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Area Control Simulator Program
Volume 4: Multiarea Models

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ABSTRACT

The purpose of this EPRI-sponsored research project was to develop a digital computer simulation program for a single-area power system and associated user's manuals. The single-area model, the Area Control Simulator, was developed and presented at the Area Control Simulator Workshop held at EPRI in Palo Alto, CA on May 1-3, 1979. The details and description of this model are covered in a Technical Manual, Volume 1, a Programming Manual, Volume 2, and a Program Listing, Volume 3 of the final report.

The remaining tasks associated with this program cover the development of a multi-area model and its delivery to Control Data Corporation for the companion project RP 1048-1.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

Over the past 50 years, all electric utilities have increased their interconnections with each other. In fact, there are currently just three groups of interconnected networks of utilities for all the power generated in the United States and Canada. Historically, area control of generation was accomplished manually. Then, analog computer generation control was developed to reduce manual control requirements. More recently, direct digital computer control systems have been installed, which provide the potential for improved control.

The growth of the interconnected networks has placed increasing demands on our ability to analyze and control each generator's performance. This has stimulated a need to mathematically simulate the control system in the interconnected networks both to evaluate current control strategies and to develop improved strategies.

PROJECT OBJECTIVES

This project under RP1048-1 had two objectives:

1. To develop a digital computer, two-area control simulator program for use by EPRI member utilities to evaluate and improve their current control strategies. This program was also being developed for use in a companion project, RP1048-1, where interconnected control performance was being analyzed by Control Data Corporation (CDC).

2. To develop a multiarea control simulator program for use by CDC on RP1048-1.

PROJECT RESULTS

The simulator programs that were developed during this project were based on a digital computer program developed by Philadelphia Electric Company (PECO) to analyze control strategies in the Pennsylvania-Maryland-New Jersey (PJM) Power Pool. The simulator program developed for EPRI can be used to analyze control actions of generators in one control area (usually a single utility) that is part of a larger interconnected network. The simulator has two features not available in other simulators currently in use:

1. It includes mathematical models and representative data for most types of generators commonly used in the United States and Canada (fossil, hydro, gas turbine, and boiling water nuclear reactor).

2. It is based on generation models that were already developed and extensively field-tested by PECO and PJM prior to the EPRI contract.

The area control simulators developed in this project were successfully used by CDC while performing the research on RP1048-1. Two versions of the area control simulator were supplied to CDC. The first used two control areas: one for the control area to be analyzed and one for the remaining interconnected utilities. The second allowed up to 10 control areas to be analyzed simultaneously. The CDC research showed that the first version was preferable for analyzing control strategies. A copy of this first version of the simulator is available from the Electric Power Software Center.

The computer program developed for this project might be classified as an engineering-grade program. This means it has been tested thoroughly as to the integrity of the programming and the accuracy of the results. However, several limitations in the use of the simulator should be pointed out:

1. The data input requires a user with good knowledge of the models.
2. The input is not user-oriented for entering large amounts of data.
3. Many of the models and their data are imbedded in the computer program and limit the flexibility of the simulator usage.

If EPRI finds there is sufficient demand by users of the area control simulator program, a production-grade version of the simulator could be developed which overcomes the above limitations. In the production-grade development, the simulator data requirements would be coordinated with the data requirements of the long-term dynamics program being developed in RP1469.

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ILLUSTRATIONS

SUMMARY

This research project has resulted in the development of two power system model programs that are generic. One is a multi-area power system simulation and the other, the Area Control Simulator, is a single-area power system simulation. Both computer programs are FORTRAN stand-alone structures that offer the following user-oriented features: print and plot routines, an integration scheme and functions to simulate dynamic behaviors; limits, deadspaces, delays, etc. One workshop has been given to date on the Area Control Simulator with associated User's Manuals detailing the design features.

These simulation programs are available through EPRI and provide an engineering tool to quantitatively and qualitatively analyze new control structures and strategies. They provide a test bed on which repeatable case studies can be analyzed and system sensitivities can be determined.

Finally, it should be reiterated; that these simulators are designed to have new or existing automatic generation control algorithms as their input and the basis of analysis. The algorithms included with these programs are merely intended to make the simulation whole and operable and are to be replaced or restructured by the user.

Section 1
PROJECT OBJECTIVES

The overall objective of this project was to develop a power system simulation model and present it at an EPRI-sponsored workshop. This effort was divided into several tasks which included a demonstration workshop for Control Data Corporation (CDC) and EPRI to discuss the structure of the model, its operation, and required data input. In this way CDC set up their work program on EPRI Contract No. 1048-1 to include the use of the Area Control Simulator. It was our purpose to develop a new FORTRAN stand-alone power system simulation program that would be independent of the Digital Simulation Language (DSL) model program previously developed by Philadelphia Electric Company (PECO). This new simulator program includes a new main control program and FORTRAN subroutines. A multi-area model case study was developed based on the system description and input data supplied by CDC. This new program was delivered to CDC with PECO providing operating instructions and assistance with its implementation.

A single-area model was developed based on specifications supplied by EPRI (Volumes 1, 2, and 3). A large number of potential users can adopt this type of simulation model. PECO prepared documentation on the single-area model so that workshop participants could have significant flexibility in the use and modification of the model to simulate particular configurations and control schemes on their own power system. A time-sharing version of the single-area power system model was made available for EPRI's use.

PECO developed a program and the required materials to conduct a demonstration hands-on workshop of the single-area power system model. The workshop was conducted to train prospective power system model users to understand and use the Area Control Simulator and to make it available to EPRI.

Section 2
MULTI-AREA MODEL

2.1 Main Program (MAIN)

Preceding the main program is the COMMON AREA CURVAL containing the current value of the system parameters. It is here that the variables are dimensioned and the user supplies the input values where appropriate. Included in the list of variables are those for the inertia model (INERTA), the external area model (EXTRNL) and the dispatch office models (LDO).

The main program itself contains access to the complete list of variables in COMMON/ CURVAL/, the current value of system parameters; COMMON/ COST/, the cost curves for each prime mover modeled; COMMON/ INITAL/, the initial value of the prime mover parameters; and COMMON/ PRTCNL/, print control parameters. The user supplies the current print time, CURPRT, (start at 0.) and the print interval, PRNTIM.

The purpose of the main program is to provide the driving function to the power system model. It must provide a structured area to accept input data. It initializes the print routine (PRINT) and calls the inertia model (INERTA), and the external area model (EXTRNL) provided KEXTRN is set equal to 1. It also calls the dispatch offices (LDO1 through LDO9) and writes the plot data onto a data set. It calls the print routine (PRINT) with the user specified print variables and then calls OUTPUT to print these variables at specified times (PRNTIM). Finally, it increments the time and the stepping variable used in the two-step integration, KEEP.

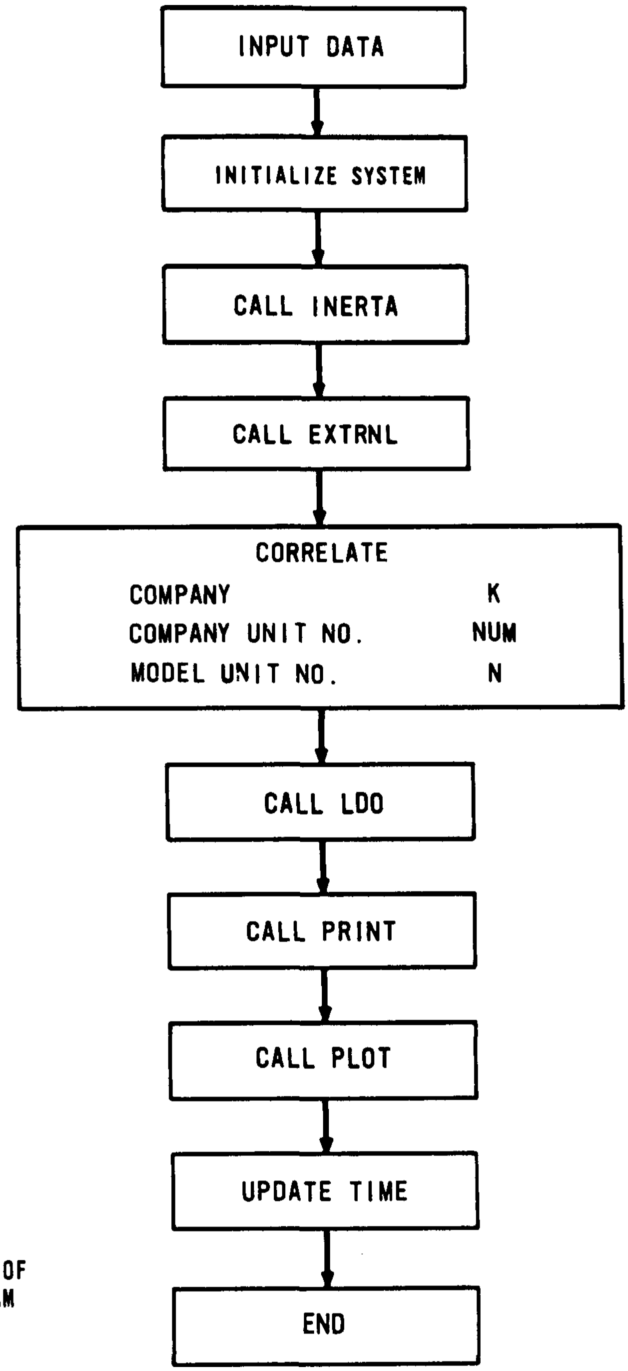
A flow chart of the major functions of the main program is given in Figure 4-1.

2.2 Input Data

The input data follows the main program in the form of block data sets, including:

- CONST1 - sets of constants associated with each prime mover

Governor Response Rate	C01
Unit Participation in Regulation	C02
Unit Generation Sensor Lag	C03



FLOW CHART OF
MAIN PROGRAM

FIGURE 4-1

Governor Controller Proportional Gain	C04
Governor Controller Integral Gain	C05

- INITAL - sets of system prime mover parameters

Initial Power Levels	PI
Megawatt Rating	MWR
Unit Types	UNTYPE
Number of Units in each Company	COUNIT

- COST - sets of prime mover cost curves.
- LABEL2 - the fossil-fueled prime mover parameters for six types of units
- WATT - the hydro-powered prime mover parameters
- GAS - the combustion turbine prime mover parameters
- ATTOM - the nuclear-powered prime mover parameters

The data sets CONST1, INITAL, and COST are directly related to the units being simulated and as such must be input for each case study configuration. The data set LABEL2 is generic to the boiler model and is fixed. The data sets WATT, GAS, and ATTOM have fixed strings of parameters for each lumped prime mover but the user must specify each string for each unit. Any unused space in an array is filled by the appropriate number of zeros.

2.3 Inertia Subroutine (INERTA)

The subroutine INERTA describes the dynamics of the system inertia. It represents a single shaft inertia model, developing system speed from accelerating torque or power. This value is developed from the balance of generations and loads from each company in the power system model. The company power levels are developed from the sum of their unit mechanical power levels. These power levels plus the sum of the company loads determine the accelerating power which is integrated to define the system speed. The accelerating power is proportioned according to each company's share of the total system inertia and sent to that company to develop electrical power and company net tie flow.

Figure 4-2 shows the inertia model's dynamics.

INERTIA AND INTERTIE MODEL- INERTA

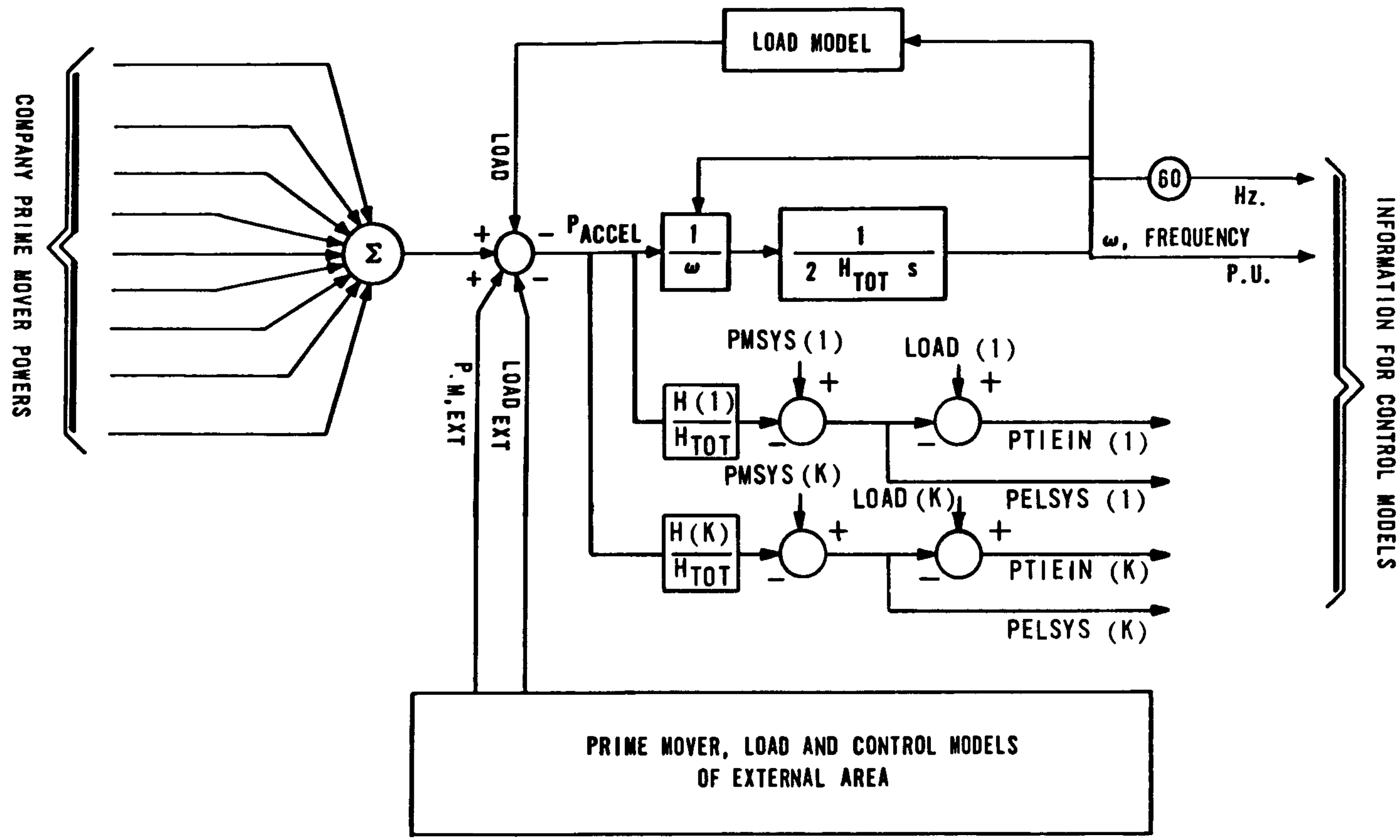


FIGURE 4-2

2.4 Load Module Subroutine (LOADER)

This subroutine reads the model load data into the system model either in the form of real load data or by calling a load model. In our case study, real load data is used with an average sampling time of three seconds.

2.5 External Area Subroutine (EXTRNL)

EXTRNL is a model of an external area which has been provided to attach to the power system model. Its use is optional (KEXTRN is set equal to 1) and it can provide the necessary system interaction when representing one or two companies. This model contains an automatic generation control (AGC) algorithm, one large aggregate boiler and one turbine. This subroutine interfaces with the main program.

Figure 4-3 represents the external area model dynamics.

2.6 Load Dispatch Office Subroutine (LDO)

This subroutine, LDO, represents the dynamics of the various company load dispatch offices. The subroutine determines the number of prime movers for each of the listed types.

UNTYPE	TYPE
1	Nuclear - BWR
2	Fossil-Fueled Supercritical Once-Through
3	Fossil-Fueled Subcritical Once-Through
4	Fossil-Fueled Drum Type - Oil-Fired
5	Hydro
6	Combustion Turbine
7	Fossil-Fueled Drum Type - Coal-Fired
8	Fossil-Fueled Non-Reheat Drum Type

The simulation automatically branches to the proper dispatch office (LD01 thru LD09). Also, the program will automatically calculate the system cost at the starting time based on the system available generation level. The model simulates the AGC algorithm including the regulation and economic dispatch signals for each prime mover. These are added to the negative value of each unit's output and telemetered back to the dispatch office (PMS) to form a unit load demand signal called Unit Control Error (UCE). This error signal drives the

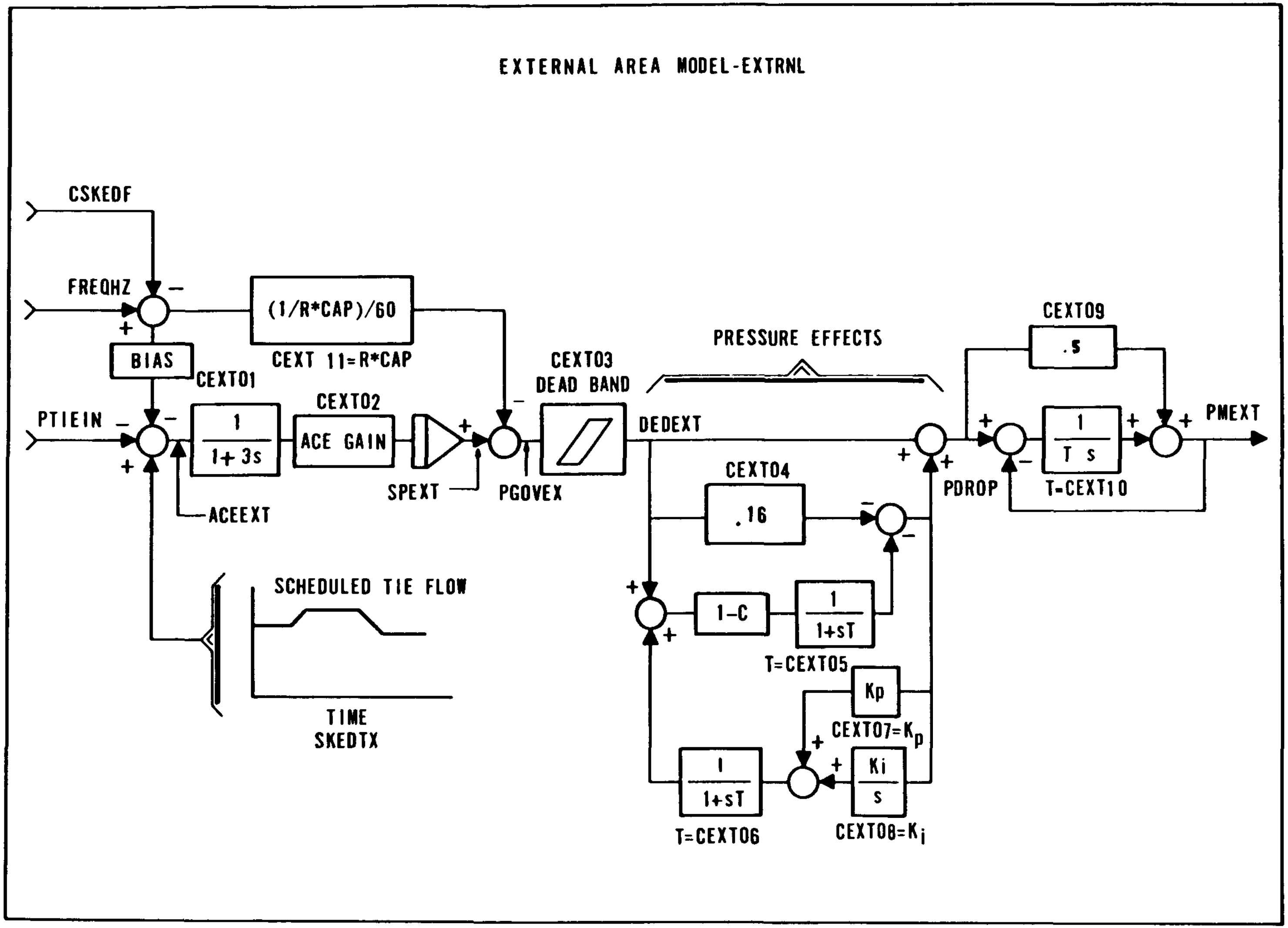

EXTERNAL AREA MODEL-EXTRNL
CSKEDF
FREQHZ
(1/R*CAP)/60
CEXT 11=R*CAP
BIAS
CEXT01
PTIEIN
1
1+ 3s
CEXT02
ACE GAIN
SPEXT
PGOVEX
ACEEXT
CEXT03
DEAD BAND
DEDEXT
PRESSURE EFFECTS
CEXT04
.16
1-C
1
1+sT
T=CEXT05
Kp
CEXT07=Kp
Ki
s
CEXT08=Ki
1
1+sT
T=CEXT06
PDROP
CEXT09
.5
1
T s
T=CEXT10
PMEXT
SCHEDULED TIE FLOW
TIME
SKEDTX

FIGURE 4-3

unit governor motor to form the governor motor setpoint (SP). The appropriate prime mover model is called and the simulation proceeds to calculate the prime mover mechanical power level (PM). The load dispatch office model parameters are array variables subscripted to each company (K) and each unit (NUM) in a given company; for example -- a typical governor motor setpoint is denoted as SP(K, NUM). This allows the model user to stack the LDO models serially, LDO1 thru LDO9 or to use one LDO model and vary the subscripted variables.

Figure 4-4 represents an example of the dynamics of the first company's LDO.

2.7 Fossil-Fueled Prime Mover Subroutine (BOILER)

Subroutine BOILER represents the boiler-turbine dynamics of either coal or oil-fired drum type or once-through type prime movers. These models include turbine valve dynamics, coordinated boiler-turbine controls, boiler controls, fuel system dynamics, feedwater system dynamics, boiler dynamics, and turbine dynamics. This model and its associated block data set represent the five types of fossil-fueled units and the one subroutine is capable of being automatically restructured and revalued for each type of unit. Only one subroutine is necessary for a simulation study case.

A schematic of the BOILER dynamics is given in Figure 4-5 and 4-6.

2.8 Hydro Prime Mover Subroutine (HYDRO)

This subroutine represents the dynamics of a hydro unit; including governor, wicket gate rate and travel limits and the turbine. These models are able to follow economic dispatch and regulation control signals. This model is applicable for run of river and pumped storage plants.

A schematic of the model dynamics appears in Figure 4-7.

2.9 Combustion Turbine Prime Mover Subroutine (GASTUB)

This subroutine represents the dynamics of a combustion turbine that are prevalent with respect to a model time step (integration interval) of one second. It includes governor motor position, unit deadband, power limits associated with ambient temperature and a controller computer time delay.

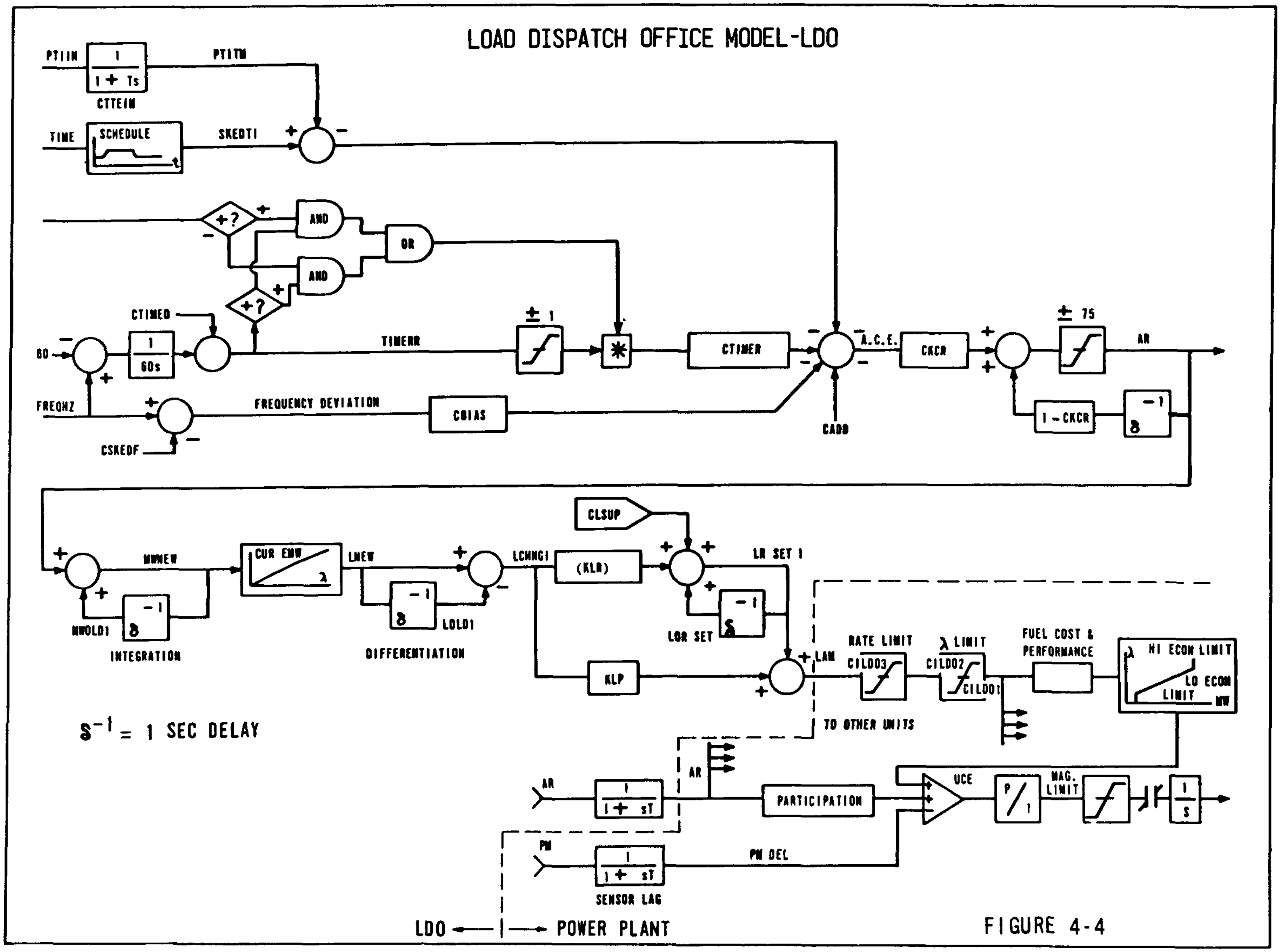

LOAD DISPATCH OFFICE MODEL-LDO
PTIIN
1
1 + Ts
CTTEIN
PTITM
TIME
SCHEDULE
SKEDTI
AND
OR
AND
CTIMEO
60
1
60s
TIMERR
± 1
CTIMER
A.C.E.
CKCR
± 75
AR
FREQHZ
FREQUENCY DEVIATION
CBIAS
CADD
CSKEDF
1 - CKCR
MWNEW
CUR ENW
LNEW
LCHNGI
(KLR)
CLSUP
LR SET 1
MWOLD1
INTEGRATION
LOLD1
DIFFERENTIATION
LOR SET
KLP
LAM
RATE LIMIT
CILDO3
λ LIMIT
CILDO2
CILDO1
FUEL COST & PERFORMANCE
HI ECON LIMIT
LO ECON LIMIT
MW
TO OTHER UNITS
s^{-1} = 1 SEC DELAY
AR
1
1 + sT
PARTICIPATION
UCE
P/I
MAG. LIMIT
1
s
PM
PM DEL
SENSOR LAG
LDO ← | → POWER PLANT

FIGURE 4-4

FOSSIL FUELED PRIME MOVER MODEL STRUCTURE

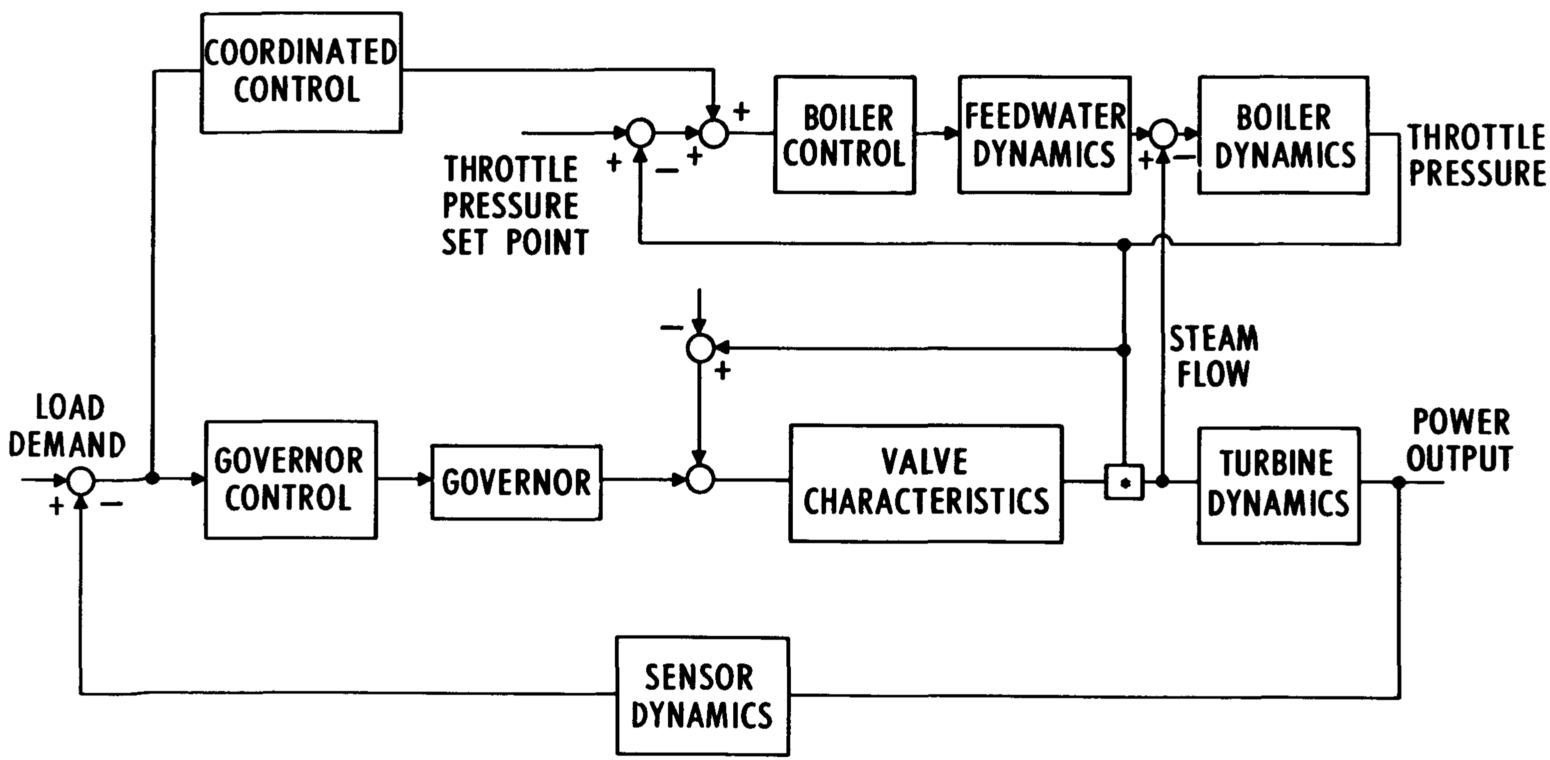


FIGURE 4-5

ONCE-THROUGH FOSSIL FUELED PRIME MOVER - BOILER

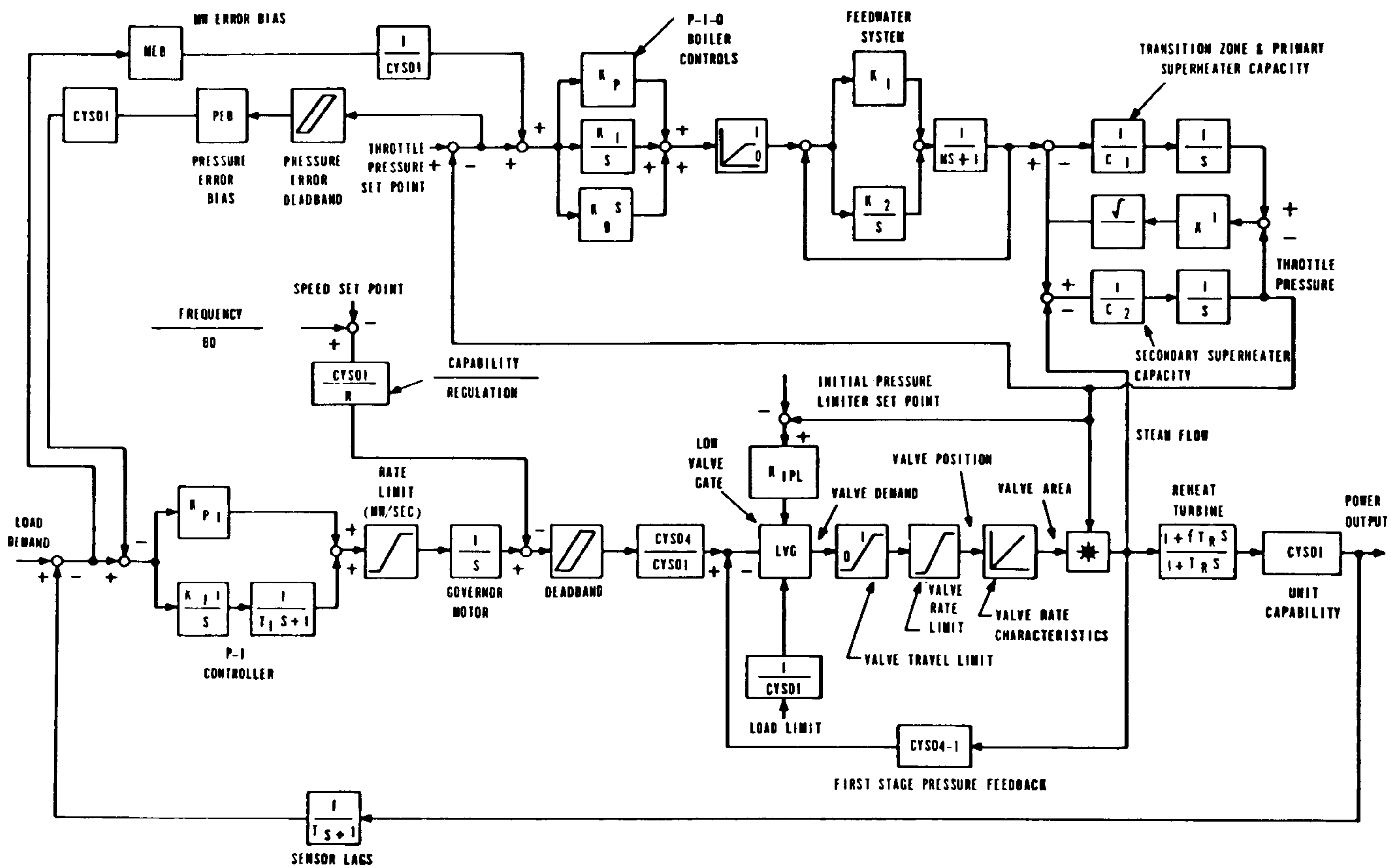


FIGURE 4-6

HYDRO MODEL

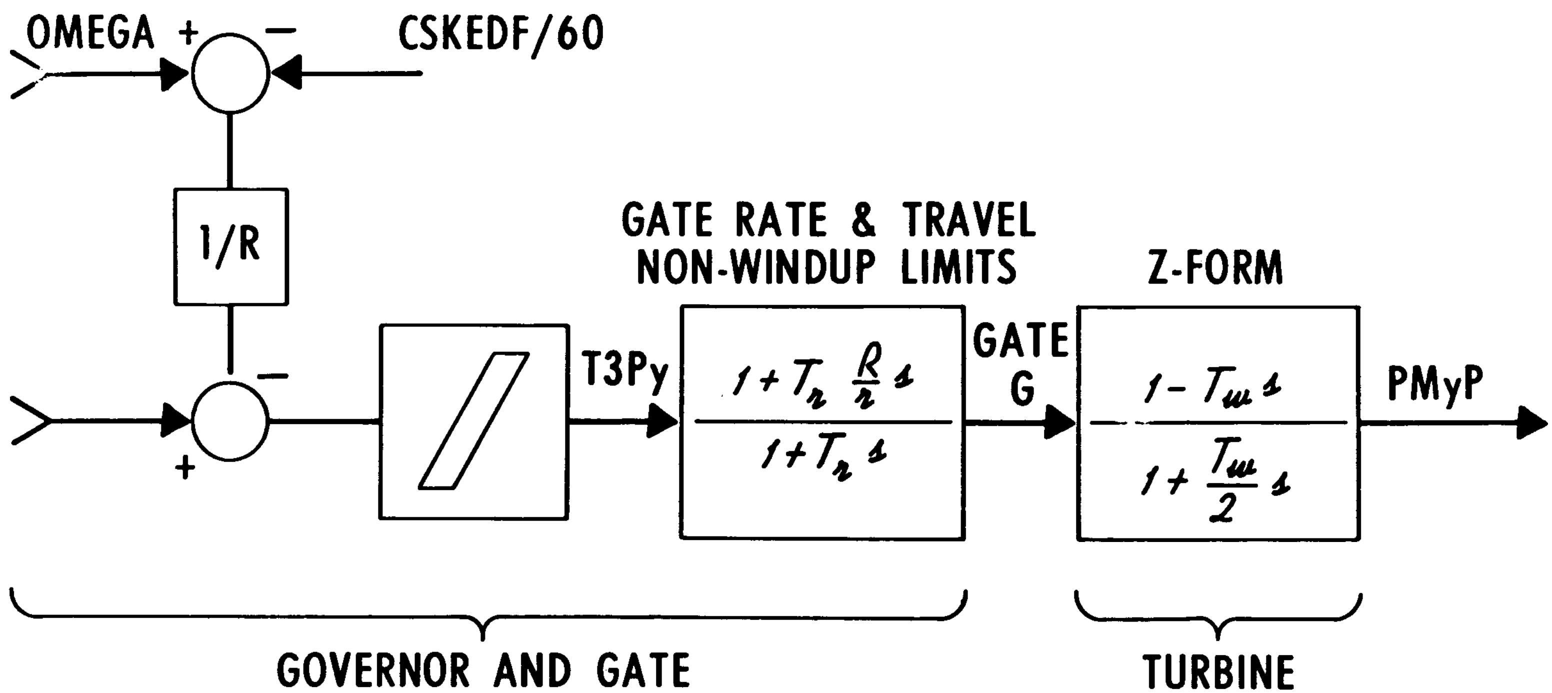


FIGURE 4-7

A schematic of the unit dynamics appears in Figure 4-8.

2.10 Nuclear Prime Mover Subroutine (NUCLER)

Subroutine NUCLER describes the dynamics of a Boiling Water Reactor (BWR) with respect to its pressure regulator offset and recirculation flow effects on the unit's mechanical power output.

A schematic of the BWR dynamics is shown in Figure 4-9.

2.11 AFGEN - A Function Generator

The function AFGEN was developed to generate output data related to specific input data, for example, the cost curves relating cost vs. megawatts. It was determined that this function should be able to interpolate between data points and be able to procede in both directions on a curve. Furthermore, in order to keep storage space to a reasonable size, ten pairs of data points must be entered for each cost curve function generator. PECO's past experience with these simulations has shown this number to be adequate. Other curves requiring a function generator can access this function provided their indices start with N = NUNIT + 1 where NUNIT is the number of prime movers in the model. This reserves the first NUNIT function generators for unit cost curves. These additional curves would require ten data pairs also.

The input variable and the function generator index number are specified.

2.12 DEADSP - A Deadspace Function

The function DEADSP provides a deadband model which can be used throughout the power system model.

The lower and upper values of the deadspace along with the input value are specified.

2.13 DELAY - A Delay Function

The function DELAY was developed to provide delays of input data as efficiently as possible and still provide the ability to work with array format variables and be able to skip out of sequence with these variables. One problem often

COMBUSTION TURBINE MODEL

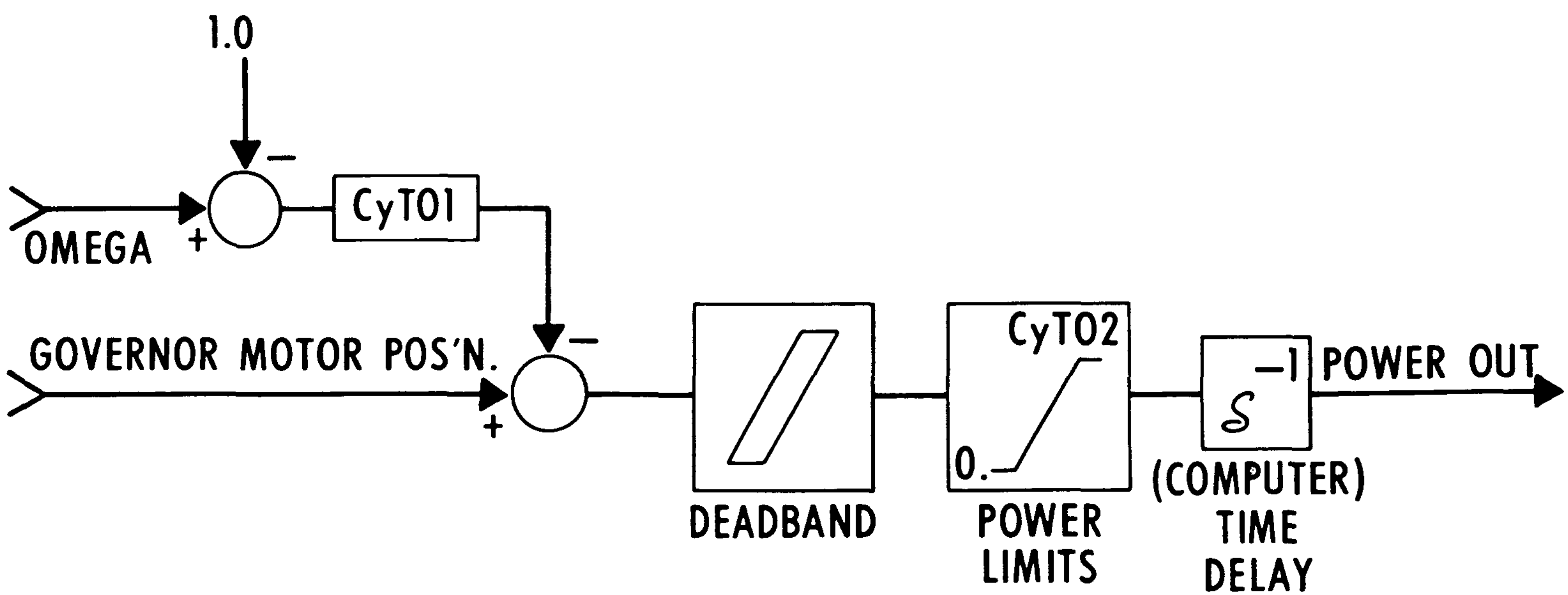


FIGURE 4-8

BWR, TURBINE AND CONTROLS MODEL

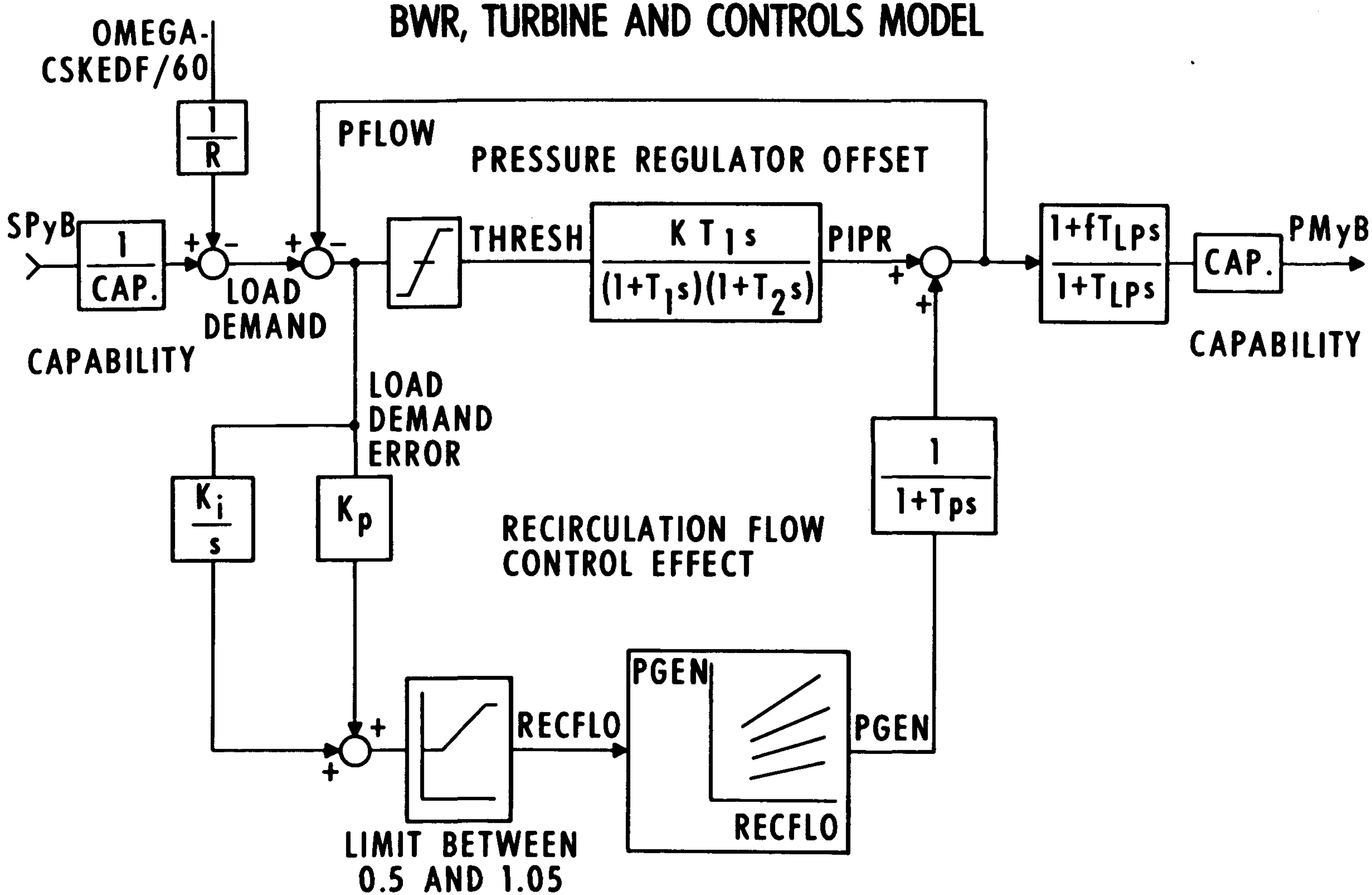


FIGURE 4-9

encountered when working with array format variables is that the entire array must be processed each integration step. We have developed a delay function that is not so limited.

The delay index number, the number of points sampled in the interval, the delay interval, and the input are specified.

2.14 DOODLE - A Plot Subroutine

This subroutine is accessed by subroutine PLOT with the plot specifiers and performs the variable plotting. It is not accessed by the user.

2.15 INTGRL An Integration Function

The function INTGRL provides the two-step trapizoidal integration scheme for the power system model. The integration interval for the model is DELT and is equal to 1 second.

The integral index number, the integral initial condition, the integral input, and the output for the last time step are specified.

2.16 INTRO - A Integration Function

This function, INTRO, provides the two-step trapizoidal integration scheme for the BOILER model. It operates at an integration interval of DELTD equal to .5 second. This integration interval is necessary to maintain numerical stability within the BOILER model. This integrator is synchronized with INTGRL on a 2:1 basis.

The integral index number, the integral initial condition, the integral input, and the output for the previous time step are specified.

2.17 LIMIT - A Limit Function

Function LIMIT provides a limiter to the power system model.

The upper and lower values plus the input must be specified.

2.18 PAGEHD - The Pagehead Subroutine

This subroutine produces the pagehead for the printout. It is not accessed by the user.

2.19 PLOT - The Plot Function

This subroutine is the specifier of the plot variables but does not plot these variables. It calls subroutine DOODLE to perform the actual plotting of output variables. Subroutine PLOT appears toward the front of the power system model immediately following the input data sets LABEL2, WATT, GAS and ATTOM. This subroutine reads the plot variable values from a temporary data set and supplies them to subroutine DOODLE. The main program wrote the values onto the temporary data set.

The user must specify the maximum and minimum values of the variables, the variable plot symbols, the plot interval and the time tic mark.

2.20 PRINT - A Printing Subroutine

This subroutine provides the user a means of printing individual variable names and their associated values at any time during the simulation study. Subroutine PRINT take the symbols and the values and stores them in parallel arrays along with the current value of simulation time. This subroutine can be called from any other subroutine in the package.

Subroutine PRINT accepts a maximum of six symbols and associated values on each call, however, as many as 200 symbols and associated values may be stored during any one time interval by making multiple calls to the subroutine. Two arguments are used to define each symbol - value pair. The first parameter is a characterizing of eight characters (padded with trailing blanks if necessary) enclosed in apostrophes. This parameter defines the symbol as a literal value for output. The second parameter for each symbol - value pair will normally be the variable name as defined in the first parameter but without the apostrophes. Fewer than six symbol - value pairs may be stored by passing a string of eight blanks enclosed in apostrophes for the first unused argument.

Subroutine PRINT checks the current time value against the time value at which it was last called. If the times are different, the symbol value tables are cleared and refilled from the beginning; otherwise, the symbol - value pairs passed as arguments are added to the end of the current list.

The calling sequence for the PRINT subroutine is as follows:

```
CALL PRINT('SYMBOL1', VALUE1, 'SYMBOL2', VALUE2, 'SYMBOL3',
VALUE3, 'SYMBOL4', VALUE4, 'SYMBOL5', VALUE5, 'SYMBOL6', VALUE6)
```

2.21 OUTPUT - The Printout Subroutine

This subroutine prints the current time and the contents of the symbol - value tables. It does not clear the tables. Therefore, if subroutine OUTPUT is called several times during the same time interval, the same symbol - value information will appear in the printed output as many times as subroutine OUTPUT is called. By having a separate printout subroutine the user has the flexibility to print only when desired, e.g. - every Nth time interval.

The calling sequence for this routine is as follows:

```
CALL OUTPUT
```

Section 3
TRANSFER MODEL TO CDC

The FORTRAN stand-alone version of the multi-area power system model was developed and run on PECO's IBM 370/158 computer. The FORTRAN program is executible and the multi-area model is balanced at the starting time (time zero) and stable throughout the case study. The simulation represents a Midwestern power company and a large external area operating during the peak-of-the-day operating conditions (11 a.m. to 12 noon). The program both prints and plots results as per the user's request.

The program (both computer card deck and computer listing) was sent to CDC. It is self-initializing and/or contains initial conditions. A listing of the PECO created load data and a tape made to be compatible with CDC computers (ASCII characterization and 800 BPI density) has also been sent to CDC. We have discussed the purpose of methods used by the computer program to help CDC with their implementation.

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