	.	0.1	0.4	1.4	3.4	5.6	7.1	.	17.9
2005	3	V-GT	.	.	.	.	.	.	.	.	.	.	2.2	9.5	11.8
2005	1	VHY6	.	.	.	.	0.1	0.3	1.0	2.3	4.7	7.4	9.7	11.4	37.0
END		TOTAL	0.1	0.3	1.3	4.3	12.4	20.4	34.3	48.3	58.3	48.3	62.3	94.0	

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FOREIGN INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR	#	PLANT	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	SUM
2006	1	VCOA	.	0.2	1.2	5.0	14.3	25.6	33.3	.	.	.	.	.	79.6
2006	1	V-GT	.	.	.	.	.	0.7	3.2	.	.	.	.	.	3.9
2006	1	VHY5	.	0.1	0.5	1.6	3.9	6.6	8.3	.	.	.	.	.	21.0
2007	1	VCOA	.	.	0.2	1.2	5.0	14.3	25.6	33.3	.	.	.	.	79.6
2007	1	VHY7	0.2	0.9	2.6	6.1	12.3	19.4	25.3	29.9	.	.	.	.	96.9
2008	1	VCOA	.	.	.	0.2	1.2	5.0	14.3	25.6	33.3	.	.	.	79.6
2009	1	VCOA	.	.	.	.	0.2	1.2	5.0	14.3	25.6	33.3	.	.	79.6
2009	2	V-GT	.	.	.	.	.	.	.	.	1.5	6.4	.	.	7.8
2010	1	VCOA	.	.	.	.	.	0.2	1.2	5.0	14.3	25.6	33.3	.	79.6
2010	1	VPOL	.	.	.	.	.	.	0.2	1.7	7.3	18.7	29.1	.	57.0
2011	1	VCOA	.	.	.	.	.	.	0.2	1.2	5.0	14.3	25.6	33.3	79.6
2011	1	V-GT	.	.	.	.	.	.	.	.	.	.	0.7	3.2	3.9
END		TOTAL	34.3	48.3	58.3	48.3	62.3	94.0	116.7	111.7	90.5	111.4	128.5	124.4	

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FOREIGN INT. DURING CONSTR. (MILLION $) (CONTD.)

YEAR	#	PLANT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2012	1	VCOA	0.2	1.2	5.0	14.3	25.6	33.3	.	.	.	.	79.6
2012	1	V-GT	.	.	.	.	0.7	3.2	.	.	.	.	3.9
2013	1	VCOA	.	0.2	1.2	5.0	14.3	25.6	33.3	.	.	.	79.6
2014	1	VNUC	0.4	2.1	6.5	18.0	39.6	66.1	91.2	109.3	.	.	333.2
2015	1	VCOA	.	.	.	0.2	1.2	5.0	14.3	25.6	33.3	.	79.6
2016	1	VNUC	.	.	0.4	2.1	6.5	18.0	39.6	66.1	91.2	109.3	333.2
END		TOTAL	111.7	90.5	111.4	128.5	124.4	151.3	178.5	200.9	124.6	109.3	1831.9

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Figure 9.2 (page 24) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

DOMESTIC CONSTRUCTION & IDC (MILLION $)

YEAR	#	PLANT	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	SUM
1998	1	V-GT	.	.	.	4.9	11.1	.	.	.	.	.	.	.	15.9
1999	1	V-GT	.	.	.	.	4.9	11.1	.	.	.	.	.	.	15.9
2000	1	V-GT	.	.	.	.	.	4.9	11.1	.	.	.	.	.	15.9
2000	1	VHY1	.	4.6	11.7	36.2	64.0	49.2	24.4	.	.	.	.	.	190.0
2001	1	V-GT	.	.	.	.	.	.	4.9	11.1	.	.	.	.	15.9
2001	1	VHY2	4.3	7.7	22.7	39.7	72.5	53.2	52.7	29.3	.	.	.	.	282.0
2002	1	VFOL	.	.	.	.	2.3	11.3	41.8	66.0	31.6	.	.	.	152.9
2003	1	VHY4	.	.	9.7	17.2	50.8	88.9	162.2	119.0	118.0	65.5	.	.	631.3
2004	2	V-GT	.	.	.	.	.	.	.	.	.	9.8	22.1	.	31.9
2004	1	VHY3	.	.	.	.	.	5.5	14.1	43.8	77.6	59.6	29.6	.	230.2
2005	3	V-GT	.	.	.	.	.	.	.	.	.	.	14.6	33.2	47.8
2005	1	VHY6	.	.	.	.	5.6	10.0	29.5	51.6	94.2	69.1	68.6	38.1	366.8
END		TOTAL	4.3	12.3	44.1	98.0	211.2	234.0	355.5	355.3	424.5	430.5	571.9	476.4	

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DOMESTIC CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR	#	PLANT	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	SUM
2006	1	VCOA	.	2.0	7.4	30.7	59.6	50.0	24.9	.	.	.	.	.	174.5
2006	1	V-GT	.	.	.	.	.	4.9	11.1	.	.	.	.	.	15.9
2006	1	VHY5	.	6.5	16.6	51.4	90.9	69.9	34.7	.	.	.	.	.	269.9
2007	1	VCOA	.	.	2.0	7.4	30.7	59.6	50.0	24.9	.	.	.	.	174.5
2007	1	VHY7	14.7	26.2	77.2	135.0	246.4	180.8	179.3	99.6	.	.	.	.	959.2
2008	1	VCOA	.	.	.	2.0	7.4	30.7	59.6	50.0	24.9	.	.	.	174.5
2009	1	VCOA	.	.	.	.	2.0	7.4	30.7	59.6	50.0	24.9	.	.	174.5
2009	2	V-GT	.	.	.	.	.	.	.	.	9.8	22.1	.	.	31.9
2010	1	VCOA	.	.	.	.	.	2.0	7.4	30.7	59.6	50.0	24.9	.	174.5
2010	1	VFOL	.	.	.	.	.	.	2.3	11.3	41.8	66.0	31.6	.	152.9
2011	1	VCOA	.	.	.	.	.	.	2.0	7.4	30.7	59.6	50.0	24.9	174.5
2011	1	V-GT	.	.	.	.	.	.	.	.	.	.	4.9	11.1	15.9
END		TOTAL	355.5	355.3	424.5	430.5	571.9	476.4	401.9	287.7	233.6	280.3	260.4	249.6	

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DOMESTIC CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR	#	PLANT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2012	1	VCOA	2.0	7.4	30.7	59.6	50.0	24.9	.	.	.	.	174.5
2012	1	V-GT	.	.	.	.	4.9	11.1	.	.	.	.	15.9
2013	1	VCOA	.	2.0	7.4	30.7	59.6	50.0	24.9	.	.	.	174.5
2014	1	VNUC	2.4	7.6	17.3	49.3	74.6	76.8	67.2	35.6	.	.	330.7
2015	1	VCOA	.	.	.	2.0	7.4	30.7	59.6	50.0	24.9	.	174.5
2016	1	VNUC	.	.	2.4	7.6	17.3	49.3	74.6	76.8	67.2	35.6	330.7
END		TOTAL	287.7	233.6	280.3	260.4	249.6	242.7	226.2	162.4	92.1	35.6	5690.2

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Figure 9.2 (page 25) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

FOREIGN CONSTRUCTION & IDC (MILLION $)

YEAR	# PLANT	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	SUM
1998	1 V-GT	.	.	.	19.5	44.2	.	.	.	.	.	.	.	63.8
1999	1 V-GT	.	.	.	.	19.5	44.2	.	.	.	.	.	.	63.8
2000	1 V-GT	.	.	.	.	.	19.5	44.2	.	.	.	.	.	63.8
2000	1 VHY1	.	2.0	5.0	15.5	27.4	21.1	10.4	.	.	.	.	.	81.3
2001	1 V-GT	.	.	.	.	.	.	19.5	44.2	.	.	.	.	63.8
2001	1 VHY2	1.9	3.3	9.7	17.0	31.1	22.8	22.6	12.5	.	.	.	.	120.9
2002	1 VFOL	.	.	.	.	6.4	31.3	115.2	182.3	86.9	.	.	.	422.0
2003	1 VHY4	.	.	4.1	7.4	21.8	38.0	69.4	50.9	50.5	28.0	.	.	270.1
2004	2 V-GT	.	.	.	.	.	.	.	.	.	39.1	88.5	.	127.5
2004	1 VHY3	.	.	.	.	.	2.4	6.1	18.8	33.2	25.5	12.7	.	98.7
2005	3 V-GT	.	.	.	.	.	.	.	.	.	.	58.6	132.7	191.3
2005	1 VHY6	.	.	.	.	2.4	4.3	12.6	22.1	40.3	29.6	29.4	16.3	157.0
END TOTAL		1.9	5.2	18.8	59.4	152.8	183.6	306.4	350.1	276.1	309.1	600.1	676.2	

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FOREIGN CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR	# PLANT	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	SUM
2006	1 VCOA	.	5.2	19.8	82.1	159.5	133.8	66.6	.	.	.	.	.	467.0
2006	1 V-GT	.	.	.	.	.	19.5	44.2	.	.	.	.	.	63.8
2006	1 VHY5	.	2.8	7.1	22.0	38.9	29.9	14.8	.	.	.	.	.	115.5
2007	1 VCOA	.	.	5.2	19.8	82.1	159.5	133.8	66.6	.	.	.	.	467.0
2007	1 VHY7	6.3	11.2	33.1	57.8	105.5	77.4	76.8	42.6	.	.	.	.	410.7
2008	1 VCOA	.	.	.	5.2	19.8	82.1	159.5	133.8	66.6	.	.	.	467.0
2009	1 VCOA	.	.	.	.	5.2	19.8	82.1	159.5	133.8	66.6	.	.	467.0
2009	2 V-GT	.	.	.	.	.	.	.	.	39.1	88.5	.	.	127.5
2010	1 VCOA	.	.	.	.	.	5.2	19.8	82.1	159.5	133.8	66.6	.	467.0
2010	1 VFOL	.	.	.	.	.	.	6.4	31.3	115.2	182.3	86.9	.	422.0
2011	1 VCOA	.	.	.	.	.	.	5.2	19.8	82.1	159.5	133.8	66.6	467.0
2011	1 V-GT	.	.	.	.	.	.	.	.	.	.	19.5	44.2	63.8
END TOTAL		306.4	350.1	276.1	309.1	600.1	676.2	609.3	551.8	655.6	821.9	811.9	860.5	

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FOREIGN CONSTRUCTION & IDC (MILLION $) (CONTD.)

YEAR	# PLANT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	SUM
2012	1 VCOA	5.2	19.8	82.1	159.5	133.8	66.6	.	.	.	.	467.0
2012	1 V-GT	.	.	.	.	19.5	44.2	.	.	.	.	63.8
2013	1 VCOA	.	5.2	19.8	82.1	159.5	133.8	66.6	.	.	.	467.0
2014	1 VNUC	10.9	34.3	78.5	224.0	338.6	348.8	305.0	161.7	.	.	1501.7
2015	1 VCOA	.	.	.	5.2	19.8	82.1	159.5	133.8	66.6	.	467.0
2016	1 VNUC	.	.	10.9	34.3	78.5	224.0	338.6	348.8	305.0	161.7	1501.7
END TOTAL		551.8	655.6	821.9	811.9	860.5	899.5	869.7	644.2	371.6	161.7	10197.3

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Figure 9.2 (page 26) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

FOREIGN FUEL INVESTMENT (MILLION $)

YEAR	# PLANT	2012	2013	2014	2015	SUM
2014	1 VNUC	22.1	202.9	.	.	225.0
2016	1 VNUC	.	.	22.1	202.9	225.0
END	TOTAL	22.1	202.9	22.1	202.9	450.0

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CAPITAL CASH FLOW SUMMARY OF CANDIDATES (MILLION $)

	FUEL			CONSTRUCTION			IDC			
YEAR	DOM.	FOR.	TOTAL	DOM.	FOR.	TOTAL	DOM.	FOR.	TOTAL	GR. TOT.
1993	0.00	0.00	0.00	4.16	1.78	5.95	0.16	0.07	0.23	6.18
1994	0.00	0.00	0.00	11.45	4.91	16.36	0.80	0.34	1.14	17.50
1995	0.00	0.00	0.00	41.13	17.58	58.71	2.95	1.26	4.21	62.92
1996	0.00	0.00	0.00	89.57	55.12	144.69	8.39	4.25	12.64	157.33
1997	0.00	0.00	0.00	190.97	140.40	331.38	20.23	12.37	32.59	363.97
1998	0.00	0.00	0.00	197.84	163.17	361.01	36.12	20.39	56.51	417.51
1999	0.00	0.00	0.00	297.95	272.09	570.04	57.51	34.27	91.78	661.82
2000	0.00	0.00	0.00	286.32	301.72	588.04	69.01	48.34	117.36	705.40
2001	0.00	0.00	0.00	348.49	217.87	566.36	76.05	58.27	134.32	700.68
2002	0.00	0.00	0.00	333.29	260.83	594.12	97.18	48.29	145.48	739.59
2003	0.00	0.00	0.00	484.78	537.73	1022.51	87.09	62.35	149.44	1171.95
2004	0.00	0.00	0.00	369.06	582.18	951.24	107.30	94.01	201.32	1152.55
2005	0.00	0.00	0.00	292.63	492.56	785.19	109.23	116.71	225.94	1011.12
2006	0.00	0.00	0.00	187.28	440.12	627.40	100.39	111.68	212.07	839.47
2007	0.00	0.00	0.00	200.34	565.04	765.39	33.22	90.54	123.76	889.15
2008	0.00	0.00	0.00	240.74	710.52	951.25	39.55	111.36	150.91	1102.16
2009	0.00	0.00	0.00	215.95	683.43	899.39	44.48	128.48	172.97	1072.35
2010	0.00	0.00	0.00	210.72	736.14	946.85	38.92	124.39	163.31	1110.16
2011	0.00	0.00	0.00	199.51	748.23	947.74	43.22	151.25	194.47	1142.21
2012	0.00	22.08	22.08	179.58	691.17	870.75	46.62	178.50	225.11	1117.95
2013	0.00	202.92	202.92	114.22	443.32	557.54	48.18	200.92	249.10	1009.56
2014	0.00	22.08	22.08	59.51	247.03	306.54	32.55	124.58	157.13	485.75
2015	0.00	202.92	202.92	11.54	52.42	63.96	24.06	109.27	133.33	400.21
DOM.	0.00			4567.04			1123.21			16337.50
FOREIGN		450.00			8365.36			1831.90		
TOTAL			450.00			12932.39			2955.11	

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Figure 9.2 (page 27) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

CAPITAL CASH FLOW SUMMARY OF DECIDED SYSTEM (MILLION $)

	FUEL			CONSTRUCTION			IDC			
YEAR	DOM.	FOR.	TOTAL	DOM.	FOR.	TOTAL	DOM.	FOR.	TOTAL	GR. TOT.
1989	0.00	0.00	0.00	23.53	10.09	33.62	9.22	3.95	13.18	46.79
1990	0.00	0.00	0.00	31.38	13.45	44.82	11.53	4.94	16.47	61.29
1991	0.00	0.00	0.00	78.44	33.62	112.06	29.98	12.84	42.82	154.88
1992	0.00	0.00	0.00	117.66	50.43	168.09	34.59	14.82	49.41	217.50
1993	0.00	0.00	0.00	259.44	165.42	424.86	65.12	44.71	109.83	534.69
1994	0.00	0.00	0.00	209.34	225.28	434.61	58.57	53.11	111.68	546.29
1995	0.00	0.00	0.00	202.08	276.39	478.47	49.53	54.84	104.37	582.84
1996	0.00	0.00	0.00	67.56	110.29	177.84	16.88	29.64	46.52	224.37
1997	0.00	0.00	0.00	24.12	64.56	88.68	2.49	6.67	9.16	97.84
1998	0.00	0.00	0.00	12.06	32.28	44.34	2.49	6.67	9.16	53.50
DOM.	0.00			1025.60			280.40			2520.00
FOREIGN		0.00			981.80			232.20		
TOTAL			0.00			2007.40			512.60	

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GLOBAL CAPITAL CASH FLOW SUMMARY (MILLION $)

	FUEL			CONSTRUCTION			IDC			
YEAR	DOM.	FOR.	TOTAL	DOM.	FOR.	TOTAL	DOM.	FOR.	TOTAL	GR. TOT.
1989	0.00	0.00	0.00	23.53	10.09	33.62	9.22	3.95	13.18	46.79
1990	0.00	0.00	0.00	31.38	13.45	44.82	11.53	4.94	16.47	61.29
1991	0.00	0.00	0.00	78.44	33.62	112.06	29.98	12.84	42.82	154.88
1992	0.00	0.00	0.00	117.66	50.43	168.09	34.59	14.82	49.41	217.50
1993	0.00	0.00	0.00	263.60	167.20	430.81	65.28	44.78	110.06	540.87
1994	0.00	0.00	0.00	220.79	230.18	450.97	59.37	53.45	112.82	563.80
1995	0.00	0.00	0.00	243.21	293.97	537.18	52.48	56.10	108.58	645.76
1996	0.00	0.00	0.00	157.13	165.41	322.54	25.27	33.90	59.16	381.70
1997	0.00	0.00	0.00	215.09	204.96	420.06	22.72	19.04	41.75	461.81
1998	0.00	0.00	0.00	209.90	195.45	405.35	38.61	27.06	65.67	471.01
1999	0.00	0.00	0.00	297.95	272.09	570.04	57.51	34.27	91.78	661.82
2000	0.00	0.00	0.00	286.32	301.72	588.04	69.01	48.34	117.36	705.40
2001	0.00	0.00	0.00	348.49	217.87	566.36	76.05	58.27	134.32	700.68
2002	0.00	0.00	0.00	333.29	260.83	594.12	97.18	48.29	145.48	739.59
2003	0.00	0.00	0.00	484.78	537.73	1022.51	87.09	62.35	149.44	1171.95
2004	0.00	0.00	0.00	369.06	582.18	951.24	107.30	94.01	201.32	1152.55
2005	0.00	0.00	0.00	292.63	492.56	785.19	109.23	116.71	225.94	1011.12
2006	0.00	0.00	0.00	187.28	440.12	627.40	100.39	111.68	212.07	839.47
2007	0.00	0.00	0.00	200.34	565.04	765.39	33.22	90.54	123.76	889.15
2008	0.00	0.00	0.00	240.74	710.52	951.25	39.55	111.36	150.91	1102.16
2009	0.00	0.00	0.00	215.95	683.43	899.39	44.48	128.48	172.97	1072.35
2010	0.00	0.00	0.00	210.72	736.14	946.85	38.92	124.39	163.31	1110.16
2011	0.00	0.00	0.00	199.51	748.23	947.74	43.22	151.25	194.47	1142.21
2012	0.00	22.08	22.08	179.58	691.17	870.75	46.62	178.50	225.11	1117.95
2013	0.00	202.92	202.92	114.22	443.32	557.54	48.18	200.92	249.10	1009.56
2014	0.00	22.08	22.08	59.51	247.03	306.54	32.55	124.58	157.13	485.75
2015	0.00	202.92	202.92	11.54	52.42	63.96	24.06	109.27	133.33	400.21
DOM.	0.00			5592.64			1403.61			18857.50
FOREIGN		450.00			9347.15			2064.10		
TOTAL			450.00			14939.79			3467.71	

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Figure 9.2 (page 28) REPROBAT Printout for the Optimal Solution of CASE93 (cont.)

Pages 33-35 report the input data given in the respective DYNPRO run. Page 33 shows the *Summary of Capital Cost* data on the OSDYNDAT (DYNPRO) file (see Page 1 of Fig. 8.4). The information on this page is reported only once by REPROBAT regardless of how many times cards type-2 are used in the DYNPRO run to change capital cost data for the expansion candidates (For the sample problem cards type-2 were used only once for all DYNPRO runs).

Pages 34-35 show the additional input data *(Economic Parameters and Constraints)* for the respective DYNPRO run (DYNPRO Run-3). Here the values of the respective variables of DYNPRO are given for the first year of the study and for any change introduced later. In each case the headings indicate between parenthesis the type of data card INDEX used in the DYNPRO runs. When a zero appears between the parenthesis it means that the values which follow correspond to default values in the program, i.e. that the respective type card was not used in DYNPRO. Thus, although no escalation ratios on capital costs were specified in DYNPRO Run-3, the default values for these escalation ratios applied by DYNPRO are shown in Page 34 of the printout. Similarly, constraints on plant addition schedule, escalation ratios on operating costs, multiplying factors for fuel cost and penalty factor on foreign expenditures in DYNPRO Run-3 were all set to the respective default values. On the other hand DYNPRO input data for cards type 14 and 15 (discount rates on operating costs), type 11 (coefficients of unserved energy cost function), type 12 (critical annual LOLP), and type 16 (salvage value option) are also given in Page 35 showing the INDEX number of each case, indicating that these values were actually read as input data.

For the optimal solution, Pages 36 to 39 give the *Expected Operating Cost Summary*, by year and by plant (fuel) type, for domestic (Page 36) and foreign (Page 37) fuel costs; for operation and maintenance (O&M) and energy not served (ENS) costs (Page 38), these costs considered as domestic expenditures; and for total operating costs (Page 39). All these pages bear a heading EXPECTED COST OF OPERATION, meaning that all values shown have been weighted by the hydrocondition probabilities and that they are expressed in monetary units (million $) of the respective year (i.e. they are not present-worth values) taking into account all escalation ratios specified in DYNPRO. In the sample problem, since no escalation on operating costs has been used in DYNPRO, the results on Page 39 are the same as for the resimulation run (REMERSIM) of the optimum solution shown in Fig. 7.7 excluding the costs of the energy not served (last column of the table on Page 39) which were calculated in the respective DYNPRO run.

Pages 40-57 report the *Cash Flows of Construction Costs* of the VARSYS plants added by the optimal solution during the planning period. Pages 40 to 42 refer to the domestic component of construction cost and pages 43 to 45 to the foreign component. The information on construction costs of a plant starts earlier than the year of commercial operation by the length of the construction period of the plant. Thus, project 1 of hydro type-A (HYD1) was added in year 2000 and the respective cost information starts in 1994 since the construction period of this project is 6 years (as shown on Page 33). It can be seen in Pages 40 to 42 that some years are repeated in the tables due to the year in which plants were actually added by the optimal solution and their respective construction period; the totals for these years are the same in all tables. As mentioned earlier all investment cost information is reported for plants added during the planning period. Hence, these tables show cash flows for years 1993-2015.

Pages 46-51 give the Domestic and *Foreign Components of the Expenditures for Interest During Construction (IDC)* associated with the capital investment costs above mentioned, and Pages 52-57 the respective *Sums of Construction Plus IDC Costs* for each VARSYS plant added during the planning period. As indicated in the cover page of the printout, all values in these tables are given in million dollars (10^6 $) and since they report cash flows, all values are given in monetary units of the corresponding year (i.e. they are not discounted). On the other hand, these values do take into account escalation using the escalation ratios on these costs that have been specified in the DYNPRO run.

In the sample problem only foreign component of fuel investment (fuel inventory) cost has been specified for one of the units (plant VNUC on Page 33) actually added by the optimal solution. Thus only *Foreign Cash Flow of Fuel Inventory Investment* are reported by REPROBAT as shown on Page 58 of the report. It can be seen in this page that the U.S. $225.0 x 10^6 foreign fuel investment for the 900-MW nuclear unit which went into operation in year 2014 respectively is spread over the two preceding years with about 10% spent in 2012 and 90% in 2013.

Page 59 provides a *Cash Flow Summary of all Capital Investment Costs* by year and type of expenditure for all candidates added by the optimal solution. This includes in sequence: fuel inventory cost; construction cost; and interest during construction, each cost item broken down into domestic, foreign and total. A last column summarizes the grand totals per year. Contrary to other tables of the report, Page 59 shows a zero for the empty spaces in the table (instead of the symbol (.) used for other tables).

The rest of the printout is produced only when the input data provides information for some of the committed (FIXSYS) plants. In the sample problem, this option was used for two FIXSYS plants (see Fig. 9.1) so that Page 60 summarizes the *Capital Cash Flow Summary* of these plants. Note that these plants are not identified in the table on Page 60.

Finally, Page 61 summarizes the *Global Capital Cash Flow Summary* corresponding to the addition of the respective entries in Pages 59 and 60.

Table 9.2 shows a cash flow summary of all costs for each year of the period 1993-2016. As explained earlier, construction costs start in 1993 owing to the construction period and year of addition of the VARSYS plants added by the optimal expansion schedule. Total operating costs (including cost of energy not served) are reported for the study period since the information concerning years 1993-1996 is not known by the program. For simplicity of the discussion, Table 9.2 does not contain capital costs of the plants added in the fixed system of the sample problem. Also, this table has been prepared to show only total costs for each type of expenditure are reported (not broken down into domestic and foreign components). All the cost data on Table 9.2 have been presented on Page 39 (Operating Cost) and Page 59 (Capital Cost) of the REPROBAT report[4].

A similar report such as Table 9.2 cannot be produced by REPROBAT since operation costs in this report correspond to expected costs, i.e. they include the escalation effect. In the sample problem, however, addition of the different types of expenditures is feasible since no escalation has been made use of in the dynamic optimization process.

Examining the values given on Table 9.2, it can be seen that the total costs for the optimal solution of our sample problem are reported to be U.S.$ 34382.7 x 10^6; of which 52.5% corresponds to operating expenditures and the remaining 47.5% to construction costs.

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[4] Alternatively, Table 9.2 could have been prepared by taking the capital cost information on Page 60 of the REPROBAT report.

Table 9.2

Cash Flow Summary of Total Costs for the Optimum Solution of the Sample Problem

(All Costs in million $)

Year	Operating Costs (including ENS)	Capital Investment Cost				Total Costs
		Fuel Inventory	Construction Cost	IDC Cost	Total Capital Cost	
1993	-	0.0	6.0	0.2	6.2	6.2
1994	-	0.0	16.4	1.1	17.5	17.5
1995	-	0.0	58.7	4.2	62.9	62.9
1996	-	0.0	144.7	12.6	157.3	157.3
1997	517.8	0.0	331.4	32.6	364.0	881.8
1998	596.7	0.0	361.0	56.5	417.5	1014.2
1999	639.2	0.0	570.0	91.8	661.8	1301.0
2000	665.9	0.0	588.0	117.4	705.4	1371.3
2001	675.4	0.0	566.4	134.3	700.7	1376.1
2002	735.6	0.0	594.1	145.5	739.6	1475.2
2003	720.3	0.0	1022.5	149.4	1172.0	1892.3
2004	738.7	0.0	951.2	201.3	1152.6	1891.3
2005	753.9	0.0	785.2	225.9	1011.1	1765.0
2006	814.2	0.0	627.4	212.1	839.5	1653.7
2007	804.8	0.0	765.4	123.8	889.2	1694.0
2008	881.1	0.0	951.3	150.9	1102.2	1983.3
2009	942.3	0.0	899.4	173.0	1072.4	2014.7
2010	1034.0	0.0	946.9	163.3	1110.2	2144.2
2011	1098.4	0.0	947.7	194.5	1142.2	2240.6
2012	1175.8	22.1	870.8	225.1	1117.9	2293.7
2013	1256.5	202.9	557.5	249.1	1009.6	2266.1
2014	1270.5	22.1	306.5	157.1	485.8	1756.3
2015	1356.9	202.9	64.0	133.3	400.2	1757.1
2016	1367.2	-	-	-	-	1367.2
TOTALS	18045.2	450.0	12932.4	2955.1	16337.5	34382.7
(%)	(52.5)				(47.5)	(100.0)

9.5 Special Remarks on the REPROBAT Capabilities

Table 1.1 summarizes the principal capabilities of the WASP-III Plus code. They concern mainly the abilities of Modules 1 to 6 and the limits to carry out a planning study for an electric power system. In principle, the same limits are also applicable for REPROBAT with the following exceptions:

1) Discount Rates on domestic (RTINLC) and foreign (RTINFC) - capital investment costs used in DYNPRO can be changed only 10 times during the study period.

2) Capital cost data (card type-2 and type-2a of DYNPRO) can also be changed only 10 times throughout the study period in the respective DYNPRO run (but only the first set is reported under option 6).

3) Construction time of decided (committed) plants to be specified in type-7 data cards can extend up to 10 years. In addition, only up to twenty thermal units and hydro projects of the decided system can be considered in the REPROBAT report.

These limitations arise from the capability of REPROBAT to handle and store information on the temporary working files.

Concerning the cash flow on construction costs reported by REPROBAT for the expansion candidates added by the DYNPRO solution (see Pages 40-57 of Fig. 9.2), this information is calculated by the program using the plant data on capital cost given in DYNPRO. The yearly expenditures are then calculated based on either a cost distribution with time provided by the user or an internal cost distribution function used as default.

For the default option, the program calculates first the total investment cost of the plant as: unitary investment cost of the plant ($/kW) times plant size (MW) times 1000. Then, this is separated into pure construction cost and IDC cost deducting from the total cost; the percentage of IDC specified in DYNPRO for this plant. The distribution of these costs (domestic and foreign components separately) over the construction period of the plant is carried out by REPROBAT assuming an "S" curve shape for the function relating expenditures to time as shown in Figure 9.3. The distribution of IDC requires in addition the specification of an interest rate. This is assumed by REPROBAT to be equal to the discount rate on capital costs (RTINLC or RTINFC depending on the cost component) used in DYNPRO. Table 9.3 gives the resulting IDC percentages for different interest rates and construction periods as calculated using the expenditure versus time function of Figure 9.3. The values shown in Table 9.3 are to be used in the DYNPRO run for the case being studied if it is required that the REPROBAT report gives the correct distribution between pure construction and IDC costs.

Alternatively, the user may specify the annual distribution (%) of the construction costs over the years of the construction period of the plant and the program will simply calculate the corresponding annual IDC using the equation discussed in Section D.13.2 of Appendix D.

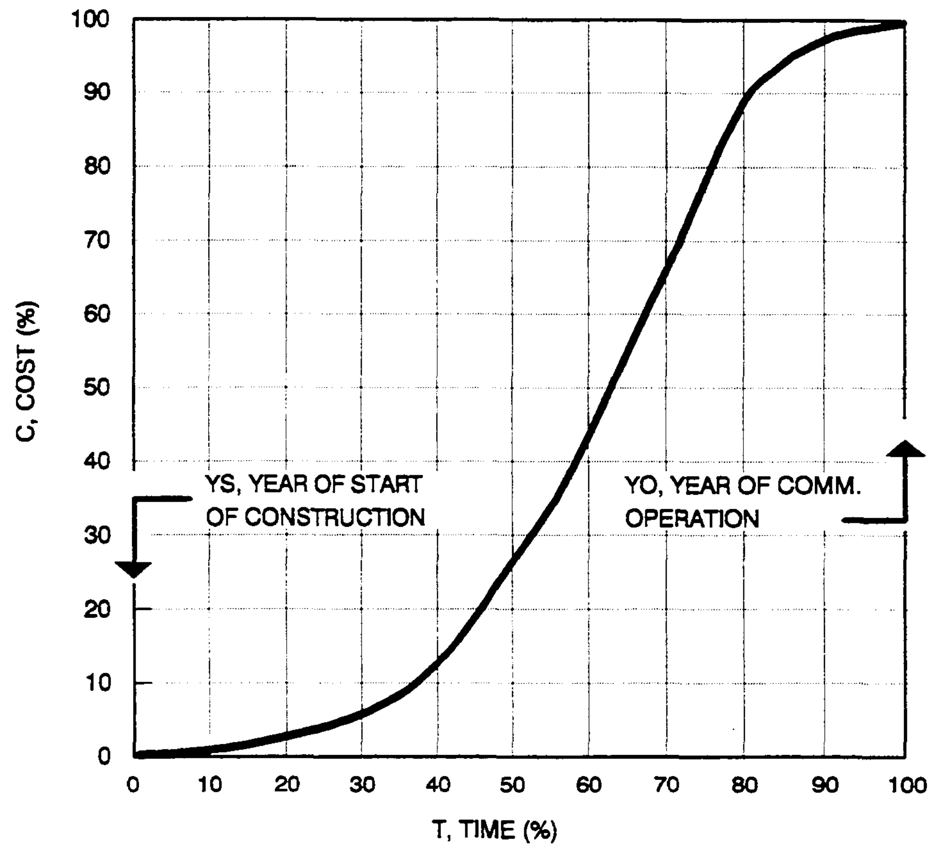
In each case, the total investment cost to be considered is escalated to the year of start of operation of the plant using the cost escalation information provided in the DYNPRO run. (see Section D.13.1 of Appendix D).

Table 9.3 Interest During Construction (IDC) in Percent of Total Construction Cost (Input of DYNPRO)

Construction Period (Years)	Interest Rate										
	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
1.0	2.08	2.49	2.90	3.31	3.71	4.11	4.51	4.90	5.30	5.69	6.08
1.5	3.11	3.72	4.33	4.93	5.52	6.11	6.70	7.28	7.86	8.43	9.00
2.0	4.13	4.94	5.74	6.52	7.31	8.08	8.85	9.61	10.37	11.11	11.85
2.5	5.15	6.14	7.13	8.10	9.07	10.02	10.96	11.89	12.82	13.73	14.63
3.0	6.15	7.33	8.50	9.66	10.80	11.92	13.03	14.13	15.21	16.28	17.34
3.5	7.14	8.51	9.86	11.19	12.50	13.79	15.06	16.32	17.56	18.77	19.98
4.0	8.13	9.68	11.20	12.70	14.18	15.63	17.06	18.46	19.85	21.21	22.54
4.5	9.11	10.83	12.53	14.19	15.83	17.44	19.01	20.56	22.08	23.58	25.05
5.0	10.08	11.98	13.84	15.67	17.46	19.21	20.93	22.62	24.27	25.89	27.48
5.5	11.04	13.11	15.13	17.12	19.06	20.96	22.81	24.63	26.41	28.15	29.85
6.0	11.99	14.23	16.41	18.55	20.63	22.67	24.66	26.60	28.50	30.35	32.16
6.5	12.94	15.33	17.68	19.96	22.18	24.35	26.47	28.53	30.54	32.49	34.40
7.0	13.87	16.43	18.92	21.35	23.71	26.00	28.24	30.41	32.53	34.58	36.58
7.5	14.80	17.52	20.15	22.72	25.21	27.63	29.98	32.26	34.47	36.62	38.71
8.0	15.72	18.59	21.37	24.07	26.69	29.22	31.68	34.06	36.37	38.61	40.77
8.5	16.63	19.65	22.57	25.40	28.14	30.79	33.35	35.83	38.22	40.54	42.78
9.0	17.54	20.70	23.76	26.71	29.57	32.32	34.98	37.55	40.03	42.42	44.73
9.5	18.43	21.74	24.93	28.01	30.97	33.83	36.59	39.24	41.80	44.26	46.62
10.0	19.32	22.77	26.09	29.28	32.36	35.31	38.16	40.89	43.52	46.04	48.46

Table 9.4 Interest During Construction (IDC) in Percent of Pure Construction Cost

Construction Period (Years)	Interest Rate										
	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
1.0	2.13	2.56	2.99	3.42	3.85	4.29	4.72	5.16	5.59	6.03	6.47
1.5	3.21	3.87	4.52	5.18	5.84	6.51	7.18	7.85	8.53	9.21	9.89
2.0	4.31	5.20	6.08	6.98	7.88	8.79	9.71	10.63	11.56	12.50	13.45
2.5	5.43	6.54	7.67	8.82	9.97	11.13	12.31	13.50	14.70	15.91	17.14
3.0	6.55	7.91	9.29	10.69	12.10	13.54	14.99	16.45	17.94	19.45	20.98
3.5	7.69	9.30	10.94	12.60	14.29	16.00	17.74	19.50	21.29	23.11	24.96
4.0	8.85	10.72	12.62	14.55	16.52	18.53	20.57	22.64	24.76	26.91	29.11
4.5	10.02	12.15	14.32	16.54	18.81	21.12	23.48	25.89	28.34	30.85	33.41
5.0	11.21	13.61	16.06	18.58	21.15	23.78	26.47	29.23	32.05	34.94	37.89
5.5	12.41	15.09	17.83	20.65	23.54	26.51	29.55	32.68	35.89	39.18	42.55
6.0	13.63	16.59	19.64	22.77	25.99	29.31	32.73	36.24	39.85	43.57	47.40
6.5	14.86	18.11	21.47	24.93	28.50	32.19	35.99	39.91	43.96	48.14	52.44
7.0	16.11	19.66	23.34	27.14	31.07	35.14	39.35	43.70	48.21	52.87	57.69
7.5	17.37	21.23	25.24	29.40	33.70	38.17	42.81	47.62	52.61	57.78	63.15
8.0	18.65	22.83	27.18	31.70	36.40	41.29	46.37	51.66	57.16	62.88	68.84
8.5	19.95	24.46	29.15	34.05	39.16	44.48	50.03	55.83	61.87	68.18	74.76
9.0	21.26	26.10	31.16	36.45	41.98	47.76	53.81	60.14	66.75	73.68	80.93
9.5	22.60	27.78	33.21	38.90	44.87	51.13	57.70	64.58	71.81	79.39	87.35
10.0	23.95	29.48	35.30	41.41	47.84	54.59	61.70	69.18	77.04	85.33	94.04



$$T = f(C) = a_0 + A_1*C + a_2*C^2 + a_3*C^3 + a_4*C^4 + a_5*C^5 + a_6*C^6 + a_7*C^7$$

a_0	=	$+0.72954$	a_4	=	$-7.36442 * 10^{-4}$
a_1	=	$+7.17832$	a_5	=	$+1.00715 * 10^{-4}$
a_2	=	$-6.16794 * 10^{-1}$	a_6	=	$-7.02449 * 10^{-8}$
a_3	=	$+2.91329 * 10^{-2}$	a_7	=	$+1.95903 * 10^{-10}$

Figure 9.3 Plant Capital Investment Expenditure against Time

If, prior to running the DYNPRO module, the user has executed a run (or runs) of the ORCOST program to produce capital cost estimates of the plants to be used as expansion candidates (see Appendix E for description of the ORCOST program), the %IDC to use in DYNPRO can be derived directly from the ORCOST printout since the calculations in ORCOST are consistent with the results of Table 9.3 (In fact, ORCOST and REPROBAT use the same curve for the function relating cost expenditures and time).

If for the case under study, the user provides capital cost estimates of the expansion alternatives not calculated under the same assumptions above mentioned and if these data are used in DYNPRO, it will be necessary to provide the corresponding cost distribution data to REPROBAT to guarantee consistency of the report.

It should be noticed that the optimization process is not affected since DYNPRO only considers total construction cost of the plants being added.

If the estimates of pure construction cost for a particular expansion candidate are known but its distribution along the construction period is not available, the user may proceed with either of the following approaches[5]:

a) Use of the "S" curve approximation: In this case, for the REPROBAT results to be consistent with the DYNPRO input data, it would be necessary that the user calculates the total capital investment cost using the values of Table 9.4. To do so, the percentage of IDC on Table 9.4 (for the respective construction period and interest rate considered) must be added to the pure construction cost data to calculate the actual construction cost to be given in DYNPRO, and the corresponding %IDC must be taken from Table 9.3. In effect Tables 9.3 and 9.4 are interrelated as follows:

$$\frac{\%IDC\ (\text{Table 9.4})}{1.0 + \left[\frac{\%IDC\ (\text{Table 9.4})}{100.0}\right]} = \%IDC\ (\text{Table 9.3})$$

As an example, let us assume that the estimate of pure construction cost for a 1000 MW plant is 1000 x 10^6 \$; a 5-years construction period and that the applicable interest rate is 11%. From Table 9.4, the percentage of IDC cost to be added to estimates of pure construction costs is 26.47% for the construction period and the interest rate assumed. Thus, the total construction cost and respective %IDC to be used for this plant in DYNPRO are:

$$\text{Construction Cost} = \frac{1000 \times 10^6 \times (1.0+0.2647)\$}{1000 \times 10^3\ \text{kW}} = 1264.7\ \$/\text{kW}$$

$$\%IDC = 20.93\ (\text{Table 9.3}) = \frac{26.47}{(1.0+0.2647)}$$

b) User-defined distribution: In this case, the user can estimate the total IDC for the given construction period and interest rate based on experience for similar projects already in operation or under construction. Then, calculate the total investment cost of the unit (or hydro project) and give this as input data to DYNPRO. Prepare a fixed expansion run of CONGEN-MERSIM-DYNPRO in which the given plant or project is added in a given year. Then run REPROBAT giving as input data an estimated capital cost distribution versus time for the plant and review the results to ensure that the total calculated IDC are in agreement with the specified values in DYNPRO.

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5 Note that this process should be done during the phase of Fixed Expansion Runs of WASP-III Plus for the case study, that is during the phase of definition of the data that will be retained for the overall expansion runs.

Alternatively, the user can calculate the annual (and total) IDC corresponding to a given annual distribution of costs following the same procedure as the one that is used in REPROBAT (see Section D.13.2 of Appendix D for details about these calculations).

An additional remark to be made on the REPROBAT calculations and report concerns the assumption made in this module for distributing the IDC cost over the construction period. REPROBAT assumes that the interest rates on capital investment cost (taken from DYNPRO) are constant over the construction period. Thus, if the user specifies in the DYNPRO module several discounting periods (with different discount rates) for capital costs, the results of REPROBAT will not be consistent with the above assumption and in this case the cash flows for investment costs included in the REPROBAT report are no longer valid.

9.6 Output File for Graphical Representation of Results

As already discussed in several chapters, REPROBAT generates an output file that can serve as the basis for preparation of graphical representation of the results (SIMGRAPH). REMERSIM and REPROBAT write onto this file information related to the optimal solution (or eventually the current best solution of DYNPRO. This includes, the results of the resimulation of the optimal solution and the corresponding cash flows on investment costs calculated by REPROBAT.

It should be emphasized that no attempt has been made within WASP-III Plus to develop the necessary programs to produce actual graphs showing these data because of the lack of standardized graphics packages that could be readily available at the user's computer facilities. However, in order to allow the user to make use of this file in connection with any graphics software available at the user's computer facilities, the following paragraphs discuss the contents and organization of this file.

SIMGRAPH[6] file (IF25) is an "unformatted direct access" file (Block length: 450 Byte, Maximum number of records: 212) and is generated only for resimulation runs (REMERSIM) of the current best solution found by DYNPRO (or ultimately the WASP optimal solution). This file contains the following information:

- General information:
  - title of study
  - code name of plant types and energy not served
  - data regarding the length of the file
  - construction schedule information for new power plants, etc.

- For each year:
  - energy demand (GWh)
  - peak load (MW)

- For each year and hydrocondition:
  - loss of load probability
  - energy not served (GWh)

---

6 SIMGRAPH must be allocated and initialized by program DIRACC in order to allow use of this file in all runs of the same case study with the same Job Control cards (see description of DIRACC in Appendix E, Section E.10)

- For each year, hydrocondition and plant type:
  - installed and available capacity (MW)
  - annual generation (GWh) and plant capacity factor (%)
  - fuel consumption (ton) and generation cost (thousand $), local and foreign.

- For each year and plant type:

  - for the VARSYS candidates added by DYNPRO (in million $)
    - local and foreign construction costs
    - local and foreign interest during construction
    - local and foreign fuel inventory costs

  - for the committed system (*) (in million $)
    - local and foreign construction costs
    - local and foreign interest during construction
    - local and foreign fuel inventory costs

(*) Only if a type-1 INDEX=7 card was used in the REPROBAT run, i.e. the investment cost of some committed (FIXSYS) units were requested to be included in the REPROBAT report.

Table 9.5 shows all variables written onto the SIMGRAPH file, listed in the same order, and identifying the meaning of each variable, their units. The organization of the file is also accompanied by information related to record length, etc. Figure 9.4 shows a partial listing of the SIMGRAPH file generated by the REPROBAT run for the case example. Since this is a direct access file, a special computer program (GRAFILE) has been used in order to generate the listing shown in this figure. Appendix E describes this auxiliary program. Some notes have been added to the right hand side of the listing in Fig. 9.4 in order to identify each type of record contained in the file.

Table 9.5 SIMGRAPH File - Contents and Meaning of Variables[7]

= FIRST RECORD (length : 148)		
	ISYEAR	- first year of simulation
	NRSIM	- number of records with simulation results
	IRSIM	- number of first record with simulation results
	ICYEAR	- first year of construction candidates
	NRCAN	- number of records with investment costs of candidates
	IRCAN	- number of first record with investment costs of candidates
	IDYEAR	- first year of construction of decided (committed) system [X]
	NRDEC	- number of records with investment costs of decided system
	IRDEC	- number of first record with investment costs of decided system
	* TITLE	- title of the study
	* NAMTYP	- code name of plant types [Y]
	[X]:	if the REPROBAT run was carried out without considering investment of decided plants, IDYEAR, NRDEC and IRDEC = 0
	[Y]:	KN - index of plant types: 1 to 10 thermal; 11-12 hydro; and 13 ENS

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7 The asterisk (*) shown for some items means that they are dimensioned.

Table 9.5 Cont.

= SECOND RECORD (length : 24 maximum)

IHYDIS	-	number of hydroconditions
* PROB	-	probability of each hydrocondition

= NEXT NRSIM RECORDS (one record per hydrocondition in each year) (maximum number of records : 150; length 436)

JAHR	-	year of simulation
L	-	hydrocondition index
ANEN	-	annual energy demand
ANPKMW	-	annual peak load
* PLOLH	-	LOLP for hydrocondition L

by plant type - KN

* RMW	-	annual installed capacity (MW)
* IPOT	-	average annual available capacity (MW)
* ENERG	-	energy generation (GWh)
* UTIL	-	average annual utilization factor of installed capacity (%)
* CCOMBL	-	annual domestic fuel consumption (ton)
* CCOMBF	-	annual foreign fuel consumption (ton)
* CETTYL	-	annual domestic generation costs (thousand $) (for KN = 13)
* CETTYF	-	annual foreign generation costs (thousand $)

= NEXT NRCAN RECORDS (one year of construction of candidates per record) (maximum number of records : 30; length : 372)

JYEAR	-	year of construction

by plant type - KN (of candidate plants)

* CCTYPL	-	annual domestic construction costs (million $)
* CCTYPF	-	annual foreign construction costs (million $)
* CITYPL	-	annual domestic IDC costs (million $)
* CITYPF	-	annual foreign IDC costs (million $)
* CFTYPL	-	annual domestic fuel inventory costs (million $)
* CFTYPL	-	annual foreign fuel inventory costs (million $)

= NEXT NRDEC RECORDS (only if REPROBAT included investment cost of decided plants) (one year of construction of candidates per record) (maximum number of records : 30; length : 372)

MYAD	-	year of construction

by plant type - KN (of decided system)

* DCTYPL	-	annual domestic construction costs (million $)
* DCTYPF	-	annual foreign construction costs (million $)
* DITYPL	-	annual domestic IDC costs (million $)
* DITYPF	-	annual foreign IDC costs (million $)
* DFTYPL	-	annual domestic fuel inventory costs (million $)
* DFTYPL	-	annual foreign fuel inventory costs (million $)

```
                 KN  INDEX OF PLANT TYPE (FOR FUEL-TYPE OR ENS)

                   ====== RECORD NB.  1 ======
                     1997     60       3  1993     23     63  1989     10     86
                      CASE 93: CASE STUDY FOR THE WASP-III PLUS USERS' MANUAL
                   NUCL  CO-1  CO-2  FOIL  GTGO  LIGN  IMPO  ****  ****  ****
                   HYD1  HYD2  ENS
                   ====== RECORD NB.  2 ======
                     3       0.75       0.15       0.10
First ---->        ====== RECORD NB.  3 ======
NRSIM              1997    1      30353.4    6000.0       0.0602514
record            1          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                  2       1019.84         1200          8930.20          84.95
                       3714963.00         0.00        191463.12           0.00
                  3        966.34         1200          7865.97          74.83
                             0.00   2973335.00         56810.57      130766.62
                  4       1316.78         1600          1409.74          10.06
                             0.00    328468.62         39446.86       39803.02
                  5        760.08          800            30.41           0.43
                             0.00     10187.54          7252.91        1852.00
                  6        239.36          294          1535.85          59.63
                             0.00   1216396.00         33937.91           0.00
                  7          0.97            1             0.36           0.05
                             0.00         0.00          2586.15          27.38
                  8          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                  9          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                 10          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                 11        399.17          500          2575.00          58.79
                             0.00         0.00          4200.00           0.00
                 12       1480.00         1600          7999.99          57.08
                             0.00         0.00         10559.99           0.00
                 13          0.00            0             0.23           0.00
                             0.00         0.00            11.45           0.00

                 ..         ..           ..              ..             ..
                 ..         ..           ..              ..             ..
                 ..         ..           ..              ..             ..

Last ---->         ====== RECORD NB. 62 ======
NRSIM              2016    3      75962.6   15015.1       0.2219942
record            1       1465.45         1800         12832.25          81.38
                             0.00       284.88         65879.94       78844.62
                  2          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                  3       5171.54         6600         34920.31          60.40
                             0.00  13168822.00        355951.25      583923.75
                  4        955.73         1200          3067.48          29.18
                             0.00    653373.12         32501.45       87692.56
                  5       2660.29         2800           448.92           1.83
                             0.00    150387.81         24298.85       27260.60
                  6        957.43         1176          8383.67          81.38
                             0.00   6639867.00        169559.25           0.00
                  7          0.97            1             0.00           0.00
                             0.00         0.00             0.00           0.00
                  8          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                  9          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                 10          0.00            0             0.00           0.00
                             0.00         0.00             0.00           0.00
                 11        675.20          940          3370.00          40.93
                             0.00         0.00          7895.99           0.00
                 12       2865.00         3400         12924.98          43.40
                             0.00         0.00         22439.98           0.00
                 13          0.00            0             4.30           0.00
                             0.00         0.00           227.94           0.00
```

Figure 9.4 Partial Listing of the SIMGRAPH file for CASE93.

```
First ----->      ====== RECORD NB. 63 ======
NRCAN              1993
record            1     0.00     0.00     0.00     0.00     0.00     0.00
                  2     0.00     0.00     0.00     0.00     0.00     0.00
                  3     0.00     0.00     0.00     0.00     0.00     0.00
                  4     0.00     0.00     0.00     0.00     0.00     0.00
                  5     0.00     0.00     0.00     0.00     0.00     0.00
                  6     0.00     0.00     0.00     0.00     0.00     0.00
                  7     0.00     0.00     0.00     0.00     0.00     0.00
                  8     0.00     0.00     0.00     0.00     0.00     0.00
                  9     0.00     0.00     0.00     0.00     0.00     0.00
                  10    0.00     0.00     0.00     0.00     0.00     0.00
                  11    0.00     0.00     0.00     0.00     0.00     0.00
                  12    4.16     1.78     0.16     0.07     0.00     0.00

                  ..          ..        ..        ..           ..
                  ..          ..        ..        ..           ..
                  ..          ..        ..        ..           ..

Last ----->       ====== RECORD NB. 85 ======
NRCAN              2015
record            1    11.54    52.42    24.06   109.27     0.00   202.92
                  2     0.00     0.00     0.00     0.00     0.00     0.00
                  3     0.00     0.00     0.00     0.00     0.00     0.00
                  4     0.00     0.00     0.00     0.00     0.00     0.00
                  5     0.00     0.00     0.00     0.00     0.00     0.00
                  6     0.00     0.00     0.00     0.00     0.00     0.00
                  7     0.00     0.00     0.00     0.00     0.00     0.00
                  8     0.00     0.00     0.00     0.00     0.00     0.00
                  9     0.00     0.00     0.00     0.00     0.00     0.00
                  10    0.00     0.00     0.00     0.00     0.00     0.00
                  11    0.00     0.00     0.00     0.00     0.00     0.00
                  12    0.00     0.00     0.00     0.00     0.00     0.00
First ----->      ====== RECORD NB. 86 ======
NRDEC              1989
record            1     0.00     0.00     0.00     0.00     0.00     0.00
                  2     0.00     0.00     0.00     0.00     0.00     0.00
                  3     0.00     0.00     0.00     0.00     0.00     0.00
                  4     0.00     0.00     0.00     0.00     0.00     0.00
                  5     0.00     0.00     0.00     0.00     0.00     0.00
                  6     0.00     0.00     0.00     0.00     0.00     0.00
                  7     0.00     0.00     0.00     0.00     0.00     0.00
                  8     0.00     0.00     0.00     0.00     0.00     0.00
                  9     0.00     0.00     0.00     0.00     0.00     0.00
                  10    0.00     0.00     0.00     0.00     0.00     0.00
                  11    0.00     0.00     0.00     0.00     0.00     0.00
                  12   23.53    10.09     9.22     3.95     0.00     0.00

                  ..          ..        ..        ..           ..
                  ..          ..        ..        ..           ..
                  ..          ..        ..        ..           ..

Last ----->       ====== RECORD NB. 95 ======
NRDEC              1998
record            1     0.00     0.00     0.00     0.00     0.00     0.00
                  2     0.00     0.00     0.00     0.00     0.00     0.00
                  3    12.06    32.28     2.49     6.67     0.00     0.00
                  4     0.00     0.00     0.00     0.00     0.00     0.00
                  5     0.00     0.00     0.00     0.00     0.00     0.00
                  6     0.00     0.00     0.00     0.00     0.00     0.00
                  7     0.00     0.00     0.00     0.00     0.00     0.00
                  8     0.00     0.00     0.00     0.00     0.00     0.00
                  9     0.00     0.00     0.00     0.00     0.00     0.00
                  10    0.00     0.00     0.00     0.00     0.00     0.00
                  11    0.00     0.00     0.00     0.00     0.00     0.00
                  12    0.00     0.00     0.00     0.00     0.00     0.00
```

Figure 9.4 Partial Listing of the SIMGRAPH file for CASE93.

CHAPTER 10

EXECUTION OF RECSIM

It was explained in previous chapters that any abnormal termination of MERSIM execution will leave the SIMULNEW file improperly closed and it will be necessary to recover the information using the RECSIM program before proceeding. This is particularly important during the dynamic optimization stage of a WASP study, when recovering the new information for several years will save valuable computer time. Additionally, it might be desirable to obtain a listing of all the configurations on the simulation files at any stage of the study. Thus, three modes of operation are possible for the RECSIM program as shown in Figure 10.1.

10.1 Control Cards

The control cards for execution of RECSIM are shown in Fig. 10.1 for the three modes of operation of the program. The first four RECSIM control cards are common to all three modes while the rest of the cards for the particular run depend on the mode operation as explained below.

10.2 Data Cards

For any mode of operation the first data card required by RECSIM specifies the mode of operation while a second data card is required to specify in columns 1 to 4 the last year for which the file to be recovered or listed seems to be complete (see below).

10.3 Recovery of an Incomplete Simulation (CASE B)

If it is desired to simply recover the good information from an incomplete SIMULNEW file onto a SIMULREC file for use in place of SIMULOLD in the next MERSIM run, the five RECSIM cards shown under CASE B should be used immediately after the control cards mentioned in 10.1. This would be the case of abnormal termination of a MERSIM run in the "initial" mode treated in Section 7.1 (i.e. SIMULOLD has been replaced by SIMULINL).

The control cards are followed by a data card to indicate the RECSIM mode of operation (INITIAL in this case) while the second card specifies the last year (in columns 1-4) for which the SIMULNEW file seems to be complete (indicated by -1 at the end). If the RECSIM run does not end properly, reduce the year number by one and repeat the run. The output of the run is similar to the one shown in Fig. 10.2.

10.4 Recover and Merge (CASE A)

In order to recover the good information from an incomplete SIMULNEW file up through its last complete year and merge it with the remaining years information from the SIMULOLD file onto the SIMULREC file, the cards listed under CASE A should be used. This will be the case if the abnormal MERSIM run occurs after several dynamic optimization schedules have been examined and provided the "merge" mode of MERSIM execution is being used.

In this mode of operation, again control cards are followed by a data card indicating the mode of operation (MERGE), and a second card to specify the last year for which the SIMULNEW file seems to be complete. If the run ends improperly, reduce by one the year number on the data card and try again. The printout will be similar to the one in Fig. 10.2.

10.5 Listing of Configurations (CASE C)

If only a listing on paper of the configurations contained on a simulation file is required, the cards listed under CASE C should be used followed by a card showing the last year for which the file is thought to be complete. The cards shown under CASE C of Fig. 10.1 correspond to a RECSIM run for listing the configurations on the SIMULNEW file; thus files 16 (SIMULOLD) and 17 (SIMULREC) have been dummied in this case. Figure 10.2 shows part of the printout produced by RECSIM in this mode of operation listing the last SIMULNEW file (from MERSIM Run-3).

10.6 Subsequent MERSIM Runs

Having successfully recovered the information from the SIMULNEW and SIMULOLD files (CASE A), SIMULREC is then assigned to file 16 and is used in place of SIMULOLD (file 16) in the subsequent MERSIM run; all other MERSIM control cards remaining the same. If the successful RECSIM run corresponds to the mode of operation under CASE B, the SIMULREC file replaces the SIMULINL file in the subsequent MERSIM run.

```
//RECSIM EXEC PGM=XBBNREC4
//STEPLIB  DD DSN=XBBT.LOADLIB.TEST,DISP=SHR
//FT06F001 DD SYSOUT=A
C
C  USE CASE A, B OR C AS INDICATED BELOW
C  ------------------------------------
C
C  CASE A  -  FOR MERGING CONTINUE:
C
//FT15F001 DD DSN=XBBP.CASE93.SIMULNEW,DISP=SHR
//FT16F001 DD DSN=XBBP.CASE93.SIMULOLD,DISP=SHR
//FT17F001 DD DSN=XBBP.CASE93.SIMULREC,DISP=SHR
//FT05F001 DD *
MERGE
year (e.g. 2013)
C
C  CASE B  -  FOR INITIAL CONTINUE:
C
//FT15F001 DD DSN=XBBP.CASE93.SIMULNEW,DISP=SHR
//FT16F001 DD DUMMY
//FT17F001 DD DSN=XBBP.CASE93.SIMULREC,DISP=SHR
//FT05F001 DD *
//
INITIAL
year (e.g. 2009)
C
C  CASE C  -  FOR LISTING CONTINUE:
C
//FT15F001 DD DSN=XBBP.CASE93.SIMULNEW,DISP=SHR
//FT16F001 DD DUMMY
//FT17F001 DD DUMMY
//FT05F001 DD *
//
INITIAL
year (e.g. 2016)
```

Figure 10.1 Control and Data Cards for Execution of RECSIM

```
CONFIGURATIONS FOR YEAR 1997 RELIABILITY
     1  0.0667   0    0    0    0    0    0
     2  0.0244   0    0    0    1    0    0
     0          -1    0    0    0    0    0

CONFIGURATIONS FOR YEAR 1998 RELIABILITY
     3  0.1592   0    0    0    0    0    0
     4  0.0656   0    0    0    1    0    0
     5  0.0246   0    0    0    2    0    0
     0          -1    0    0    0    0    0

CONFIGURATIONS FOR YEAR 1999 RELIABILITY
     6  0.0374   0    1    0    1    0    0
     7  0.0936   0    0    0    2    0    0
     8  0.0156   0    1    0    2    0    0
     9  0.0383   0    0    0    3    0    0
    10  0.0057   0    1    0    3    0    0
    11  0.2895   0    0    0    0    1    0
    12  0.0229   0    1    0    1    1    0
    13  0.0564   0    0    0    2    1    0
    14  0.0089   0    1    0    2    1    0
    15  0.0223   0    0    0    3    1    0
    16  0.0030   0    1    0    3    1    0
     0          -1    0    0    0    0    0

CONFIGURATIONS FOR YEAR 2000 RELIABILITY
    17  0.1265   0    1    0    1    0    0
    18  0.0270   1    1    0    1    0    0
    19  0.0245   0    2    0    1    0    0
    20  0.0044   1    2    0    1    0    0
    21  0.0649   1    0    0    2    0    0
    22  0.0592   0    1    0    2    0    0
    23  0.0115   1    1    0    2    0    0
    24  0.0103   0    2    0    2    0    0
    25  0.0017   1    2    0    2    0    0
    26  0.0295   1    0    0    3    0    0
    27  0.0266   0    1    0    3    0    0
    28  0.0046   1    1    0    3    0    0
    29  0.0040   0    2    0    3    0    0
    30  0.0005   1    2    0    3    0    0
    31  0.0629   0    0    0    4    0    0
    32  0.0118   1    0    0    4    0    0
    33  0.0104   0    1    0    4    0    0
    34  0.0017   1    1    0    4    0    0
    35  0.0015   0    2    0    4    0    0
    36  0.4085   0    0    0    1    1    0
    37  0.0832   0    1    0    1    1    0
    38  0.0167   1    1    0    1    1    0
    39  0.0150   0    2    0    1    1    0
    40  0.0025   1    2    0    1    1    0
    41  0.0415   1    0    0    2    1    0
    42  0.0376   0    1    0    2    1    0
    43  0.0068   1    1    0    2    1    0
    44  0.0061   0    2    0    2    1    0
    45  0.0009   1    2    0    2    1    0
    46  0.0905   0    0    0    3    1    0
    47  0.0179   1    0    0    3    1    0
    48  0.0160   0    1    0    3    1    0
    49  0.0026   1    1    0    3    1    0
    50  0.0023   0    2    0    3    1    0
    51  0.0382   0    0    0    4    1    0
    52  0.0069   1    0    0    4    1    0
    53  0.0061   0    1    0    4    1    0
    54  0.0010   1    1    0    4    1    0
    55  0.0009   0    2    0    4    1    0
     0          -1    0    0    0    0    0
```

Figure 10.2 Sample of the RECSIM Printout. Listing of Configurations on the SIMULNEW file created by MERSIM Run-3 of the Sample Problem

CHAPTER 11

SEARCH FOR OPTIMAL SOLUTION

11.1 Basic Information

The running of the WASP-III Plus modules requires a certain number of input data which are essential in the search for an optimal expansion schedule for the power system being studied. Table 11.1 depicts in a conceptual way the most important data linked to the WASP module where either these data have to be input or they have an impact on the results. No attempt has been made to include in Table 11.1 all the input data and their corresponding physical units since the full description of each piece of information needed by the WASP modules is contained in the preceding sections.

It should be stressed here the importance of data preparation for the various WASP modules, particularly concerning: the load forecast and load seasonal variation; the hydrological conditions (years of rainfall); the technical and economic characteristics of thermal and hydroelectric plants to be included in FIXSYS, and those for the plants to be used as candidates for system expansion; the construction cost of these expansion candidates; the discount rate(s) on the various types of expenditure; the escalation ratios (if any) on capital and operating costs; the loading order of the plants as required for the simulation of system operation; the acceptable limit for the annual LOLP of the system; etc. All these data must be decided with great care before undertaking a WASP study, since changes introduced later may imply repeating the whole dynamic optimization process; thus, leading to wasting valuable computer time.

As mentioned in Chapter 3 through Chapter 9, some data are internally checked by the WASP modules for consistency with data given in other modules, and also to make sure that the capabilities of the program for storing information (i.e. the dimensions of the respective variables in the program) are not exceeded (see Appendix B for description of the corresponding checks). However, a large amount of input data is simply read (and used) by the computer as it appears on the respective data card. Therefore, it is very important to check carefully all printouts produced by the WASP modules especially during the debugging phase of control and data cards of WASP treated in the following section.

11.2 Input Data Validation and Debugging, Running a Predetermined Expansion Plan

It is recommended that the control cards and input data validation and debugging of the WASP modules be done running a predetermined expansion plan, in other words, running WASP for an expansion plan composed of only one configuration of the system for every year in the study period. Figure 11.1 is a flow chart of this procedure, in which a symbol indicates the appropriate points for user-machine interaction. Table 11.2 stresses additional points to be kept in mind when running the various WASP modules for the input data validation and debugging.

It is important to remember that modules LOADSY, FIXSYS and VARSYS all independent between each other so that they can be run in any order, but they must be run before the first CONGEN run. Besides, once modules LOADSY, FIXSYS and VARSYS are debugged and found correct, there is no need to run any of them again, unless inconsistency or incorrectness in the data were detected when running CONGEN, MERSIM, DYNPRO or REPROBAT.

Table 11.1 Most Important Data for WASP-III Pus Computer Runs

TYPE OF DATA	LOADSY	FIXSYS	VARSYS	CONGEN	MERSIM	DYNPRO	REPROBAT
LOAD FORECAST							
First year of study	X	X	-	X	X	X	X
Study period	X	X	-	X	X	X	X
Number of periods per year	X	X	X	X	X	X	X
Load duration curves	X	-	-	-	X	-	-
Maximum demands	X	-	-	X	X	-	X
Seasonal multipliers of peak demands	X	-	-	X	X	-	-
HYDROELECTRIC PROJECTS							
Number of hydro conditions	-	X	X	-	X	X	X
Probability of hydroconditions	-	X	X	-	X	-	-
Technical data	-	X	X	X	X	-	X
Grouping of hydro projects	-	X	X	-	X	-	X
Preferred sequences of hydro projects	-	-	X	X	-	X	X
Addition or retirement of projects	-	X	-	X	X	-	X
Spinning reserve capabilities	-	-	-	-	X	-	-
THERMOELECTRIC UNITS							
Technical data	-	X	X	X	X	-	X
Fuel types	-	X	X	-	X	-	X
Maintenance requirements	-	X	X	-	X	-	-
Forced outages	-	X	X	-	X	-	-
Spinning reserve capabilities	-	X	X	-	X	-	-
Addition/retirement of units	-	X	-	X	X	-	X
SYSTEM ECONOMICS							
L.O. order of thermal plants	-	-	-	-	X	-	-
Fuel costs	-	X	X	-	X	X	X
O&M (non-fuel) costs	-	X	X	-	X	X	X
Capital investment costs	-	-	-	-	-	X	X
Interest during construction	-	-	-	-	-	X	X
Plant economic life	-	-	-	-	-	X	X
Construction periods	-	-	-	-	-	X	X
Depreciation option	-	-	-	-	-	X	-
Cost of energy not served	-	-	-	-	-	X	X
Reference date for present worth calculations	-	-	-	-	-	X	-
Reference date for calculation of cost escalation	-	-	-	-	-	X	-
Discount rates	-	-	-	-	-	X	X
Escalation rates	-	-	-	-	-	X	X
SYSTEM RELIABILITY							
Maximum and minimum reserve margins	-	-	-	X	-	-	X
LOLP limits	-	-	-	X	-	X	X
Spinning reserve requirements	-	-	-	-	X	-	-
Maximum unit size	-	-	X	X	-	-	-
ACCURACY OF COMPUTATION							
Number of Fourier terms	X	-	-	-	X	-	-
REPORTING OPTIONS	X			X	X	X	X

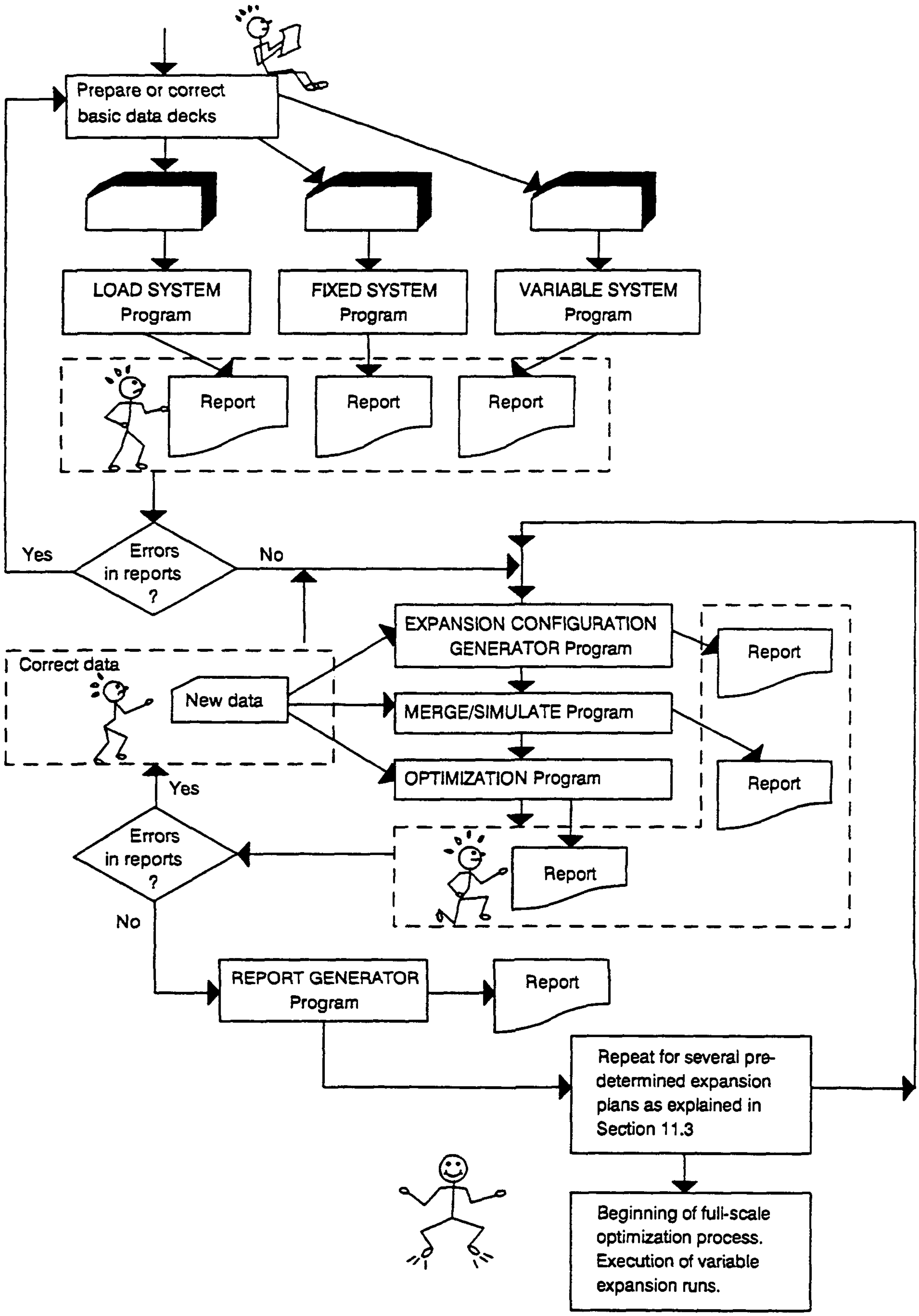

Figure 11.1 Man-machine Interaction in Running the WASP Code for a Pre-determined Expansion Plan (Adapted from ORNL 73-7759 RI)

Table 11.2

Input Data Validation and Debugging: Running a Predetermined Expansion Plan

STEP	MODULE	OUTPUT OPTIONS REQUIRED			REMARKS
		Printing of:	First run	Last run	
STEP 1	LOADSY	Fourier coef.	Yes	No	These modules can be run in any order.
	FIXSYS	No option	-	-	
	VARSYS	No option	-	-	
STEP 2	REPROBAT	Report options:	LOADSY FIXSYS VARSYS only		To obtain a handy output for quick reference and check of the files from LOADSY through VARSYS.
STEP 3	CONGEN	FIXSYS and VARSYS files	Yes	No	To be run after LOADSY, FIXSYS and VARSYS have been successfully run. (Request LOLP calculation <u>only</u> if necessary.)
STEP 4	MERSIM	FIXSYS and VARSYS files	Yes	No	To be run after CONGEN has been successfully run File 15:SIMULNEW File 16:SIMULOLD (File 16: SIMULINL if SIMULOLD is not empty)
		Results of simulation	Maximum for some years; intermediate for other years and minimum for remaining years	Intermediate for all years	
STEP 5	DYNPRO	VARSYS file	Yes	No	To be run after MERSIM has been successfully run
		Listing of the states considered in the run	Yes	No	
STEP 6	REPROBAT	Full report	-	Yes	To be run after all other modules have been successfully run. File 15:SIMULNEW

<u>Note</u>: REPROBAT can be run after any of the STEPS has been successfully completed but the report output options should obviously cover only those modules already run.

The first step is, thus, to run LOADSY (with the option for printing of Fourier coefficients = 1), FIXSYS and VARSYS in order to peruse input data and correctness of the results. See Chapters 3, 4 and 5 for the procedures to prepare the control cards and input data and to revise the printed outputs of these modules. Once the user is satisfied with the results, a last run of these modules (setting in LOADSY the Fourier coefficients printing option = 0) is recommended.

An additional comment must be made regarding the option for the load duration curve (LDC) input data to be used in the LOADSY run(s) for a particular case study. As explained in Chapter 3, the LDC input data for each period can be given optionally, in polynomial form or by points of the curve. If the latter option is used, it is recommended that the user revise the output of LOADSY to check that the energies and load factors calculated by the program from the input representation point-by-point match the respective values calculated by LOADSY using the Fourier series approximation to LDC. If these results are too divergent (difference > 1%), it is suggested to use the polynomial form option for LDC input data. This requires running first any of the WASP related programs POLIN or CALLOAD (described in the Appendices) or any similar program which calculates the coefficients of the polynomial representing the LDC of the periods.

In spite of the above, the use of the point-by-point option is strongly recommended since this permits a closer representation of the system load duration curve particularly for the points of greatest importance, namely the inflexion at the knee of the base load where generation by baseload plants (the most economic) are to be measured, and the area closer to the peaking portion, where LOLP and ENS will be determined as well as generation by peaking (expensive) units are to be calculated.

The second step is to run the REPROBAT module with the output options limited to LOADSY, FIXSYS, and VARSYS in order to make further analysis of the information contained in their respective files (LOADDUCU, FIXPLANT, and VARPLANT). This analysis may still reveal that some additional changes are needed in the data supplied to these modules before proceeding to the next step. See Chapter 9 for preparing the control cards and input data for REPROBAT.

The third step is to run the CONGEN module with a pre-determined expansion plan for the system being studied (see Chapter 6 for preparing the CONGEN control cards and input data). The first run of CONGEN should be done using the maximum output option, i.e. requesting printing of the FIXSYS and VARSYS files, again to ascertain that these are correct and that they are properly read by the program. Also, this run could be done setting the LOLP calculation option so that the program is requested to calculated the LOLP for all configurations in order to have a correlation between LOLP and reserve margins. This is particularly important if the user does not have prior knowledge of this correlation for the given power system.

Step 4 is to run the MERSIM module following the procedure explained in Chapter 7. The first MERSIM run should be also executed requesting printing of the FIXSYS and VARSYS files for the same reasons described above for the first CONGEN run. For this first MERSIM run, the user should judge in which years of the study period, maximum, intermediate or minimum outputs of the results of the simulation are necessary for perusal of the correctness of data and results. The printout of the run ought to be revised very carefully as explained in Section 7.4, and any error in input data corrected and the program re-run before proceeding to other steps. As a result of this revision, it may be necessary to correct some input data of the preceding WASP modules (and re-run the applicable module(s)).

Great care should be devoted to input a realistic economic loading order of the plants since annual operating costs calculated by MERSIM are function of this L.O. Several runs may be performed to investigate the effect of varying the number of Fourier terms used in the representation of the inverted load duration curve, upon the calculation of the system's annual operating costs, LOLP and energy not served. A compromise should be reached between accuracy of the results and the computation time required to perform the simulations, by selecting as low a number of Fourier terms as deemed necessary by the user's judgement and experience. Note that in these runs file 15 and file 16 are labelled SIMULNEW and SIMULINL, respectively; i.e. MERSIM is run in the "initial" mode as explained in Section 7.1. A last run in this series would need using only intermediate output option for all years of study (and without requesting printing of FIXSYS and VARSYS files) in order to reduce the printout.

Module DYNPRO is run in the fifth step, after MERSIM's last successful run and using the procedure detailed in Chapter 8. As mentioned before, great care should be exercised in checking all economic data and constraints given in this module. It is advisable that, before proceeding to the dynamic optimization phase of the WASP study, the user performs simple hand calculations to total annual production costs for different capacity factors of the plants which are to be used as expansion candidates as illustrated in Table 11.3 for a thermal candidate (VNUC) and a hydro project (VHY2 of HYD2) of CASE93.

For thermal units, calculations are carried out for 0% and 100% of plant capacity factor (all data for these capacity factors are known). Plotting these two values on a graph the curve of annual production costs versus plant capacity factor can be approximated to a straight line as shown in Figure 11.2 for the thermal plants considered as expansion candidates in our sample problem. In the case of hydro, since the simulation module will try to make use of all available hydro energy to off-load thermal plants, the representation of these projects on Fig. 11.2 becomes a single point (Note that if it were not for this premise in module MERSIM, the theoretical representation of hydro projects in this figure should be also a straight line parallel to the x-axis, since annual production costs are independent of capacity factors). A graph such as in Fig. 11.2 (usually called Screening Curve) helps the user in checking whether the plants used as expansion candidates are actually competitive (at least theoretically, since operating costs are calculated in MERSIM weighing the results for different hydro conditions by their respective probabilities). For instance, it can be seen in Fig. 11.2 that the nuclear plant (VNUC) is more economical than any other thermal candidate for annual capacity factors greater than 80%; coal plants (VCOA) for capacity factors between 40% and 80%; oil-fired plants (VFOL) in the range between 20% and 40%, and the gas turbines (V-GT) for capacity factors less than 20%. Break-even points between two plants at a time can also be determined from Fig. 11.2[1]. After plotting the graph for the user's case, obviously those plants which are not actually competitive for a wide range of capacity factors should be eliminated from the list of expansion candidates in the VARSYS module. This is demonstrated for CASE93 in Fig. 11.2 where the costs for a 600 MW nuclear unit are also plotted (dashed line). Since this plant is obviously not competitive with other base load units (VCOA and VFOL) for the 0% - 80% range of capacity factor, it was decided to eliminate this candidate from VARSYS before proceeding with the execution of the WASP study for CASE93. This is also very important for hydro projects and their respective sequence to be used in VARSYS since the ranking of these projects must be decided by the user.

---

[1] The use of Screening Curves is described in detail in Section 6.6 of the publication Electric Generating System Expansion, A Guidebook, IAEA TRS 241, Vienna, 1984.

Table 11.3

Example of Calculations of Total Annual Production Costs Using Data for CASE93

I. PLANT DATA

Plant		FC	O&M Cost		I	FIC	T
Name	Size (MW)	Fuel Cost at f=100% ($/MWh)	Fixed ($/KW-m)	Variable ($/MWh)	Investment Cost ($/KW)	Fuel Inventory Cost ($/KW)	Life time (years)
VNUC	900	6.1	3.05	0.0	2050.0	250.0	30
VHY2 (HYD2)	300	-	0.55	-	1450.0	-	50

II. CALCULATIONS OF ANNUAL PRODUCTION COSTS [APC ($/kW-year)]

$$(APC)_f = [r]_i^T \times I + \frac{i \times (FIC)}{100} + 12 \times (O\&M_{fixed}) +$$
$$8.76 \times [(FC)_f + (O\&M_{variable})_f] \times \frac{f}{100}$$

where:

i = annual interest rate (8% in this case)

f = average annual capacity factor of the plant (in%)

$[r]_i^T$ = annual capital recovery factor: $[r]_{8\%}^{30}$ = 0.08883 and $[r]_{8\%}^{50}$ = 0.08174

A. For the VNUC Plant

$(APC)_{f=0\%}$ = 0.08883 x 2050 + 0.08 x 250 + 12 x 3.05 = 238.7 $/kW/year

$(APC)_{f=100\%}$ = $(APC)_{f=0\%}$ + 8.76 x [6.1 + 0.0] x 1.00 = 292.14 $/KW-year

B. For the VHY1 hydro project

The annual available energy in the "normal" year (hydro condition 1 for CASE93) of this project is 1510 GWh. Thus, its average capacity factor (referred to the installed capacity, 300 MW in this case) is 57%.

$(APC)_{f=57\%}$ = 0.08174 x 1450.0 + 12 x 0.55 = 125.12 $/KW-year

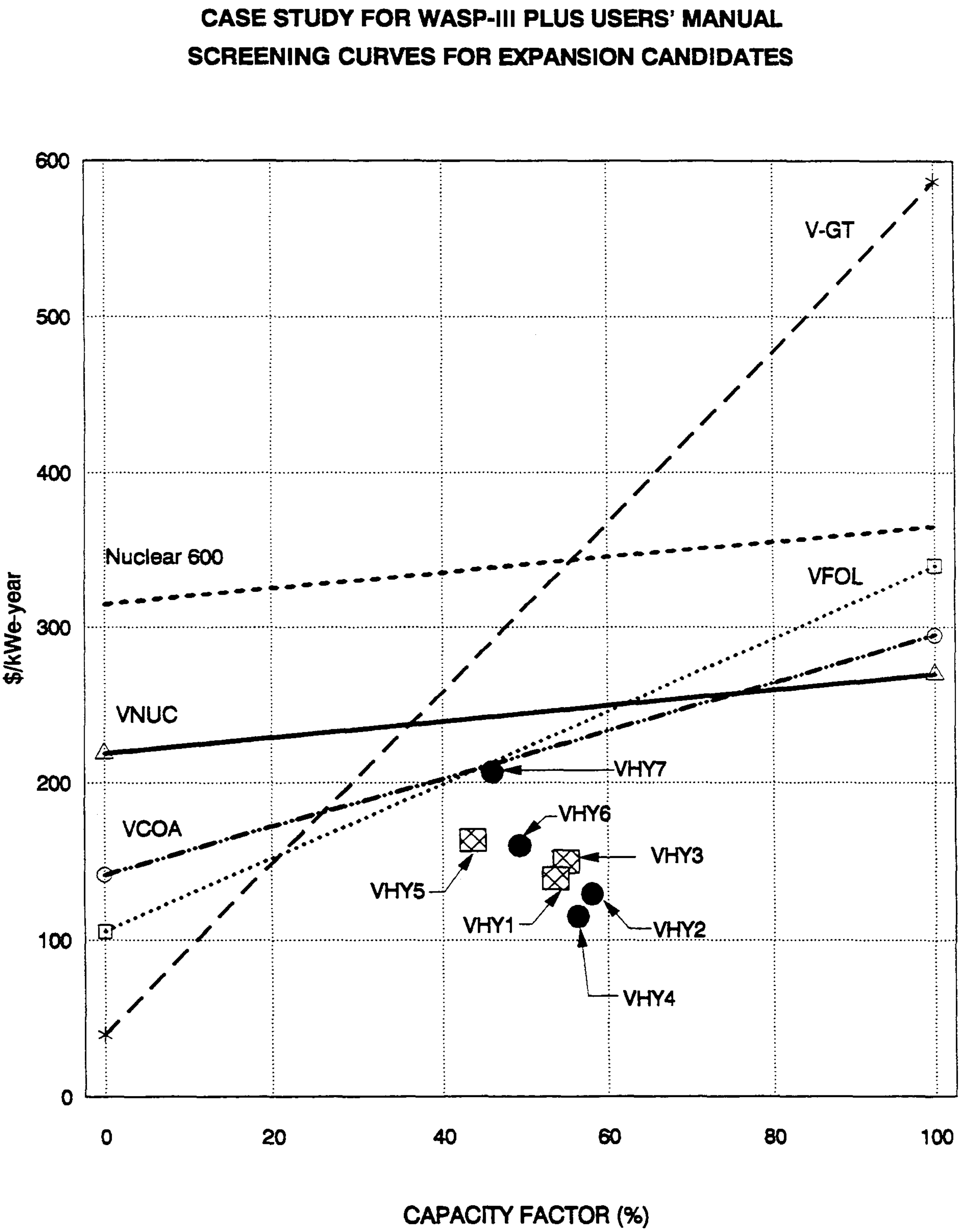

Figure 11.2 Annual Production Costs versus Plant Capacity Factor of Expansion Candidates for the Sample Case

11.3 Execution of a Series of WASP Runs for Pre-determined Expansion Plans

As explained in Chapters 1 and 6, the computer time requirements for a WASP study are highly dependent on the total number of configurations generated throughout the dynamic optimization phase (in the search for the optimal solution for the expansion problem), which in turn depends greatly on the starting point selected by the user for the full-scale dynamic optimization phase of his/her study. Thus, after having executed the WASP runs corresponding to the data validation and debugging of the modules, it is advisable to evaluate a certain number of predetermined expansion patterns of system development to select a favorable area to be used as starting point for the dynamic optimization phase, as shown in Fig. 11.1.

The step required to execute such series of runs is essentially similar to the ones explained in Section 11.2 except for the following (these are summarized in Table 11.4): Steps 1 and 2 of Section 11.2 are not required since LOADSY, FIXSYS and VARSYS have been already successfully run.

The execution of the CONGEN run (third step of Section 11.2) is done without requesting printing of the FIXSYS and VARSYS files since these files have been already checked for the first pre-determined expansion plan. Each new CONGEN should be selected by the user according to own experience and judgement, in order to study several combinations of the candidates plants and to use the WASP modules to evaluate the corresponding costs.

Step 4 (MERSIM run) is executed using the "merge" mode of operation as explained in Section 7.1 (and without requesting printing of FIXSYS and VARSYS file). Thus, it is required to place the control cards of RENAME before the MERSIM deck in order to save the information about configurations previously simulated, and to change in the MERSIM control cards file 16 to SIMULOLD before executing the first MERSIM run of the series. Alternatively, the execution of RENAME can be done separately before running MERSIM (which is to be done only after RENAME has been successfully run; also with file 16 as SIMULOLD) or the user may simply follow the same procedure as explained in Section 11.2 for the first predetermined expansion plan. In the latter case, file 16 in MERSIM is labelled SIMULINL. This is, however, not recommended since saving the information calculated throughout this series may imply great savings of computer time, particularly owing to the fact that the predetermined expansion patterns usually contain some or more of the yearly configurations in common. Furthermore, this information may be also useful for the dynamic optimization phase since most of these configurations are likely to be included in some or more variable expansion plans. If the "merge" mode of operation is chosen for the MERSIM runs of this series, they must be executed using the same data cards for each MERSIM run so that all simulations are performed under identical instructions. For these runs, the intermediate or minimum output options may be asked for, as conveniently.

Step 5 (DYNPRO run) is done without asking for printing of the VARSYS file. After this run, if it is required to keep a record of the REPROBAT report for each expansion pattern (and if the "merge" mode of MERSIM operation is used), an intermediate step is needed as shown in Table 11.4. This corresponds to executing a REMERSIM run following the same procedure explained in Section 11.4, but asking for minimum or intermediate output options. On the other hand, if the "initial" mode of MERSIM operation is used for the runs, REPROBAT reports may be obtained following the procedure already described in Section 11.2 (i.e. running of REMERSIM is not required). The report options to be asked for in REPROBAT are left to the discretion of the user; however, the LOADSY, FIXSYS and VARSYS reports should be eliminated to reduce the length of the printout.

Table 11.4

Execution of a series of Predetermined Expansion Plans

STEP[1]	MODULE	OUTPUT OPTIONS REQUIRED Printing of:	REMARKS
STEP 1	-	-	Not required
STEP 2	-	-	Not required
STEP 3	CONGEN	FIXSYS and VARSYS files not required.	To be executed after the debugging phase has been completed for all modules.
STEP 4	MERSIM	FIXSYS and VARSYS files not required. Minimum or Intermediate results of simulation for all years as required	To be run after CONGEN has been successfully run. For "merge" mode of MERSIM operation add control cards for RENAME and label: File 15: SIMULNEW File 16: SIMULOLD For "initial" mode of MERSIM operation see Table 11.2.
STEP 5	DYNPRO	VARSYS file not required Listing of states considered in the run may be required (optional)	To be run after MERSIM has been run.
	REMERSIM	Minimum output with the results of simulation for all years	To be executed if the "merge" mode of operation is used for the MERSIM run and if a report is to be produced by REPROBAT: File 15: SIMULRSM File 16: SIMULINL File 13: EXPANREP or EXPANALT Not required if "initial" mode of operation is used in MERSIM.
STEP 6	REPROBAT	Use report options as necessary (e.g. deleting LOADSY, FIXSYS and VARSYS)	Optional To be run only after REMERSIM has been successfully run if the "merge" mode of operation for MERSIM is used: File 15: SIMULRSM If the "initial" mode of MERSIM operation is used REPROBAT is run according to Table 11.2

[1] Using same step numbers as Table 11.2

11.4 Search for the Optimal Solution; Running Variable Expansion Plans

Once the series of pre-determined expansion plan runs have been successfully completed, the user can start performing the series of variable expansion plan runs for the dynamic optimization of the system expansion. A flow chart of this procedure is illustrated in Figure 11.3, where the appropriate user-machine interaction points are indicated. Some important points, to be remembered while performing the computer runs, are emphasized in Table 11.5.

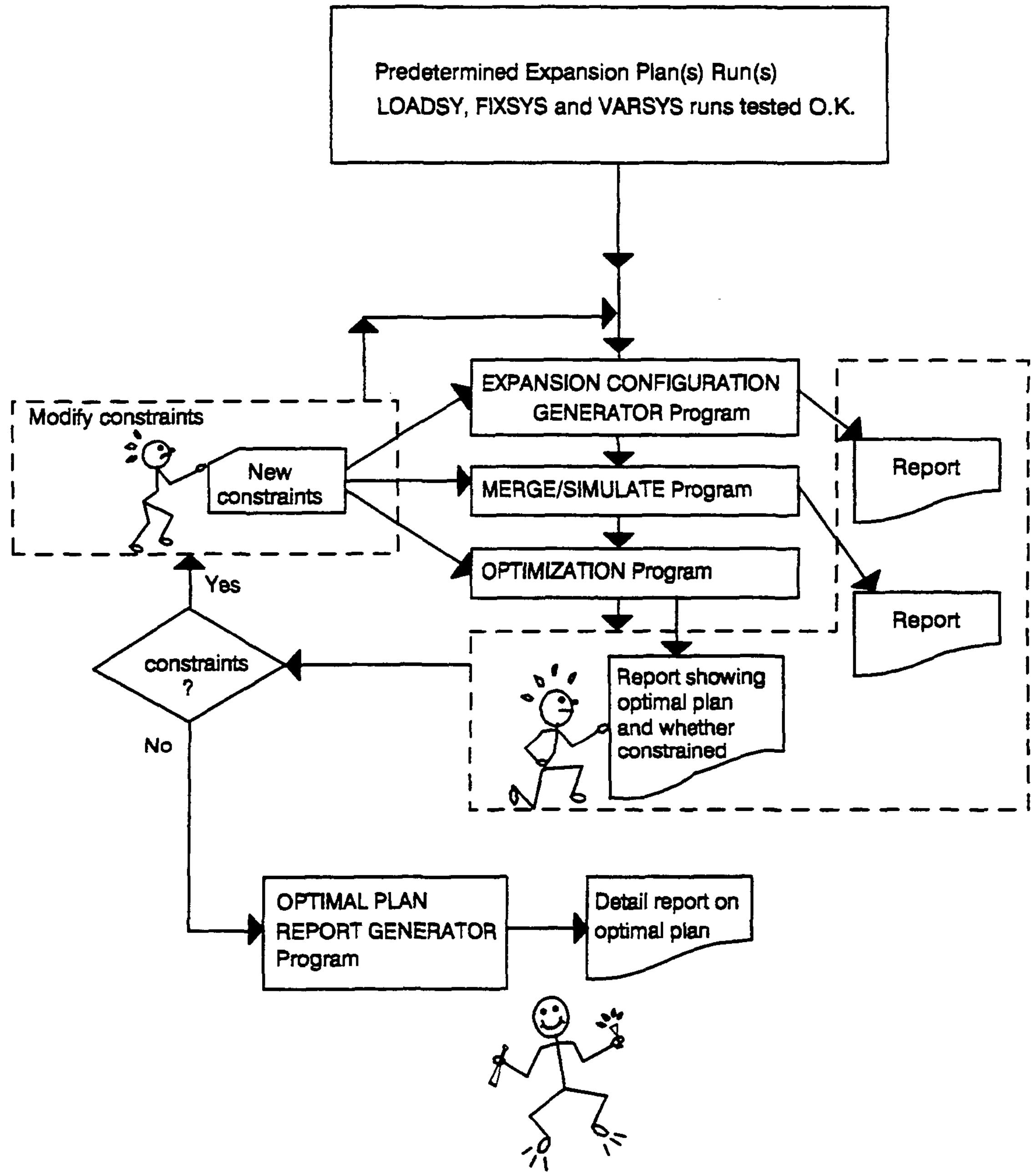

Figure 11.3 Man-machine Interaction in Running the WASP Code for Variable Expansion Plans (Adapted from ORNL 73-7759 RI)

Table 11.5

Search for Optimal Solution; Running Variable Expansion Plans

STEP	MODULE	OUTPUT OPTIONS REQUIRED	REMARKS
STEP 1	CONGEN	No printing of FIXSYS and VARSYS files	Open tunnel widths. Prior to run CONGEN make sure that RENAME has been successfully run.
STEP 2	MERSIM	No printing of FIXSYS and VARSYS files Minimum output of results of simulation for all years.	"Merge" mode of operation of MERSIM must be used. MERSIM is to be run after RENAME and CONGEN are successfully run. File 15: SIMULNEW File 16: SIMULOLD
STEP 3	DYNPRO	No printing of VARSYS file No printing of list of states considered in the run	To be run after MERSIM. Request five solutions. Examine the messages in the printout and use them as a guide for relaxing the constraints in following CONGEN run accordingly.
STEP 4[1]	RENAME	--	It is strongly suggested to run RENAME as a separate step to guarantee that simulations are saved prior to the next iteration.
STEP 5	REMERSIM	Maximum output for the optimal solution As necessary for intermediate best solution	To be run after DYNPRO has found the message-free (unconstrained) solution or eventually to obtain a REPROBAT report of the best solution found by the current DYNPRO run. File 15: SIMULRSM File 16: SIMULINL File 13: EXPANREP
STEP 6	REPROBAT	Full report for optimal solution. As necessary for intermediate best solution	To be run only after REMERSIM has been run. File 15: SIMULRSM

[1] This step has been singled out to remind the user of the need to save simulations before the next iteration.

The first step of the full-scale dynamic optimization process is to prepare a CONGEN run following the procedure explained in Chapter 6, and using the information (starting point) derived from the series of predetermined expansion plan runs. Great care should be devoted to the selection of tunnel widths for the various candidate thermal plants and hydroelectric projects since too wide tunnel widths will lead to a large number of possible configurations, whereas too-narrow tunnel widths will produce a reduced number of configurations on a limited number of expansion paths. Table 11.6 may be used as a guide for tunnel width selection as follows.

For example, if in a given year a tunnel width of 3 units (or projects) is selected for each of 5 candidates plants, all combinations of them will produce: 4 x4 x4 x4 x4 = 1024 possible configurations in the year; many of them, of course, may be rejected by the constraints imposed by the reserve margins or eventually the LOLP limits. However, with such a choice it is likely that the 300 configurations per year capability of CONGEN will be exceeded.

On the other hand, if a tunnel width of 1 unit is selected in a given year for each of 6 candidates plants, a maximum of 2 x2 x 2 x 2 x 2 x 2 = 64 configurations in that year can be expected, of which only a few may survive the reserve margins and/or LOLP constraints. It will be shown later, when discussing the run of DYNPRO, that a tunnel width of at least 2 units (or projects) is required for a candidate plant in order to obtain an unconstrained expansion plan for that plant. For a set of 6 candidate plants with a tunnel width of 2 units or projects for each candidate, a maximum of 729 configurations can be expected in a year, as shown in Table 11.6.

Table 11.6

Range of Tunnel Widths and Possible Number of Configurations in the Year as a Function of the Number of Competing Candidate Plants

Number of Competing Candidate Plants	Guide for Tunnel Widths for each Candidate Plant	Maximum Possible Number of Yearly Configurations
2	3 to 9	16 to 100
3	2 to 4	27 to 125
4	2 to 3	81 to 256
5	1 to 2	32 to 243
6 or more(*)	1 to 2	64 to 729

(*) In this case keep the reserve margins as narrow as judged necessary in order to avoid having an exploding number of configurations.

The second step is to run MERSIM as explained in Section 11.3 (i.e. in the "merge" mode of operation) in order to save all information generated in previous simulation runs. MERSIM is executed following the procedure described in Chapter 7 with minimum printout option for the results of the simulation. It is important to check that the MERSIM run was successful and that all years of the study are shown "closed" (a -1 in the printout indicates end of year). In case of aborted MERSIM runs with improper ending of file 15, a RECSIM run is advisable to be performed as described in Chapter 10. In this case, remember that if the information recovered from SIMULOLD and SIMULNEW files have been written on the SIMULREC file, the next MERSIM run must be done with file 15 labelled SIMULNEW and file 16 labelled SIMULREC. After having successfully completed this run, a subsequent run of MERSIM should be done replacing back the control card assigning again file 15 to SIMULNEW and file 16 to SIMULOLD.

Step 3 is to run DYNPRO (refer to Chapter 8 for running this module). In general, for each variable expansion plan, a best solution for the run will be reported containing yearly indications of which plants have been constrained by the tunnel widths used in CONGEN. These messages should be used as a guide for changing (relaxing) the constraints for the next CONGEN run as explained in Chapter 8. Figure 11.4 will help in the understanding of the logic to be followed when changing the minimum number of units (or projects) and tunnel widths constraints selected for a given candidate plant. This figure shows how the value of the objective function for a given case changes according to the permitted number of one single expansion candidate.

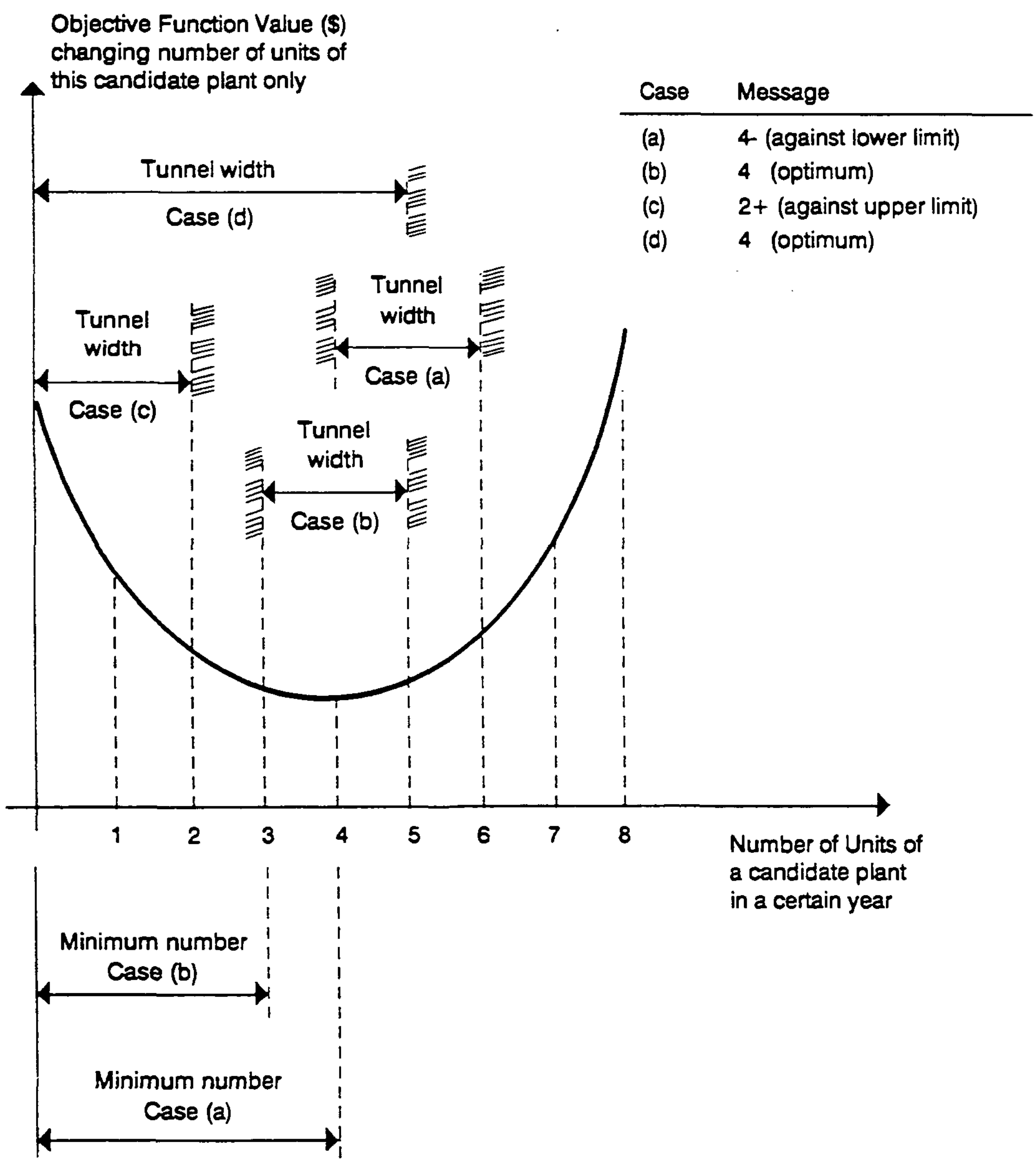

Figure 11.4 Interpretation of the Messages Reported by DYNPRO

For example, Case (a) of Fig. 11.4 gives the option taking either 4, 5, or 6 units of the candidate plant (minimum number of units, or projects =4; tunnel width =2). If the objective function versus number of units of this plant has a shape as shown in Fig. 11.4, DYNPRO will choose 4 units of the plant and will report that the solution is constrained by the lower limit, i.e. 4- will appear in the printout. This is so because the DYNPRO run did not have the chance of testing 3 units for this plant. A subsequent run (Case (b) in the figure) allowing a minimum number of units =3 and tunnel width =2 (options are now 3, 4, or 5 units of the plant) will permit the computer to detect that the objective function is minimum for 4 units of the plant considered. Case (c) of Fig. 11.4 will report the best solution as 2+ (against upper limit) since the options left to the computer were 0, 1, or 2 units only. A run such as Case (d), giving the computer the choice between 0, 1, 2, 3, 4, or 5 units of the plant, will also detect that 4 units minimize the objective function for this case. Figure 11.4 also makes clear that a message-free solution is only possible if the computer is allowed to test at least one unit above and one unit below the optimum; in other words allowing a tunnel width of 2 units.

After the first variable expansion DYNPRO run is successfully done, several iterations involving sequential execution of CONGEN-MERSIM-DYNPRO will in general be needed to reach a message-free solution (or unconstrained solution) in DYNPRO. The key point in reaching quickly the optimum is to make a careful analysis of the messages provided by DYNPRO in order to prepare the subsequent CONGEN run for the next iteration. As a rule of thumb in the preparation of a new CONGEN run, the user can simply keep the same tunnel widths of the previous run but increasing by one the minimum number of units (or projects) required of those plants marked with (+) messages, and decreasing by one the minimum number of units (or projects) required for those plants with (-) messages. This rule, however, does not apply generally if the non-overexpansion option for LOLP calculation is used in CONGEN due to the additional restriction imposed to the generation of configurations; in this case CONGEN will choose, among the possible configurations, those containing the least number of units or projects of expansion candidates which is required to meet the reserve margin and LOLP constraints (see Appendix on description of Key Algorithms in WASP); therefore, special attention is needed in preparing the CONGEN run of each new iteration if this non-overexpansion option is used for the run.

Prior to executing each new iteration, a run of RENAME is strongly recommended as indicated in Step 4 of Table 11.5. This will allow CONGEN to identify the real number of "new" configurations needed to be simulated in the subsequent MERSIM run and appropriately estimate the execution time for that run. Similarly, the work by MERSIM will be reduced as only new configurations will need to be simulated in the run.

It is also advisable that the user plots in a graph the value of the objective function for the solution #1 reported by each DYNPRO run versus the respective iteration number. Figure 11.5 plots these values for the sample problem illustrated in this manual. It is interesting to notice in this figure that the last three iterations did not produce an improvement of the value of the Objective Function. Nevertheless, they were required to eliminate some of the DYNPRO messages for intermediate years.

Once the unconstrained solution is reported by DYNPRO, the user must proceed to Step 5, i.e. to run REMERSIM for resimulation of the optimal solution, following the explanation given in Section 7.6. It must be remembered that the same control cards and input data used in the standard MERSIM run should be used, except that now files 15, 16 and 13 are labelled SIMULRSM, SIMULINL and EXPANREP respectively, and that the output option must be changed to maximum output for all years of the study.

As explained in Section 7.6, careful revision of the REMERSIM output is needed in order to check that the system operation as simulated by the program for each configuration (period and hydrocondition) can be considered as reasonable according to user's judgement and experience on power system analysis and on the particular power system of study. In some cases, as a consequence of the revision of the REMERSIM printout, it may be required to continue the dynamic optimization process by executing new iterations with variable expansion plans and correcting input data to Module 4 so as to remove the unsatisfactory results reported by REMERSIM. In some other cases, even the input data to Modules 2, 3 or 5 must be corrected and the applicable module(s) re-run in order to remove the incorrect results of the resimulation. Obviously, these data corrections (particularly those concerning plant characteristics and costs, loading order instructions, etc.) will affect the simulation of system operation, making the new MERSIM results no longer compatible with those contained in the simulation files (SIMULNEW and SIMULOLD). Thus, this would correspond to re-starting the whole WASP study as explained in Section 11.2 onward but avoiding execution of those steps already successfully completed (for example, it would not be required to re-run LOADSY (first step of Section 11.2) nor the series of predetermined expansion plans (Section 11.3)).

After the above step is successfully completed, the REPROBAT module can be run (Step 6) to obtain a full report on the optimal solution, and selecting the proper output options for the run. Remember that in this case file 15 must be labelled SIMULRSM.

In some cases, a total or partial report of the best solution found by DYNPRO so far (in the current iteration) may be required, even if this solution has been constrained by the restrictions in CONGEN (i.e. not the optimal solution). If so the user should follow the procedure of steps 5 and 6 as explained above.

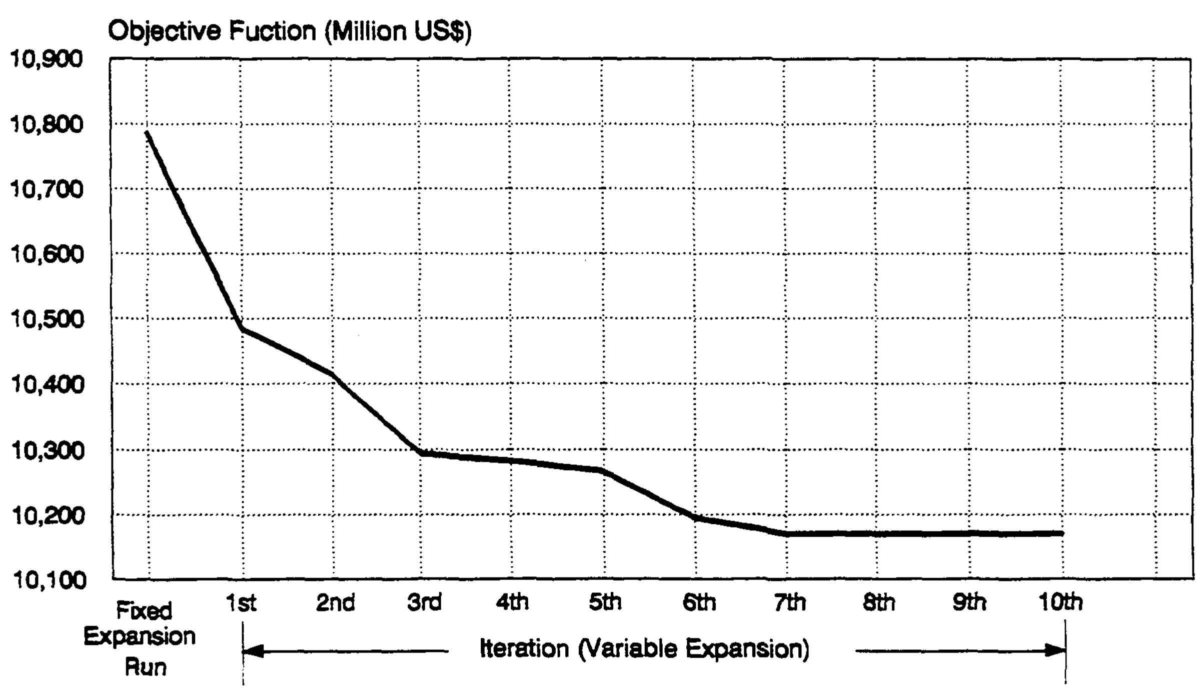

Figure 11.5 Evolution of the Objective Function Value During the Optimization Process for the Sample Problem (CASE93).

11.5 Analysis of the Optimal Solution[1]

Once the overall optimal solution for the expansion problem has been found by WASP, the user must analyze the results in order to determine whether this economic optimal expansion schedule is also a feasible program from the stand-point of the system's characteristics and the country's economic and financial situation. In this analysis, the planner will check such aspects as:

- Frequency Stability to determine whether the largest unit (or project) capacity included in the optimal schedule might produce instability of the system frequency.

- Transmission system development (network development for bulk power transmission) and associated costs.

- Plant Additions Schedule and costs.

- O&M Costs of the system.

- Manpower Requirements for additions of nuclear and conventional stations and the associated transmission system.

- Fuel Requirements to satisfy the expansion schedule.

- Financial Capabilities of the country to undertake the program.

- Environmental Constraints.

- etc.

As a result of this analysis, it might be required to re-run WASP for a new series of variable expansion plans to calculate a new optimal solution which fulfills the above checks.

The procedure is illustrated in a simplified way in Figure 11.6, where WASP related computer programs (available at IAEA) for helping the user in this analysis have been identified between parenthesis (see Appendix E for a description of WASP related programs). In the figure, the above-mentioned checks are displayed in separate blocks; the proper path to reach any block is identified with arrows (full line); and the arrows in dashed line show the paths for the cases needing executing of new WASP runs.

Apart from the necessary sequence identified by the paths in Fig. 11.6, there is no special order in which these checks should be carried out although a logical order would follow quite closely the above list, so that the process is stopped if the optimal solution is feasible from the financial capability of the country to undertake the expansion program. This solution could be used as "reference" solution for the execution of the sensitivity analysis explained in the following section.

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[1] It should be emphasized that the analysis of the WASP Best Generation Expansion Schedule proposed in this section does not constitute a Feasibility Study for any of the power plants that are included in the schedule, nor of the whole generation addition schedule and related investments.

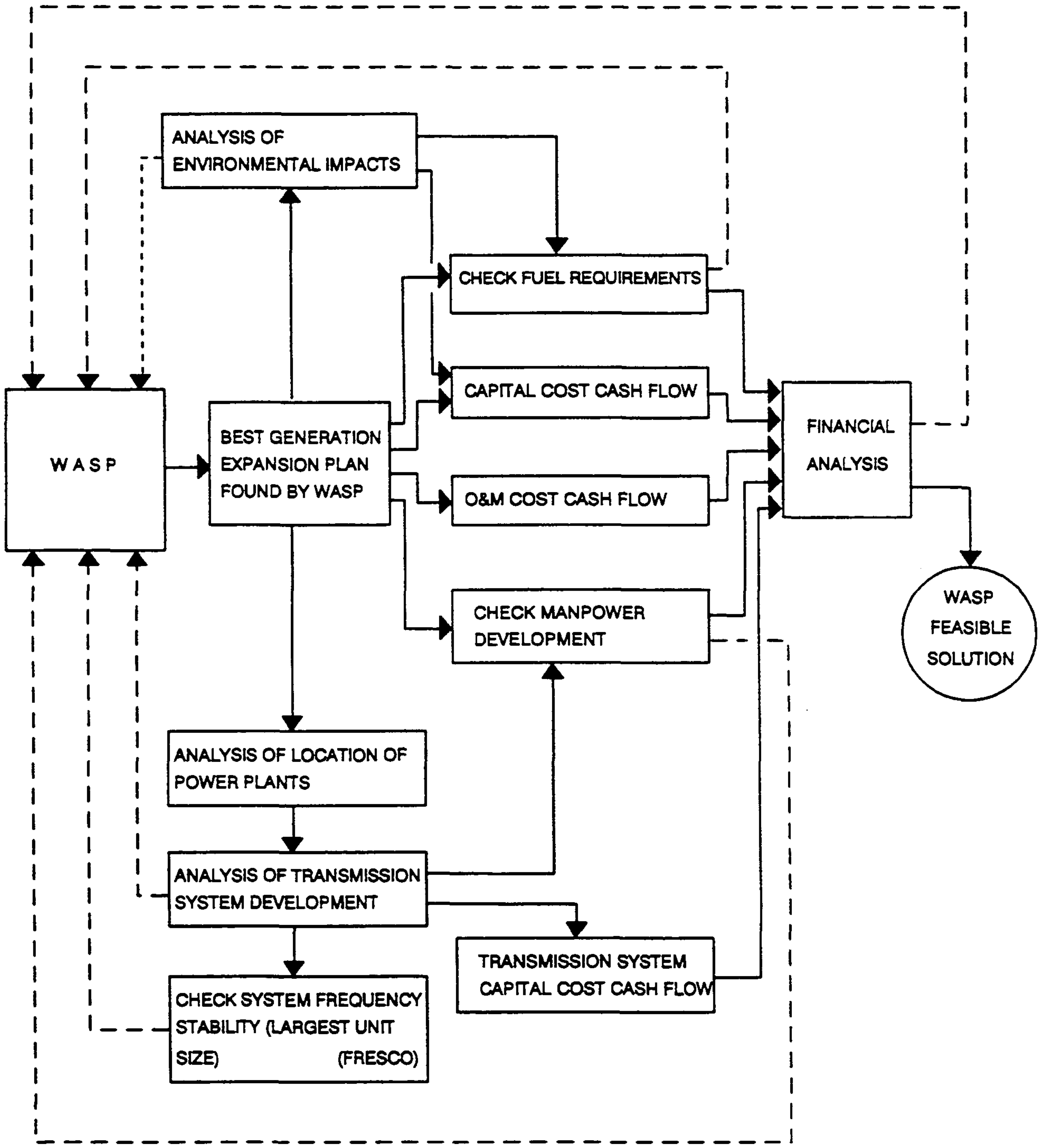

Figure 11.6 Analysis of the WASP Output

11.6 Sensitivity Studies

Sensitivity studies can be performed to evaluate the effects of the various economic parameters on the "reference" optimal solution, by simply rerunning the DYNPRO module. These studies are easy to conduct, particularly if the new values for the parameters do not cause the optimal solution to move against the tunnel boundaries, a few new iterations of CONGEN-MERSIM-DYNPRO may be required to find a new constraint-free optimum.

The economic parameters that may be studied include:

(1) Plant capital cost;

(2) Capital cost escalation ratios;

(3) Capital cost discount rates;

(4) System reliability requirement (critical LOLP);

(5) Additional (DYNPRO) constraints on expansion schedule; and

(6) Energy not served cost.

The economic parameters affecting the fuel prices may also be varied in sensitivity studies. However, some care must be taken to ensure that the changes in these parameters would not cause a change in the loading order used for the simulations. Hence, sensitivity studies can be made for reasonable perturbations of the following variables:

(1) Fuel cost escalation factors;

(2) Fuel cost discount rates; and

(3) Penalty factor on foreign expenditures.

If it is desired to make large changes in these variables, which would violate the restriction for the loading order mentioned above, sensitivity studies could still be made; however, in this case, the operating costs for all states would have to be recalculated.

Sensitivity studies involving modifications such as the load forecast (LOADSY), committed schedule of plant additions and retirements (FIXSYS), the preferred sequence of installation of hydroelectric projects (VARSYS), to name a few, would require to process a complete new WASP study.

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