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THE "VILLAS CARROUSEL" PV-WIND HYBRID PROJECT

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ABSTRACT

A pilot project was carried out to supply electrical services for an ecological hotel (eco-hotel), using solar and wind energy in Southeast Mexico. Fifteen small photovoltaic-wind hybrid systems were designed and built by researchers of the Electrical Research Institute of Mexico, as part of a cooperation agreement with the mexican company Carrousel Operadora Turística, aimed at developing a technology package to supply electrical services to similar hotels sited in remote areas. Each hybrid system includes one wind generator of 500W nominal capacity, one PV panel ranging in power from 150W to 320 Watts peak, one lead-acid battery bank of 570 ampere-hour in capacity, and an electronic charge controller.. This paper describes the systems and summarizes the results from the first twelve months of operation.

1. INTRODUCTION

In August of 1995, the Electrical Research Institute of Mexico (IIE) and the tourism company Carrousel Operadora Turística signed a cooperation agreement to carry out a pilot project, as proof-of-concept for the application of locally available solar and wind resources to supply electricity to eco-hotels on the mexican coast of the Caribbean Sea. Design and construction work leading to the installation of 12 Photovoltaic-Wind hybrids (PVWH) began one month later. These systems became operational in December of that same year. Later on, 3 more PVWH were installed to cover the needs for an expansion of the hotel. The eco-hotel Villas Carrousel went into commercial operation in mid January of 1996 and as of the time of this writing, the non-conventional electricity supply systems had completed one full year of operation.

Two of the 15 PVWHs now installed at the hotel were instrumented and equipped with a datalogger to monitor their performance. A record is kept of the main events, technical and non-technical, that have occurred during this first year of operation. The present work describes some of the lessons learned in this project.

2. VILLAS CARROUSEL

The hotel was built in two stages and includes all the facilities that belong to a regular modern hotel. In the first stage, eleven small buildings called "villas" were built to house the guest rooms. Under ideal conditions such villas would have been constructed scattered on the hotel grounds. In this pilot project, however, due to the lack of ground space, the villas were built side by side one next to the other, to form a long building with its main axis parallel to the beach in the NE-SW direction. A swimming pool and an outdoors bar surrounded by gardens and rest areas which end at the beach can be found in front of the villas. The first stage of the construction also included the reception building, a sports court and the parking lot behind the villas. Later on, a second stage of construction was added, which includes the kitchen and diningroom, more guest rooms, and the living quarters for the hotel staff. The hotel is built on a terrain with a total ground area of 5,850 m^2, while total construction area amounts to 4,224m^2.

Villas of two (type A) and three (type B) floor levels are available. Each villa includes a common living area on the ground floor, and a number of guest rooms distributed in the different floors. The hotel has a total of 45 guest rooms. Most hotel buildings have split sloping roofs with the front part facing due southeast at an angle of 30° from the horizontal. Fresh water is a scarce commodity in the region, which gives a further motivation to recycle spent water for gardening purposes. Hot water for bathrooms and other services is produced with flat-plate solar collectors on the roofs of the buildings.

3. PV-WIND HYBRID SYSTEMS

3.1 System selection

Four different alternatives were available for the electrification of the eco-hotel Villas Carrousel: stand-alone PV, stand-alone wind, PVWHs, and grid connection. PVWHs was the system of choice for a number of reasons, including the local availability of solar and wind resources, a lower initial cost than stand alone PV, higher plant factors *vis-à-vis* stand-alone PV or wind, and a good ecological image. However, due to budget constraints to carry out the project, and given the fact that electricity from the grid was available within a few meters from the hotel site, the decision was made to use PVWHs for lighting purposes only and the grid as back up for the larger loads such as water pumps, refrigerators and air conditioners. This combined scheme allows a smooth operation of the hotel while at the same time provides a test bed for the implementation of renewable energy technologies in this type of business.

The decision was also made of using several small PVWH units (one for each villa, service building and outdoor lighting) instead of one single larger system for the whole complex, in spite of the favorable economies of scale of the bigger system. This decision was based on several practical considerations, including a lower concentration of failure risks and the fact that under more favorable conditions in future projects, the villas would be scattered over a larger ground area, each villa being served by one small PVWH unit.

PV modules for each individual PVWH were installed on the roof of the corresponding building. Each building includes a small room to house the battery bank, the electronic charge controller and other accessory equipment. The wind generators of the first 11 systems were installed on small metal towers mounted on the roof of each villa. The rest of the wind generators are installed on self-supported tubular towers 18 m high. Mounting wind generators on the roof of each building was not an ideal solution, but had to be implemented due to ground space limitations.

3.2 Systems Design Criteria

All PVWHs are designed to supply 100 percent of the lighting loads of their corresponding building. Lighting loads were established by the architects following their own functional and aesthetic criteria, in order to assure adequate lighting levels according to the specific service provided to the hotel guests. High efficiency compact fluorescent lights are used throughout the project in order to minimize electrical requirements. To size the systems, daily lighting loads were simulated based on the assumed behavior of an energy conservation-minded hotel guest. Two days of system autonomy were specified based on the characteristics of the solar and wind resources at the site. Electricity storage for this purpose is provided by deep cycle lead acid batteries.

All PVWHs were specified to operate at 12 volts, on direct current to avoid the use of inverters and step up transformers as a money-saving, energy-efficiency and system reliability measure. Hence, all electric circuits were sized using minimum voltage drop criteria instead of maximum current flow criteria normally used in electric circuit design. Systems control and protection was specified to be performed by a microprocessor-based appartus, which administers the battery bank and controls the operation of the wind and PV generators. Given the pilot nature of the project, no economic criteria were imposed for system design.

3.3 Systems Description

All 15 PVWHs have the same architecture, which includes one PV panel, one wind generator, one battery bank and one charge controller. Electricity produced by the PV and wind generators is fed directly to the load. Surplus electricy is sent to the battery bank for storage. Excess electricity from the wind generator is burned out in a resistor which serves as part of its dynamic braking system. When there is no load, batteries are full, and the sun is shining, the PV panel is put in an open circuit mode by the charge controller. Loads are fed through a distribution board. A detailed description of each individual component is given in the following paragraphs.

PV Panels. For testing purposes, three kinds of silicon PV modules are included in the PVWHs (single crystal, polycrystal and triple-junction amorphous) but each individual system uses only one kind of PV module. PV panel power is not uniform for all PVWHs, for two reasons: first, loads are not of the same magnitude and, second, individual module power is not the same for all commercial modules. PV panel power in the PVWHs ranges from 150 W for type B villas to 320 for the dinningroom. Modules in the PV panels are connected in parallel.

Wind Generator. The wind generator in all PVWHs is a horizontal axis, up-wind machine with a three blade rotor which spans an area of $2.5m^2$. This machine is capable of generating 500 W at wind speeds of 11 m/s, by means of an induction generator. This wind generator is the "avispa" (wasp) model designed and built at the Non-Conventional Energy Unit of IIE.

Charge Controller. The electronic charge controller is a microprocessor-based equipment whose main function is to manage the charge/discharge cycles of the battery bank. It is also in charge of applying excitation currents to the wind generator and controlling the dynamic braking systems for the wind machine. The electronic charge controller was custom designed and built at IIE and includes features to detect failed battery banks and open fuse conditions, as well as self-checking devices to detect and diagnose possible failures in the electronics and control elements.

Battery Bank. Electricity is stored in lead-acid, flooded, secondary batteries. Each battery bank includes six deep cycle batteries of 6 V nominal voltage each, connected in a series-parallel array for a total bank storage capacity of 570 ampere-hour (Ah) at 12 V. Batteries for this project were manufactured by the mexican company Robinson and belong to the BCI battery group GC-2 normally used for electric vehicles.

Data Acquisition.. Data acquisition is carried out by means of a CR-10 model data logger from Campbell Scientific Inc. Ten minutes averages, maximum and minimum values of these parameters, as well as the integral value where applicable, are stored in removable RAM memory modules. Logged data is transferred to a personal computer for further analysis. Data quality is automatically checked and individual sensor calibration is periodically verified. Good quality data collection for the period of this report has been over 98 percent. Minor problems with sensor reliability account for the rest.

4. TECHNICAL PERFORMANCE

Operational results for villa #3, for the period from January 19th through December, 1996 can be summarized as follows:. System availability has been 100 percent for most part of this period, albeit with a medium monthly service factor (fraction of time when electrical loads are being served) of between 40 and 60 percent, corresponding to a total of 4,439 hours of electricity supply in the period.

Total electricity generation amounts to 448 kWh, corresponding to an average hourly generation of around 54.3 Wh. Peak generation power is in the range of 439 and 497 W, which occurs during the Spring, while peak demand has reached 356 W, normally occurring in the Winter. Daily electricity generation has been around 2-5 times larger than daily electricity consumption, which means that the electrical service per villa could be expanded at least that much without further increasing the system generating capacity.

Contribution from PV to total electricity generation during the period has been almost 2 times larger than that from the wind machine, in spite of the fact that installed wind generating capacity is almost two times larger than PV, and that the wind regime at the site is good enough for power generation. A number of factors can help explain this limitation, including the fact that while the PV panel has been generating for over 350 hours per month, most of this time, the wind generator has only been producing electricity for less than 200 hours per month, limited by the operational conditions of the system.

Battery banks have performed to expectations, with some minor problems that were resolved int he early adjustment period as described below.

4.1 Main Technical Problems

Some technical problems emerged in the first few weeks of system operation, which fortunately have already been resolved. Some of these problems developed as a consequence of the rush during systems construction and installation; others have appeared as the result of the harsh marine environment at the site; and yet others have derived from the way hotel guests use electricity.

Systems fine tuning. The PVWHs installed at the hotel were tailor-made for this project. Except for the batteries and the PV modules which were purchased from established dealers, all systems components were designed and built with this project in mind. However, due to the short period allowed for systems construction and installation, a number of design adjustments had to be carried out on-site during the first few weeks after the systems installation. Among the main design changes carried out, the following are included: redefinition of some control variables; improvements in the wind machine dynamic braking system; and redesign of some portions of the electrical circuits.

Special attention was given to the problem of battery outgassing and overheating, caused by a system control strategy not suitable for the generating conditions at the site and the electricity consumption patterns in the hotel. This problem was detected during the battery monitoring activities and has already been solved. Battery cells operate now practically at room temperature without gassing, which will favorably impact the useful lifetime of the battery banks.

Marine environment. Corrosion of metal components due to the salty mist carried in from the sea by wind, represents the main threat to systems component durability. The wind machine, which is the most exposed element of the system to this environment has been upgraded to withstand corrosion. By original design, all the main outside components were manufactured from fiberglass, including the rotor and the body hub. Stainless steel is used in other main elements of the machine.

Siting of wind machines. Two problems developed from the fact that wind machines were installed on the roof of the villas. One is the transmission of vibrations from the machine into the building structure, which translate into noise. The other was an aerodynamic problem arising from the fact that the wind machines are too close to each other, due to the lack of ground space mentioned earlier. When the wind blows from the east or southeast direction, almost perpendicular to the building main axis, which is most of the time, the wind generators operate smoothly. However, when the wind blows from the northeast, parallel to the building main axis, some of the wind generators end up standing within the turbulent wake of the machine in front. Operation in the turbulent regime induces excessive vibration in some critical parts of the machines, which could result in early fatigue and reduced lifetimes thereof.

The first problem was minimized by using a set of cushion devices at the machine base. The second problem was reduced repositioning some of the wind machines to a higher elevation, outside the influence of the turbulent wake in the worst case situation. It has been found recently that the sloping roofs of the buildings also impact the performance of the wind machines by creating a vertical component of the wind velocity at higher wind speeds.

Meteorological Conditions. Hurricanes and tropical storms represent a serious threat for the survival of the wind machines. Preventive measures were devised and built into the designs, so that the rotors can be removed from the machines with a simple operation at the first warning that such a meteor may be hitting the area. Removed rotors are easily put back in place on the machines once the critical condition has disappeared. Electricity is supplied to the load from that stored in the battery bank and from the daily generation of the PV modules while the wind machines are out of operation, usually only a few days per event.

Wind utilizability factor. The "Avispa" wind machine is designed to generate 500 W of power at 11 m/s wind speed. It has been observed, however, that contribution of the wind machine to the total generation has been lower than expected. This is due to the fact that electricity consumption has not always been as high as anticipated and thus the electronic charge controller cuts off wind generation by braking the wind machine when batteries are full, giving priority to PV generation to make up for the energy demanded by the load.

5. CONCLUSION

The Villas Carrousel Project has been an interesting experience which has produced several valuable results. On the purely technical side, the project fostered the development of a PVWH package, which after 15 system-years of experience is now upgraded and ready for further commercialization. The project has also produced relevant and timely information on the problems and difficulties of introducing renewable energy systems into the operational structures of a commercial hotel. Some have been resolved, but others are still open for further study. Information produced includes issues of operation and maintenance, public perception, guests reactions, and management implications. Finally, the project opens ground in a yet unexploited and certainly attractive nich market for PVWHs, namely, ecohotels.

6. ACKNOWLEDGEMENTS

The author wishes to acknowledge the logistics and economic support provided by Operadora Turística Carrousel to carry out this project. A number of researchers, technicians and other support personnel from IIE-UENC contributed to the project; it would not have been possible to carry out the project without their help and devoted work.

A BRIEF DESCRIPTION OF POLANCO'S HYBRID SYSTEM

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ABSTRACT

Since 1995, a hybrid system wind - PV is in service in Polanco, Uruguay. A brief description of this system and the criteria employed in its design are outlined. The experience obtained during two years operation are described from the points of view of the equipments reliability and of the electrical service provided. Future prospects of this kind of installations in Uruguay as part of the rural electrification policy are presented.

1. URUGUAYAN ELECTRICAL SYSTEM-RURAL ELECTRIFICATION

The uruguayan national electrical system has values of peak power consumption of 1200 MW and generated electrical energy of 6400 GWh per year. It is connected with the argentinian system through two 500 kV overhead lines. A very high percentage of the energy is generated at hydroelectric power plants.

Although the national electrical service reaches a very high percentage of the country's population (approximately a 95%), there are areas with a very low density of population, which are distant from the national network. In these areas the use of alternative renewable energy could be economically feasible in autonomous systems. The topography of these regions is more or less hilly without important geographical accidents. These areas are practically exclusively dedicated to traditional cattle raising, an activity which does not require intensive use of electrical energy. Therefore, the problems of energy supply which are brought up refer to individual consumptions or to very small housing groups located at great distances among each other and from the existing distribution network.

The typical rural home consumption is about 100kWh/month, with densities varying from 30 to 5 km/user, wherefore the connection to the system of distribution makes no sense from the economic point of view.

The choices which are most attractive to satisfy these requirements are: photovoltaic systems, wind systems, and the combination of both of these. Small, mini and micro utilization of hydroelectric energy must be added to these above mentioned choices.
The Work Group on Renewable Energy has already advised with a program to electrify schools, police stations and dispensaries distant from the national electrical network, with numerous installations using energy of photovoltaic and wind origin.
At the same time, the possible use of renewable alternative sources in cogeneration with the national electrical system seems to be very interesting from the economic point of view.

2. POLANCO'S HYBRID SYSTEM

The objective of the Polanco Project was to install an appropriate energy solution for the supply of electric power to the houses of the small village of Polanco using solar and wind energy, and at the same time, to achieve a solution modular, economic and reliable and that could be used in other places.

The selected solution considered the economic, social, technical and environmental conditions that concours in Polanco, procuring that the developed solution could be applicable in other places of similar social and technical characteristics.

2.1 Energy consumptions

The energy consumptions under consideration are associated to the following energy services:

- Houses: Conservation of foods, television, radio and illumination.
- Communal Saloon: illumination.
- Dispensary: illumination.
- Pumping Station: drinkable water pumping.
- Public Lighting:
- Grocery: illumination, conservation of foods.
- Telephone office: illumination, conservation of foods, equipment.

The school is far from the village and has no service from the hybrid system.

The following appliances are out of consideration: washers, irons, dishwashers, electric heaters, air conditioners, electric cookers, electric welding, and any other of intensive consumption of electric power or that implicates heating of any type.

The level of electrification for each house is the usual in rural electrification with a maximal consumption of 5 A 220 V 50 Hz. The maximum simultaneous is limited to 3.5 kW per circuit (approximately 300 W per house).

2.2 Design criteria.

For the selection of the technical solution Ecotècnia uses the following criteria:

- Demand: The energy solution must satisfy the 85% of the load in the worst period of the year.
- Cost: As the replacement of the equipments will be done by the users, their cost is a very important variable.
- Reliability: As this is a demonstration project of an autonomous system it is very important to minimize the time out of service.
- Simplicity of construction: The equipments and installations may contain pieces or components of good quality in a quantity as small as possible in order to reduce the number of failures.
- Interchangeability: It is desirable that the system has interchangeable modules in order to increase the readiness of the group.
- Simplicity of operation and maintenance: The characteristics and the number of equipments and components should be selected in order to minimize the tasks of O+M.

The system of distribution of electricity should be similar to the conventional one for rural areas except for the use of heating devices.

2.3 Systems technical description

The supply of electric power for Polanco consists of 4 independent systems including generation, accumulation, conversion and distribution of power:

- 3 systems each one of them with:

* One10 kW windmill, 7 m. of diameter, with its controller of batteries load.

* One PV array with 27 Isofoton solar cells 53 Wp, totally 1431 Wp, with its regulator.

* Stationary Battery 48 V, 1416 Ah (10 h).

* Converter of 4.000 VA:

  - 1 system formed by:

* One2,5 kW, 5 m. of diameter with its controller of batteries load.

* Stationary Battery 48 V, 600 Ah (10 h).

* Converter.

In the original design another system was included with a 10 kW windmill. Each PV array had 63 solar cells instead of 27.

The three hybrid systems feed each one an independent circuit of 12- 13 houses, while the small system would supply the communitary services (pump, saloon and dispensary).

In case of fault of energy, there is an auxiliary 5 kW generator which can supply the energy for the pump or whatever of the circuits.

The windmills have been placed at enough distance between them so that losses due to aerodinamic interference are not more than 5%.

Two circuits are provided with acquisition and registration of data. The picked up data are:

* Energy from the PV array.
* Energy from the windmill.
* Energy supplied to the load.
* Solar energy on the plan of the solar array
* Speed of wind in m/ s. (mean value)
* Maximal battery voltage registered in the last period without regulation.
* Minimal battery voltage from the last out of service due to low battery.
* Number of complete cycles of load battery.
* Number of out of service due to low battery.

Watthourmeters are placed in every circuit that feed the houses.

The connection of each circuit to the converters is carried out through one 32 A plug.

Each converter has two sockets so it can be connected to two circuits at the same time but it is impossible to connect one circuit to two converters.

In this way, in exceptional circumstances, all the load could be supplied from two converters.

The hybrid plant of Polanco is in service since February 22 th., 1995.

2.4 Electrification works.

The electrification works include the following elements:

- Generation systems
- Building to install batteries and the control system
- Batteries
- Regulation and protection
- Conversion of the energy to 220 V 50 Hz
- Systems of measurement and watthour meters
- Earthing
- Registration of data
- Distribution of electricity
- Indoor electrical installation

The project also included the wind measurements carried out before the beginning of the project, the installation of the equipments and the survey tasks during one year.

The distribution of the electric power is carried out with two wire overhead lines 220 V/ 50 Hz.

The reasons for this choice are:

- Obtain a quality of service similar to the conventional electrification, without dependence of the market of apparatus for direct current, that are more expensive and of scarce distribution.

- Reduce the distribution losses.

- Reduce the cost of the distribution network.

The design of the systems of control is guided to minimize the operation tasks.

The use of potential transformers, clocks and watthourmeters is minimized to avoid their energy losses.

2.5. Participants in the Project.

In the technical execution of this project participated:

* Project and technical attendance: Ecotècnia s.c.c.i (Spain)
* Director of the project: Miquel R. Miró. (Spain)
* Coordinator en Uruguay: Uri Groisman. (Uruguay)
* Installation of the hybrid plant: Enurec Ltda. (Uruguay)
* Converters and PV controllers: Trama Tecnoambiental.(Spain)
* Batteries: Tudor (Spain)
* PV solar cells: Isofoton. (Spain)
* Windmills: LMW Renewables. (Holland)

The project has been financed by the following institutions:

- European Commission (DGI).
- Comisión Honoraria pro-Erradicación de la Vivienda Insalubre Rural (MEVIR)
- Dirección Nacional de Energía del Uruguay.
- Institut Català d´Energía (ICAEN).
- Agenzia per lo Sviluppo Tecnológico dell´Emilia Romana (ASTER).
- Programa de las Naciones Unidas para el Desarrollo (PNUD)
- National Utilities (UTE).
- Telecommunications National Administration (ANTEL).
- Administración Nacional de Combustibles, Alcoholes y Portland (ANCAP).
- Intendencia de Lavalleja.

3. SYSTEM OPERATION

The service provided by the hybrid system had several troubles. The reasons that explain this fact are the following.

Due to financial difficulties, the original design was reduced and perhaps neither the relation between windmills and solar cells nor the number of independent systems are the optimal ones.

Most of the refrigerators installed are very old and its start current and energy consumption are over the values assumed in the design. The illumation devices and TV sets are suitable to the criteria established.

The small windmill had troubles and is out of service since the beginning. Several modules of the PV regulator and converters had troubles and had been replaced but

EXPERIENCIES WITH A SMALL SCALE SOLAR/WIND PILOT INSTALLATION FOR BASIC ELECTRIFICATION IN THE CHILEAN ALTIPLANO

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ABSTRACT

Basic rural electrification programmes are already carried out in the rural areas of northern Chile by local communities and local governments using photovoltaic systems. Solar Home Systems, 12 V DC are installed for individual households while systems for schools, public lighting etc. are realized with bigger systems, 220 V AC.

Within a cooperation with the Solar Institute of the Fachhochschule Jülich, Germany, the Renewable Energy Center of the University of Tarapacá designed, installed and evaluated the first solar/wind hybrid installation for basic electrification in northern Chile, realized in Colpitas, a typical small village in the chilean altiplano.

The following paper presents results and experiencies of this first pilot installation.

1. INTRODUCTION

Colpitas is a typical village in the chilean altiplano, belongs to the community of General Lagos near the frontier to Peru and Bolivia at a geografic latitude of -18 °. Altitude is 4200m above sea level. The center of the village consists of a school and some public buildings while main part of the families live in the surroundings. Main income is cattle breeding.

Actual water supply is done by a nearby operated well with a connected pipeline system, which delivers good water both in quality and quantity. Years ago a diesel generator was installed for electricity supply, but failed soon after installation, so that in the actual situation before the new system implementation there was no electricity available in the village.

Thermal energy for cooking is provided by a gas cooker in the school, the individual households use wood cookers.

2. PROJECT OBJECTIVES

Main objective was the basic electrification of the village and hereby contributing to an improvement of the actual living conditions of the village's inhabitants.

Combining both, the high solar and wind potential in the region, the pilot installation allowed to evaluate this hybrid aplication under the specific local conditions in tecnical and economical aspects and find out areas of optimization.

3. PROJECT IMPLEMENTATION

Considering the local conditions, especially the dispersed population and location of the individual houses, it was decided to realize the project in two parts :

- Solar home systems. 12 V DC, for the individual houses
- PV/Wind hybrid system for basic electrification of the school, public buildings and public lighting

Within a cooperation with the Solar Institute of the Fachhochschule Jülich, Germany, the systems were installed in septembre of 1994.

3.1 Description of the hybrid system

A schematic diagramme of the main components is given below, using the following main components:

- solar generator, 212 W_p, 4 x M55
- charge regulator solar, ASP, 1 x SR25
- wind generator, 300 $W_{nom.}$, D303 Harbarth

- charge regulator wind, D303
- batteries, 800 Ah, 12 V, 8 x C100, Varta Solar
- inverter ASP 1000 W

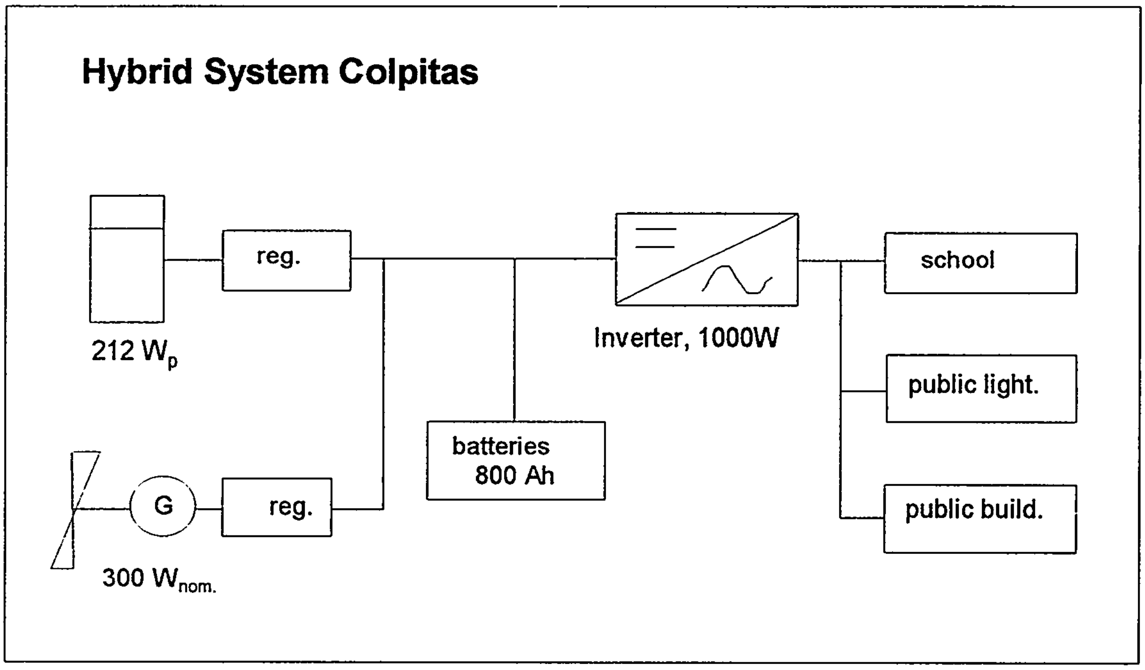


Diagramme No. 1 : Schematic diagramme of the hybrid system

3.2 Implementation of a monitoring system

In order to realize a long term monitoring and a tecnical and economic evaluation of this pilot installation a data logger system was installed measuring the following parameters :

- solar irradiance horizontal, CM11
- solar irradiance horizontal, solar cell
- solar irradiance inclined, solar cell
- wind speed and direction
- ambient temperature
- air pressure
- solar charge current
- wind charge current
- battery voltage
- consumer current DC

The selected equipment is a MODAS 1220 datalogger system, which is in operation since novembre 1995, storing all parameters in a 10 min. time intervall.

4. FIRST EXPERIENCIES AND DATA ANALYSIS

4.1 Meteorological data

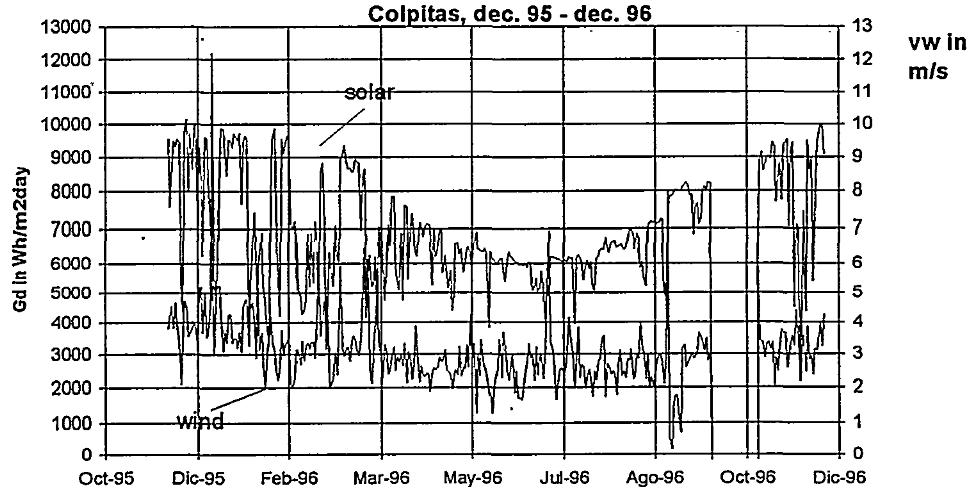
Due to the location of Colpitas in the chilean altiplano with an altitude of 4200m a lower air pressure and air density has to be taken into account. Typical measured values of the air pressure are in the range of 625 hPa with very small daily and seasonal changes.

Maximum temperatures in summer (months between dec. and feb.) reach values of 24 °C, while minimum temperatures in the months july and august can go down up to -20 °C.

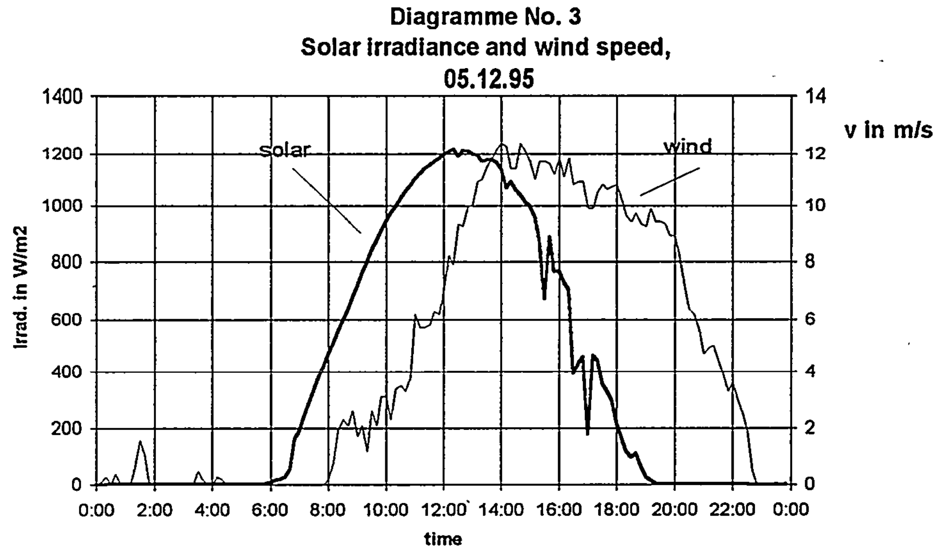
The resulting air density can be calculated to 0.78 kg/m^3 as an average value.

The chilean altiplano represents a region with an extremely high solar radiation potential. Diagramme No. 2 shows the mean daily wind speed and the daily global radiation, measured with a CM11 pyranometer on the horizontal plane. The yearly average value of the daily global radiation is G_d = 6.3 kWh/m^{2}day.

Diagramme No. 2
Daily global radiation and mean wind speed
Colpitas, dec. 95 - dec. 96

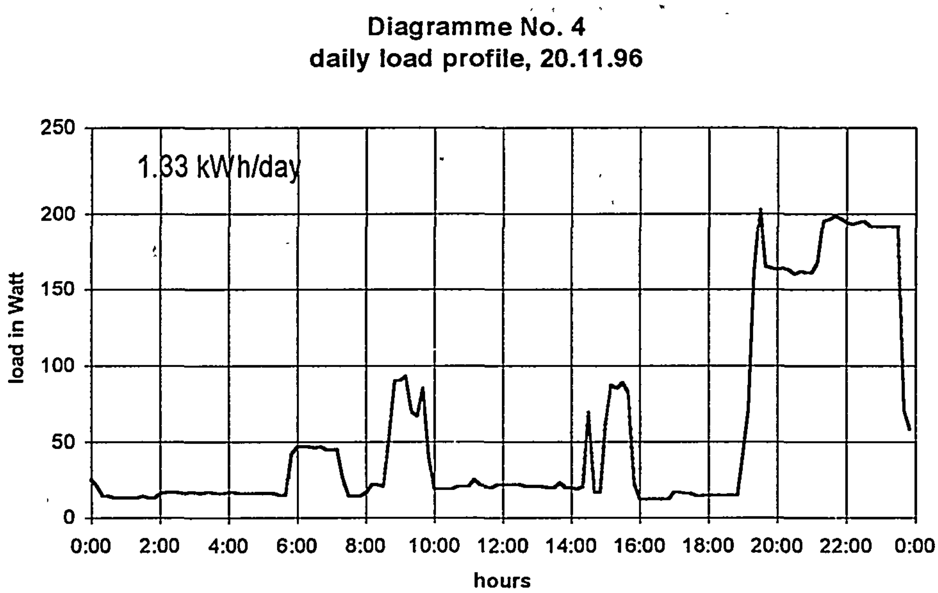


The measured mean wind speed with an average of around 3 m/s indicates first of all a quite low energy potential, but the daily profile of the wind velocity with strong winds in the afternoon and evening hours represents together with the solar radiation profile an interesting aplication for a hybrid system. Diagramme No. 3 gives a typical daily profile of solar irradiance and wind velocity.



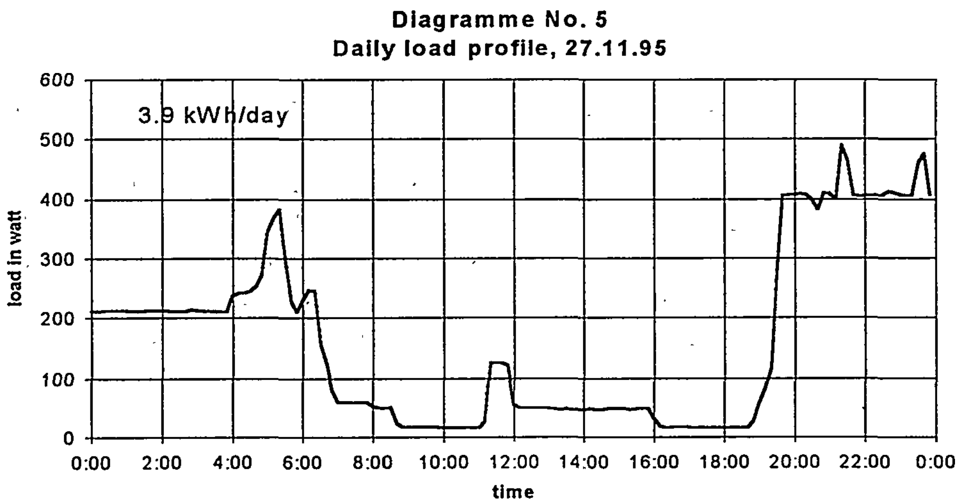
4.2 Electrical energy demand

One of the most important results of the first data evaluation is the real determination of the electrical energy demand, because in the planning phase only estimationes and asumptions could have been done. A typical daily profile of the consumer load shows diagramme No. 4, with a daily electrical energy consumption of $W_{el.}$ = 1.33 kWh/day. The public lighting is included here with a total of 120 W, operating 5 hours in the evening.



A problem which occurs generally in a large number of 220 Volt AC installations is the connection of additional loads, available in the local market. Diagramme No. 5 shows an example, where loads up to 500 W were connected to the system operating a few hours with a total daily electrical energy consumption of 3.9 kWh/day, exceeding the system's capacity.

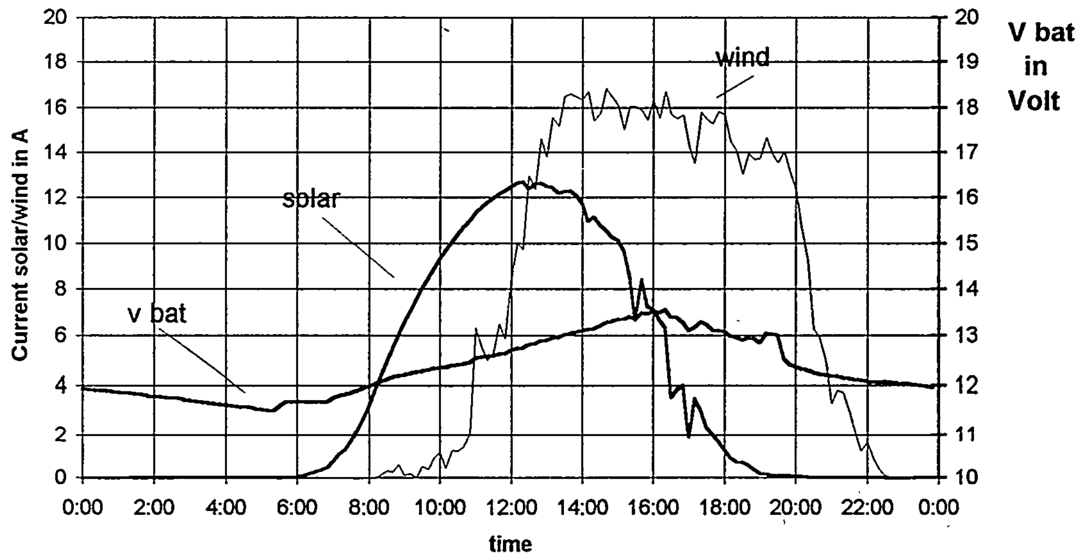
A good education programme for the users is absolutely necessary here in order to realize an adequate system's operation and garantize a long life time of the system.



4.3 Solar and wind charging cycle

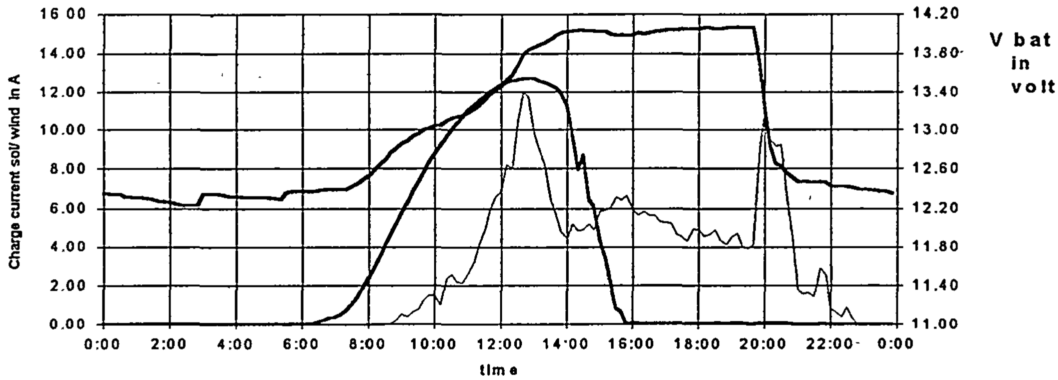
With the solar irradiance and the wind speed curves, given in diagramme-No. 3, the following curves in diagramme No. 6 demonstrate the resulting charging currents of both, the solar panels and the wind generator. Considering the system's losses in the batteries, the inverter etc. the average daily available electrical energy for the consumers can be determined to 1.6 kWh/day. Both power sources deliver electrical power in accordance to the data sheets of the suppliers.

Diagramme No. 6
Wind and solar charging cycle, 05.12.95



The solar charging circuit and the wind charging circuit are equipped with charge regulators to avoid the battery's overcharge. The solar charge regulator is a series regulator type, while the wind charge regulator disconnects in case of overcharge protection the batteries and connects an additional load (250 W bulbs) to the wind generator. Diagramme No. 7 represents a typical regulating condition. With a battery voltage of 13.8 Volt the wind charge regulator activates the bulb loads, a further battery voltage increase activates the solar charge regulator at a level of 14.1 V. (temperature compensated)

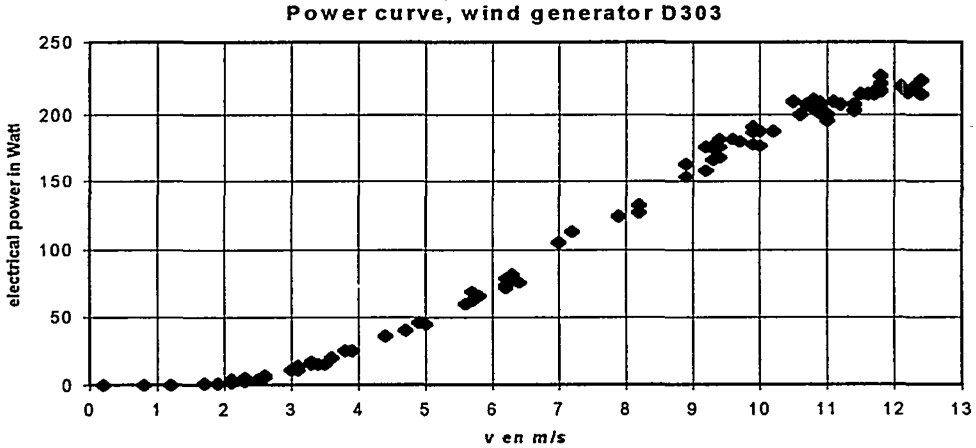
Diagramme No. 7
Charge regulating, 12.01.96



4.4 Windgenerator curve

The wind charging curve given in diagramme No. 6 allows to determine the wind generator caracteristics, the electrical output versus windspeed. The resulting curve shows diagramme No. 8. The wind generator produces an output power of 220 Watt, with a nominal wind speed of 12 m/s. Due to the already mentioned lower air density the electrical output power reduces to around 75 % of the nominal value of 300 Watt.

Diagramme No. 8
Power curve, wind generator D303



4.5 Battery voltage

Monitoring the battery voltage gives precise information about the system's behaviour and operation, especially for the charging procedures as well as the discharge caracteristics. Diagramme No. 9 gives the daily minimum and maximum values of the batteries for the period of november '95 up to september '96. Two problem areas can be identified :

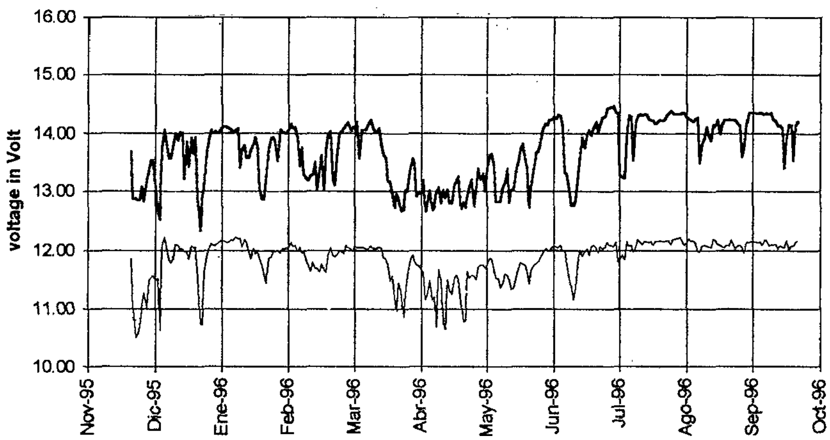
Period of november '95 to january '96 :

Several deep discharges are registered due to a rather high electricity consumption in this period, but an acceptable recuperation and recharge of the system can be observed. The deep discharge cycles down to a battery voltage of 10.5 Volt also indicate an unadequate level of deep discharge protection. In the majority of 220 V AC systems, the deep discharge control is realized by the inverter's internal low battery control circuit. But the inverter's cut off level with a value of 10.5 Volt is too low in order to protect the battery from deep discharge.

Period of april and may '96 :

Several deep discharges without an adequate recharge were observed. Main problem here was the wind generator breakdown, described in the following chapter. In these two months only the solar panels charged the batteries resulting a system operation in a rather low voltage range. In the following months the system performance could be improved by a drastical reduction on the consumer side, the installation of one additional solar panel and the installation of at least a small wind generator, type Rutland 50 W.

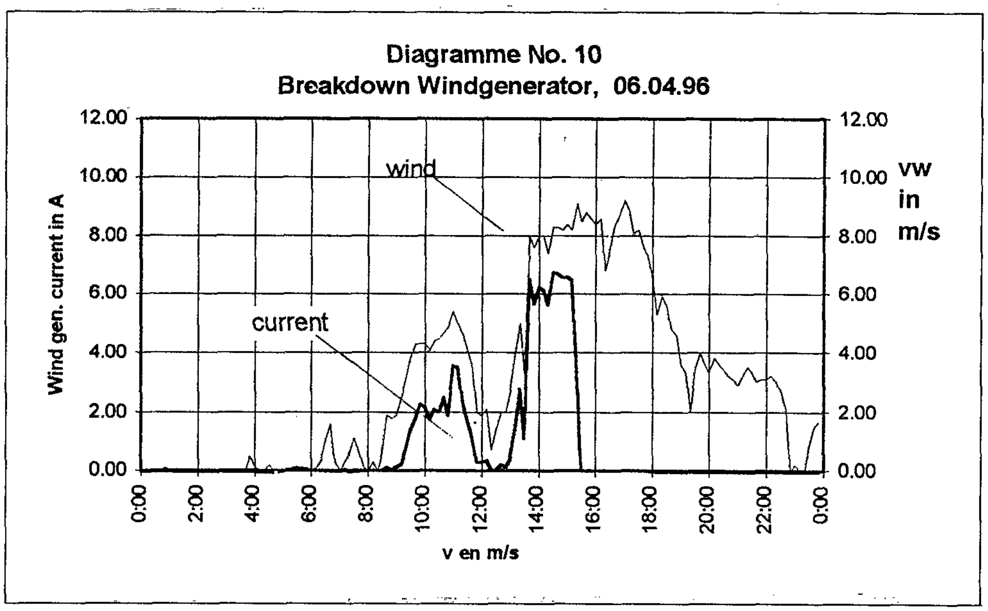
Diagramme No. 9
Battery voltage, daily max. and min. values



4.6 Wind generator break down

After an operation of 19 months the wind generator broke down in the first week of april '96, two of the three wings were broken. Up to now the exact failure cause could not have been determined, probably a fatigation of the wing's material (100% nylon) under the extreme ambient conditions caused the problem. (high solar UV radiation, daily ambient temperature cycles of around 20 - 30 °C, low air pressure)

Diagramme No. 10 shows the wind generator breakdown on 6 th of april '96.

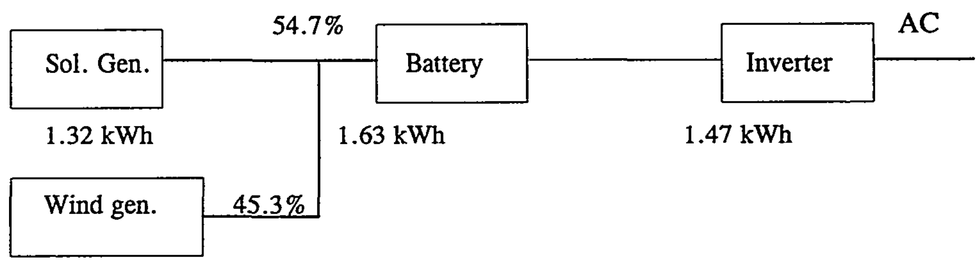


4.7 A balance solar/wind

For the system's energy balance, the data obtained in the months of december '95 until march '96 (normal operation) were used. The following accumulated charges in Ah were registered :

solar generator :	8308 Ah	equal to 54.7 %
wind generator :	6871 Ah	equal to 45.3 %
total :	15179 Ah	

With an average battery voltage of 13 V during charging the daily produced electrical energy can be calculated to $W_{el.}$ = 1.63 kWh/day on the DC side. With an estimated battery efficiency of 90 % the electrical energy on the inverter's input side is 1.47 kWh/day. Finally, with a measured value of the inverter´s efficiency of 90 % the produced electrical energy on the consumer side is 1.32 kWh/day AC. (due to charge regulating the generator's utilization factor is in the range of 83 %, therefore the available electrical energy is higher than the produced energy and can be calculated to $W_{el.}$ = 1.6 kWh/day on the AC side.



4.8 Ecomomic aspects

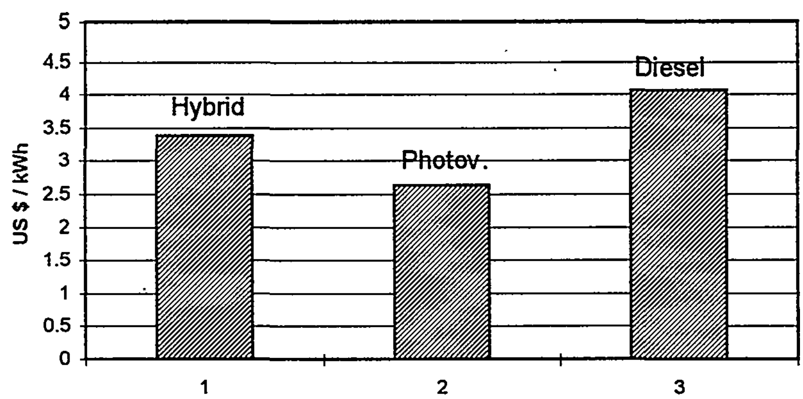
Beside the system's tecnical evaluation emphasis was given also on the economical analysis of this pilot installation. The cost anuity method was applied in order to compare this hybrid system with a conventional diesel power supply system and a pure photovoltaic system.

Hybrid system :	1 wind generator D303, 4 solar panels M55
Photovolatic system :	7 solar panels M55
Diesel system :	1 generator Norinco, 3 kW

The daily available electrical energy is in all three systems 1.6 kWh/day.

For these three different systems the specific energy costs (price / kWh) were calculated. Diagramme No. 11 gives the obtained results under the specific conditions in Colpitas. A pure photovoltaic system is the most economic solution with a specific energy cost of 2.63 US$/kWh, followed by the hybrid system with 3.38 US$/kWh and finally the conventional system with 4.06 US$/kWh.

Diagramme No. 11
Specific energy costs, Colpitas



OVERVIEW OF PV WIND HYBRID SYSTEM ACTIVITIES IN GERMANY

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ABSTRACT

Photovoltaic solar generators combined with Diesel engines, in some cases additionally with wind energy converters, and battery energy storage are powering isolated mountain lodges, information centres in nature parks, isolated farms or dwellings all over Europe.

A total of 300000 buildings in Europe are estimated to be not connected to the public grid. This represents a major market potential for photovoltaics, as often photovoltaic power generation is less expensive than a connection to the electric utility.

The Fraunhofer Institute for Solar Energy Systems ISE has planned, realized and monitored about 30 hybrid remote energy supply systems with PV generators typically around 5 kW for loads typically around 20 kWh per day.

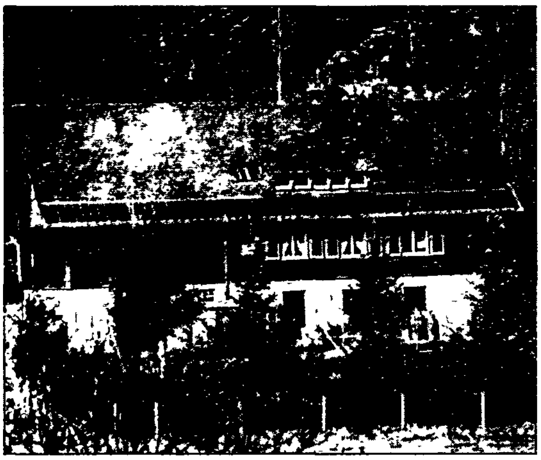
More than one hundred years of operational experience accumulated so far, are a sound foundation on which to draw an interim balance over problems solved and technical questions still under development.

Room for further technical development is seen in the domain of system reliability and the reduction of operating costs as well as in the optimization of the utilisation of the electric energy produced by the PV generator.

1. REALIZED PV HYBRID ENERGY SUPPLIES

In 1987, the first hybrid PV-Diesel-Battery System with continuous AC power supply was installed by the Fraunhofer Institute for Solar Energy Systems ISE in a remote building in Germany, the Rappenecker Hof" [Schmid 1988]

Since then, the Institute has equipped or helped to equip about 30 other remote houses with PV systems in the power range of 1-10 kW.



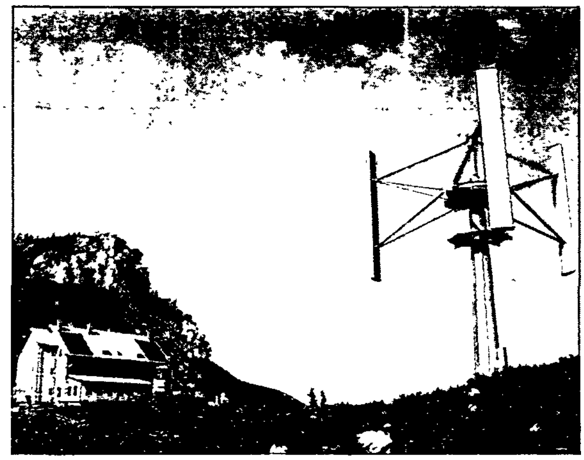


Fig. 1: Brotenau (dwelling) Fig. 2: Rotwandhaus (mountain lodge)

The purposes of these projects were the following:

- Continuous electricity supply for dwellings, mountain lodges, mountain inns, farms etc. without a grid connection.
- Reduction of the operating times of the previously installed electrical generators (diesel or gas). The non-renewable fuels, diesel and gas, should be replaced as far as possible by renewable solar energy. This also greatly reduces the environmental effects caused by non-renewable energy sources.
- A high supply reliability for commercial operation of electrical equipment, e. g. cooling of food, operation of kitchen equipment, lighting and radio telephone.
- An AC supply because many household and commercial appliances are obtainable only for AC, or are already installed.

In table 1 an overview of the different realized systems is given. Each system has a more or less conventional back-up generator. In some systems the waste heat is used for domestic hot water or for heating. In some systems an additional generator which uses renewable energy sources like wind or hydro power is integrated.

Name	Function	Electric Generators	PV size [kW_p]	Battery size [kWh; V]	Inverter size [kW]	Mean daily load [kWh]	Operation since
Rappenecker Hof	hiker inn	PV-Diesel-Wind	4,8	32; 162	4	9	1987
Talhof	dwelling	PV-LPG	1,8	26; **	3	4,5	1989
Brunnstein-hütte	mountain lodge	PV-Rape-Oil	0,9	12; 24	1,6	2	1990
Meiler Hütte	mountain lodge	PV-Diesel-Wind	1,1	14; 24	2,0	2	1990
Purtscheller Haus	mountain lodge	PV-Gasoline	1	14; 24	1,6	2	1990
Bognago	therapeutic community	PV-Diesel	4,3	32; 162	3	16	1991
Haus Langer	dwelling	PV-Diesel	1,8	19; 168	3	2,2	1991
Mindelheimer Hütte	mountain lodge	PV-Diesel	5,4	49; **	10	40	1991
Nördlinger Hütte	mountain lodge	PV-Gasoline	1,5	14; 24	1,6	***	1991
Rotwandhaus	mountain lodge	PV-Diesel-Wind	5	64; 162	10	30	1992
Self-Sufficient Solar House	dwelling	PV-Hydrogen-Fuel Cell	4,2	20; 48	3	2,2	1992
Sudeten-deutsche Hütte	mountain lodge	PV-LPG	1,5	14; 24	1,8	***	1992
Unterkrummen-hof	hiker inn	PV-Diesel	4,5	32; **	4	10	1992
Watzmannhaus	mountain lodge	PV-Diesel	5	32; **	10	20	1992
Brotenau	dwelling	PV-Diesel	3,2	26; 162	3	8	1993
Freiburger Hütte	mountain lodge	PV-Diesel-Cogeneration	5	52; **	10	35	1993
Frenz	dwelling	PV-LPG	1	12; 24	1,6	0,5	1993
Grünhütte	mountain inn	PV-Diesel	4,9	52; **	10	23	1993
Stein	farm	PV-Biogas-Cogeneration	4,9	32; **	10	33	1993
Laufenburg	hiker inn	PV-LPG	4,5	32; 162	3	3,5	1994
Bullauer Bild	dwelling	PV-Diesel	5,1	29; 48	3	3,0	1995
Gfällmattenhof	conference house	PV-LPG *	1,5	19; 48	3	***	1995
Kaysersberg	dwelling	PV-LPG-Hydro *	2,4	18; **	3	3	1995
Krähenbach	dwelling	PV-Diesel	2,6	19; 24	1,8	***	1995
Teufelsmühle	mountain inn	PV-Diesel *	11,5	768; 115	20	80	1995
Adrion	farm	PV-Diesel-Cogeneration	17,1	67; **	10	20	1996

Table 1: Overview of the realized hybrid Photovoltaic-Diesel-Battery Systems

Explanations: All mountain lodges (except the Rotwandhaus) are operated in the summer season only, typically between June and October. LPG is liquid petrol gas. AC-coupling is marked by (*), all other systems are DC-coupled. Batteries marked (**) have five voltage levels to support the special Fraunhofer ISE inverter. (***) figure not available

2. SYSTEM LAYOUT

Most of the hybrid PV-diesel-battery systems realized world wide are DC-coupled systems (figure 3). Different generators are working via separate charge controllers/rectifiers to the DC storage battery.

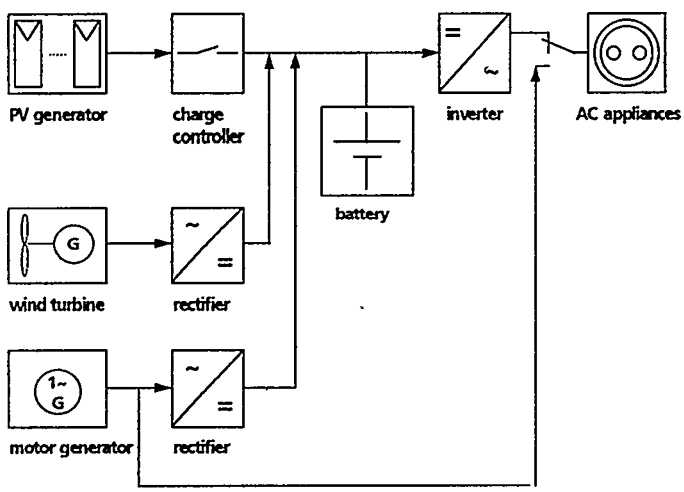


Fig. 3:

DC-coupling of different generators. Example from the Rotwandhaus, a mountain lodge in the Bavarian Alps.

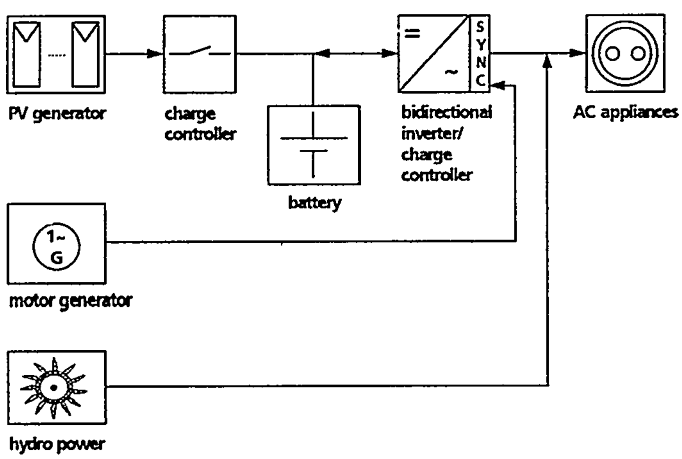


Fig. 4:

AC-coupling of different generators, Example from the project Kaysersberg, a private dwelling in Alsace, France.

An inverter generates the desired AC sine wave, it builds the AC-grid in frequency and voltage, if power generation and consumption are equal, the battery does not take part in the power flow. Otherwise the battery stores the surplus of generated power or delivers the additional power which is needed by the load. In order to protect the battery against damage, one charge controller, in most cases the PV charge controller, disconnects the inverter before the battery becomes completely discharged. If there is not enough renewable power and if, at the same time, the state of charge of the battery is low or if the consumers need more power than the inverter can deliver, a back-up generator is started from the control system. In this case the back-up generator supplies the consumers directly with AC power and charges the battery via its own rectifier.

The big advantage of the DC-coupled system layout is, that it is proven in many applications and that reliable components are available on the market. The necessity of adapted charge controllers for each generator however, may lead to systems with relatively high installation costs, especially if there are more than two generators.

The heart of an AC-system is a bi-directional inverter (figure 4). Only the PV generator, providing DC power, works directly to the batteries. All AC power sources are connected to the output of the inverter, thus supplying primarily the AC consumers with electricity and feeding only the surplus of power back to the storage batteries. In the system which is shown in figure 4, the hydro power turbine is equipped with an asynchronous generator, the back-up motor with a synchronous generator [Preiser 1997]. Power management is done by only one electronic device, the inverter. This may lead to a simplified system concept. The inverter now must be able to work in different modes (charging or discharging the battery), it has to build the local AC-grid in frequency and voltage and it has to be synchronized to any other synchronous electric generator in the system.

Due to these high requirements for the inverter, there are only very few bi-directional inverters on the market available, some of them still have prototype character.

The concept of AC-coupling may be pushed even further by providing the PV generator with its own inverter. Photovoltaic power is then fed into the system on the AC-side of the bidirectional inverter [Kleinkauf 1994].

3. OPERATING EXPERIENCE

The experience gained and some lessons learnt about the main components will be reported in the next sections.

3.1 Photovoltaic Generator

The solar module certainly is the most reliable and least problematic component of any photovoltaic system.
Nevertheless, three points should be observed.

- The power specification for the modules is usually made with a tolerance of ±10 %. Unfortunately, some manufacturers did deliver most of their modules at the lowest limit of the tolerance range (-10 %).

- To protect against an electrical shock if a module is defect, either the open circuit voltage of the solar generator must be limited (at standard test conditions) to 120 V, or the modules must be protective insulated, or access to the PV generator to unauthorized persons must be prevented.

- Lightning protection for the adjoining electrical system must be realized at the solar generator, according to the special requirements of the project site [von Dohlen 1994].

It should not be hidden, that in some of the PV systems included in table 1, several problems with defect modules (modules of a certain type and production period) did occur.

3.2 Batteries and Charge Controllers

As a result of poor operation management, the lead batteries which are used, often had a lifetime of only three to five years. To extend the lifetime, the following points should be observed:

- It is essential to avoid a discharge of the battery by more than 100 % of the rated capacity. This deep discharge is possible as the discharge current in PV plants is usually lower than the 10 hour discharge current Y_{10}.

  To avoid this deep discharge, we recommend to raise the discharge cut off voltage from 1.8-1.85 V/cell to 1.9-1.95 V/cell, preferably varying with the load.

- Reduce the charging final voltage from 2.4-2.45 V/cell to 2.3-2.35 V/cell to reduce battery grid corrosion at high voltages, provide at least two, five-hour gassing recharges at 2.5-2.6 V/cell each month. The gassing recharge is of course not recommended for sealed batteries.

- Regularly charge the battery full and compensate the charge inhomogeneities, at least once a month. This is particularly important in winter.

If the foregoing recommendations are followed, operational lifetimes of the batteries of typically eight years should be reached.

3.3 DC-AC Inverter

The most important requirement for the inverter is a high efficiency value (> 90 %) for the partial load range (5-10 % of the rated power), as the ratio of peak load to average load for a household or a mountain lodge typically is 25 : 1. To reach the high part load efficiencies the self consumption of the inverter must be smaller than 1 % of its nominal power. Additionally, the inverter must have a two to threefold surge current capability (inrush currents of inductive loads) and a sine wave output voltage.

A number of years ago, the Fraunhofer ISE has developed the first inverter which fulfilled all these requirements [Schmid 1988]. It operates on the principle of a five-bit power digital voltage converter. Five voltage sources in a binary series, with nominal battery voltages of 12 V, 24 V, 42 V, 84 V and 162 V are necessary and build an output sine wave voltage with 32 steps. Because no transformer is needed, the 3 kW and the 10 kW version have a self consumption of only 10 W and threefold surge current capability for 5 seconds. Some of the PV hybrid systems listed in table 1 are equipped with the Fraunhofer ISE inverter

It should be mentioned however, that this special inverter requires the division of all DC parts of the system (PV generator, charge controller, battery) into five independent voltage groups. This leads to a complex systems architecture and relatively high installation costs.

Today a number of inverters with operating qualities as good as that of the Fraunhofer ISE inverter are on the market.

3.4 Wind Energy Converter

Three of our PV hybrid systems are equipped with a wind energy converter (table 1 and table 2).

location and altitude above sea level [m]	**power [kW] at wind speed [m/s]**	**manufacturer**	**type**	**tower height [m]**	**electrical generator**
Rappenecker Hof 1000 m	1 12	LMW The Netherlands	horizontal axis 3 blades	10	permanent excited synchron generator
Rotwandhaus 1765 m	20 13	Heidelberg Motor Germany	vertical axis	8	permanent excited synchron generator
Meiler Hütte 2366 m	1,5 12,5	Bergey USA	horizontal axis 3 blades	6	permanent excited synchron generator

Table 2: Features of the used wind energy converters

Because of its high reliability - after initial problems - the wind energy converter from the Rappenecker Hof (figure 5) is choosen to show the contribution of wind power to the total electricity consumption (figure 6 and figure 7.)

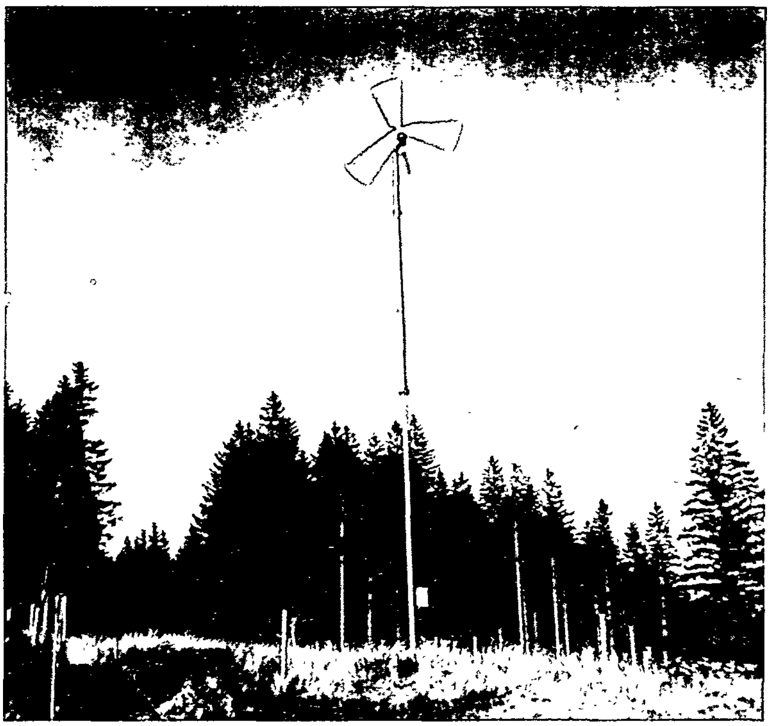
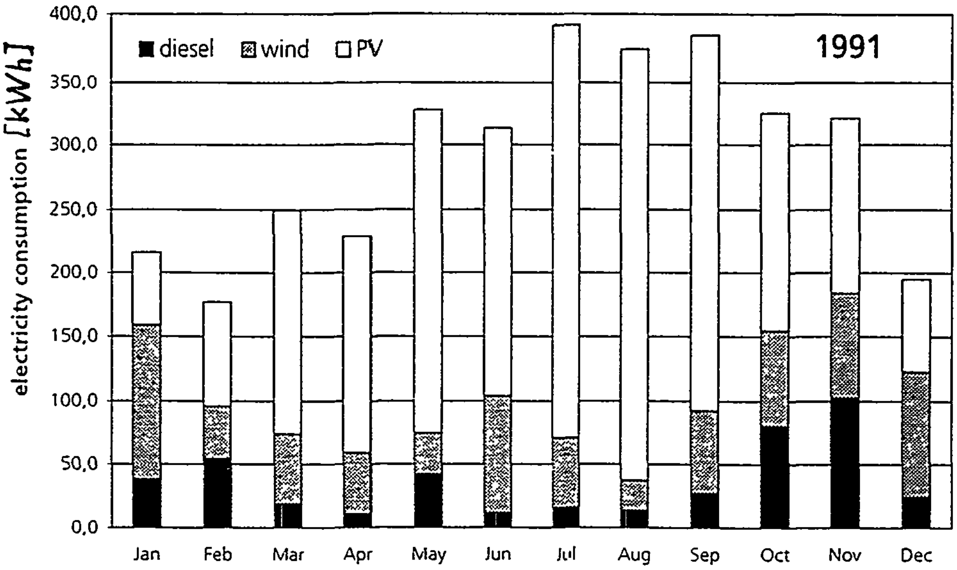


Fig. 5: Wind energy converter at the Rappenecker Hof



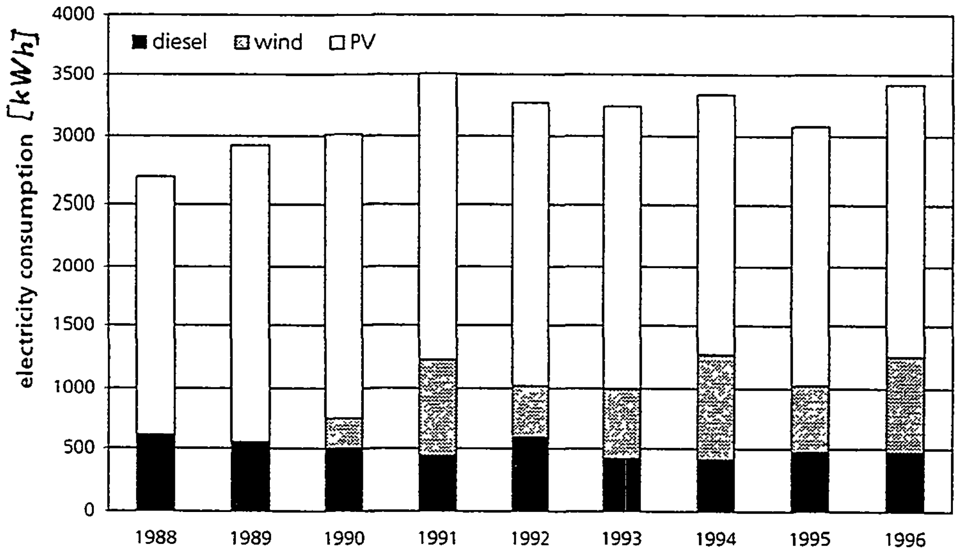


Fig. 6 and 7: Yearly and monthly distribution of the different power sources to the total electricity consumption for the Rappenecker Hof.

After the wind energy converter started operation at the end of 1990, the contribution of the diesel generator during the winter has been halved and was partially substituted by wind energy. The seasonal complementarity of abundant sun and little wind in summer and the reverse situation during winter and the transition periods can be clearly recognized.

Generally it can be said that a wind energy converter is cheaper than a photovoltaic generator with the same rated power but it needs more maintenance. Main reasons are the moving parts, the rapid changes of wind power especially in the mountains and that smaller wind energy converters are not so far developed as bigger ones.

To ensure a reliable operation it is necessary to carry out two maintenance's per year. These include the controls of all screws, bearings, welds, lines and all electrical parts. The maintenance and in particular the repair works must be done by trained people, the best mechanics for the mechanical parts and electricians for the electrical parts. In high altitudes (> 1500 m) with heavy loads of snow and ice the wind energy converter must be dismantled during winter to prevent it from damaging. It seems that vertical axis wind turbines (except savonius rotor) (figure 2) are not that much effected by ice and snow as horizontal axis wind turbines.

3.5 Appliances

The first step in the planning process of each hybrid renewable energy supply is to take a close look at the supply side of the system. Energy saving is necessary to reduce the size and the costs of the PV generator. Reductions by a factor of 2 to 3 in comparison to conventional grid-connected houses are possible. This can be done by installing energy saving appliances e.g. fluorescent lamps, low consumption refrigerators, washing machines and dishwashers with hot water inputs.

Today and to our experience, no appliances with energy consumption's higher than those in table 3 should be accepted.

Appliance	Conditions	Energy consumption
Refrigerator[1)]	Without freezer, normalized to 100 l content	0.10-0.20 kWh/day[2)]
Freezer[1)]	Normalized to 100 l content	0.20 kWh/day
Washing machine[3)]	5 kg hot wash 95°C	1.6 kWh per load
Dish washer[3)]	12 table settings 60°C	1.2 kWh per load

[1)] Caution: The compressors of refrigerators and freezers need an initial surge of 10-20 time the rated current for 200 ms. [2)] The smaller value for units bigger than 300 l content, the bigger one for units smaller than 150 l content. [3)] Without hot water input.

Table 3: Energy consumption of energy-saving appliances.

If all the points mentioned above are observed, a four-person household can achieve an annual consumption of about 800 kWh, not including electricity for building services (electric doorbell, outside light, circulation pump, ...). Even when not completely energy-optimized, a four-person household can manage with an annual consumption of 1500 kWh, including building services.

3.6 Supply Reliability and Maintenance

In a stand-alone PV hybrid system the high supply reliability of the public grid cannot be duplicated. In the public power supply, a high supply reliability is achieved with a multitude of power stations which are operating simultaneously or can be switched in on short notice. In addition, the distribution network is closely cross-linked and is subject to constant maintenance. In general, none of these characteristics apply to stand-alone PV hybrid systems; the reserve power station is mostly one back-up fossil fueled generator, the distribution network is not cross-linked but radial, the short circuit power of the network is severely limited and the maintenance is often neglected.

Our experience with PV hybrid systems which are not subject to regular maintenance shows that these systems fail two times a year in average. One of these failures can be removed by the system owner himself, the other one needs a professional repair service.

To reduce failures it is necessary to carry out one control and one maintenance of the whole system each year. The control means simple function control of each component, the maintenance additionally includes measurements like single battery cell voltage and acid density, replacement of defect parts like fuses, topping up of battery water.

In particular cases (e.g. very remote location) it is strongly recommended to have duplicates of essential components such as the inverted, the charge controller and the back-up generator.

4. ENERGY FLOWS AND ENERGY LOSSES

A quantitative understanding of energy flows and energy losses in PV systems is a prerequisite for the assessment and comparison of different system layouts; it quantifies the margins for system optimization and it aims, in the end, at the reduction of investment and operating costs and at the increase of operational life time.

4.1 Evaluation Criteria and Evaluation Tools

In the analysis of the, technically more simple, grid coupled PV systems, a quantity which has been named Performance Ratio“ is widely used. Let $E_{NOMINAL}$ [kWh] be the solar irradiation falling on the aperture area of the PV generator in, say one year, multiplied by the efficiency of the PV modules at standard test conditions ($G = 1000$ W/m^2, $T_{MODULE} = 25$ °C, spectrum ≅ AM 1.5). Due to a number of mechanisms including e. g. inverter losses , only a part of $E_{NOMINAL}$ will finally serve the load. Let EPV_{USE} [kWh] be that part. The Performance Ratio (PR) is then defined as EPV_{USE} devided by $E_{NOMINAL}$.

The best grid connected systems today reach Performance Ratios of around 0.8 [Kiefer 1995]. The mechanisms, which lead to Performance Ratios of less than 1.0 are well understood. The loss of useful output of the PV generator is in part due to the fact, that the real world operating conditions are not identical to the internationally defined standard test conditions. This effect is treated in the concept of Realistic Reporting Conditions - RRC" [Bücher 1995]. Further losses occur through PV module mismatch, cabling losses, losses in the inverter etc. All losses are dependent on the actual energy flows and operating conditions, the only way to separate and to quantify the different effects is time resolved computer modeling [Gabler 1995].

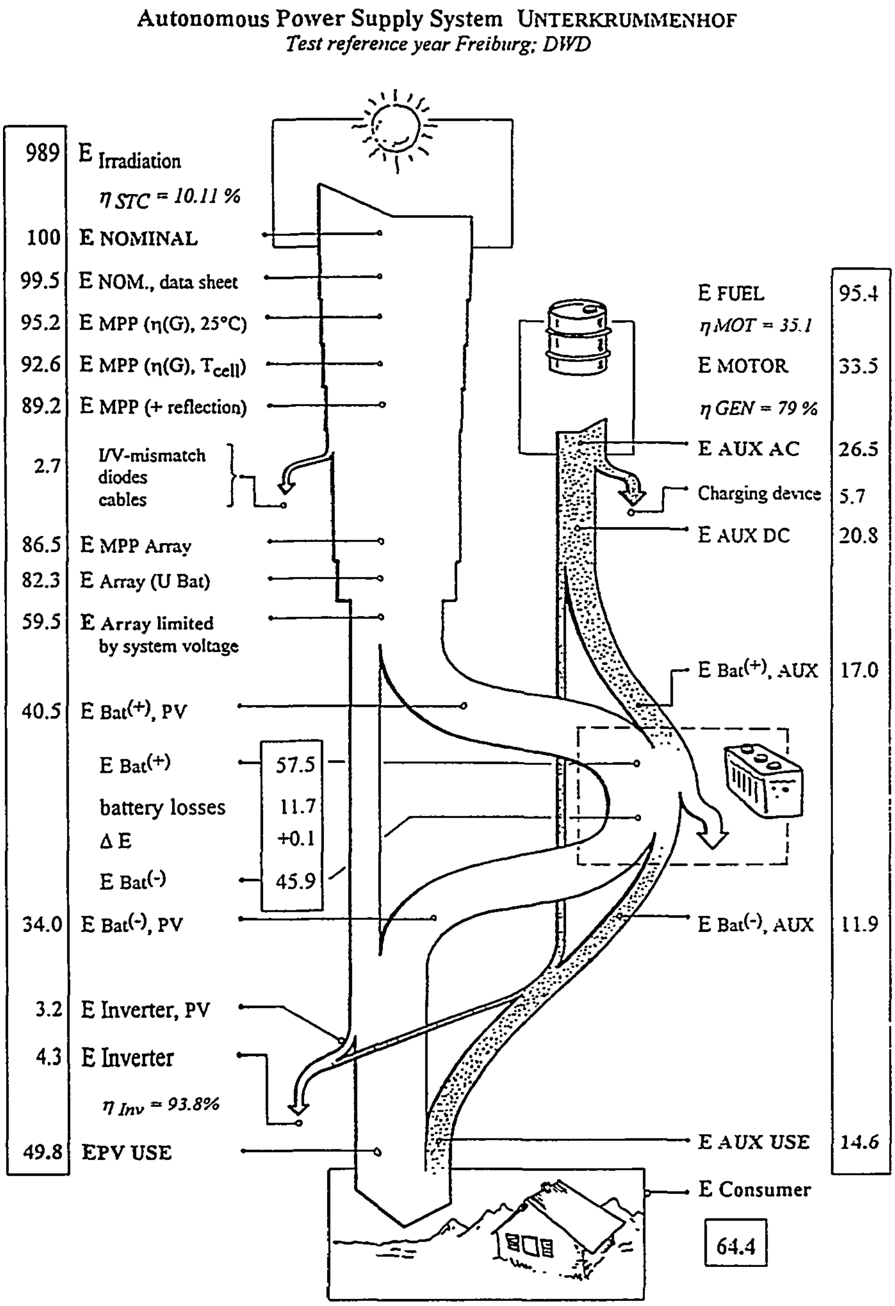


Fig. 8: Annual energy flows of the PV hybrid system Unterkrummenhof

4.2 Energy Flow Analysis for a PV Hybrid System

Performance Ratios of stand-alone PV or PV hybrid systems do not reach the high values of grid connected systems. An empirical analysis of a number of installations which were realized and evaluated under the EU-THERMIE programme found annual Performance Ratios of between 0.3 and 0.6 [Munro 1995].

We have performed a computer model analysis of a PV-diesel-hybrid installation, the hikers inn Unterkrummenhof" in the Black Forest. The Unterkrummenhof system has a PV generator, a diesel back-up generator, a battery storage and an inverter of the Fraunhofer ISE design. Input to the computer model are hourly values of radiation and temperature from a test reference year and measured load data. The model simulates each single system component together with the properties of charge controllers and the energy management equipment. Figure 8 shows the complete picture of the annual energy flows.

The picture gives the quantitative values for the energy production from the PV generator and the diesel generator, the energy flow through the storage battery and to the load. At the end of the year, 49,8 % of the nominal energy production of the PV generator have served the load, the Performance Ratio is 0.5.

To demonstrate the sensitivity of the operation on the varying external parameters, figure 9 shows monthly performance values.

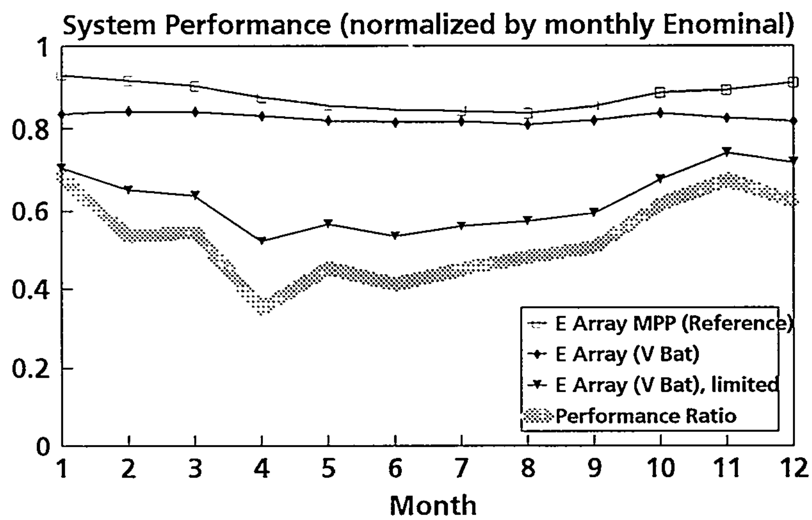


Fig. 9: Monthly performance values (abbreviations see fig. 8)

The biggest single power loss occurs through the limitation which the charge controller sets to the power flow from the PV generator into the battery in situations where the battery has reached its full state of charge. Simulations showed, that different settings of the voltage levels (according to the requirements for the battery) for the charge controller have only minor effects on the annual Performance Ratio and thus on the share of utilizable solar power.

We do not have space here for a systematic discussion on PV hybrid system layout and optimization based on quantitative computer modeling. We know however that there is still ample room for optimization of PV hybrid system layout, especially through better management of the energy flows in the system. Energy management of course not only has to optimize efficiencies" of energy utilization but it also has its role in pushing the still unsatisfactory short life times of storage batteries to their very technical limits.

5. ACKNOWLEDGMENT

Part of this work was supported by the German Ministry of Education, Science, Research and Technology (BMBF) and the Commission of the European Union.

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THE HYBRID GENERATION SYSTEMS OF CAMPINAS-AMAZONAS AND JOANES-PARA

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ABSTRACT

The Brazilian Amazon region is an ideal location for isolated mini-grid systems. Thousands of Diesel systems have been installed to supply electricity to this sparsely populated region. However, the availability of renewable resources makes the Amazon well-suited to renewable energy systems. This paper describes the technical characteristics and touches economic aspects of two hybrid systems being installed in this region through the cooperative effort of multiple partners: Brazilian CEPEL/ELETROBRAS and State Electric Utilities and U.S. Department of Energy, through NREL. It focuses on the market potential for hybrid systems in Northern Brazil and discusses the configuration of the two prototypes, the effort to implement both systems and the preliminary results of these projects.

1. INTRODUCTION

Through a cooperative effort of CEPEL, NREL (United States National Renewable Energy Laboratory), ELETROBRAS (Brazilian holding for Electric Energy) and local electricity distribution utilities, a joint technology research and demonstration task is being implemented to install PV and wind systems in Brazil and assess its market potential and equipment reliability and fitness to our specific needs [1]. As part of this program, two hybrid power systems were procured for villages in the Amazon region of Brazil (see Figure 1) [2]. This paper focuses on the market potential for hybrid systems in Northern Brazil and discusses the configuration of the two prototypes, the effort to implement both systems and the preliminary results of these projects.

2. AMAZON REGION: ELECTRIC ENERGY ASPECTS

The Amazon region in Brazil is sparsely populated, with 17 million people living in 5 million km^2. This translates to less than 12% of the country's population in 58% of the total area. Electricity generation, where it exists, is based mainly on isolated Diesel systems ranging from a few kilowatts in small villages, to tens of megawatts in some capital cities. Only 9% of Brazil's electric energy is consumed in Amazonia, but consumption has been increasing at a rate of about 18% per year for the last 20 years, while the national rate increased at only 8.2%. Over 30% of the population does not have access to electric energy [3].

More than 300 mini-grid systems are operated by local utilities, and thousands more are privately owned. Table 1 gives the distribution of system capacity for the 300 systems operated by the utilities. Normally, the small systems operate for only 6 to 12 hours per day [4].

Table 1. Distribution of Utility Diesel Systems, by Size

System Size (kW)	% of Total # of Systems
0 - 100	10
100 - 500	37
500 - 1000	23
> 1000	30
Total	**100**

The cost of remote electricity is high and depends strongly on system size. In villages with Diesel systems smaller than 100 kW, the cost can be greater than US$ 0.50/kWh. These high costs are due largely to operation and maintenance and low capacity factor, and secondarily, to high fuel costs. The small systems are normally unreliable. As a result of the present situation, small remote villages experience both high electricity cost and very low-quality energy service. High electricity costs are not borne by villagers. Hence, such service, when provided, is subsidized.

In 1995, the total Brazilian national budget for fossil fuel to run the utilities' isolated systems reached almost $250 million, which corresponds to more than 1 billion liters of Diesel and 320,000 gross tons of oil. Recently, it was proposed that this budget be directed gradually to fund renewable-energy projects wherever funds were subsidizing the operation of Diesel systems.

3. AMAZON REGION: RENEWABLE RESOURCES AVAILABILITY

The Amazon region is extremely rich in renewable-energy resources. The average insolation is 5 kWh/m^2-day, with very little variation throughout the year. The wind regime has proven to be significant near the coast, and there are other promising locations as well. Biomass, either through planted wood or vegetable oil, and hydroelectric also have a great potential.

To quantify the availability of solar and wind resources at both hybrid power sites, measuring stations have been installed and resources monitored.

4. DESCRIPTION OF THE HYBRID SYSTEMS

Apart from research and demonstration interests, both hybrid systems are expected to reduce fuel consumption, increase the lifetime of Diesel generators currently installed at the sites, and improve service quality. The designs of the systems are significantly different. The Campinas system will meet the entire load requirement, and the Joanes system will operate in a "peak shave" mode, transferring the peak demand of the village to "off peak" periods at the Diesel generation plant. In this way, it will use the maximum energy available from renewable sources. In Joanes, renewable generation is expected to reach 120 MWh/year, or some 45% of the total present demand. A concurrent program for energy conservation in the village is expected to boost the fraction of the load met by renewable energy to over 60%.

Joanes

The first system, a 50-kW PV-wind-battery hybrid, is being installed in the village of Joanes, located at the municipality of Salvaterra, on Marajó Island, state of Pará (see Figure 1) [5]. The system design and power processor hardware were supplied by New World Village Power Company (NWVP) of Vermont (USA). This system will operate either isolated or interconnected to the local grid. While in the interconnected mode, it will either deliver excess energy to or charge the battery bank from the grid.

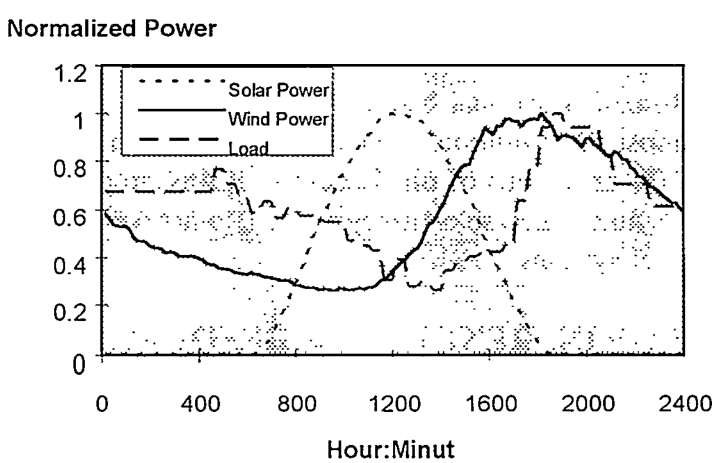

Figure 2. Daily load and generation profiles,
Village of Joanes - annual daily average (1994/1995).

One year of solar radiation (global horizontal, direct normal, and diffuse), ambient temperature, and wind (speed and direction) data for the site is available. During this period (May 1994 to April 1995), the average wind speed was 6.58 m/s, and the daily average global-horizontal radiation was 5.30 kWh/m^2. There is a good match of resource availability to the demand during a typical day. Figure 2 shows the average normalized daily profile of load, wind, and solar energy for Joanes.

The ratio of diffuse to global radiation ranged from 0.26 in July 1994, to 0.63 in February 1995, whereas the clearness index ranged from 0.40 in April 1995 to 0.60 in September 1994. The average temperature was approximately 27°C.

Figure 3 shows the estimated energy balance for Joanes considering the installation of the hybrid system ("Solar" and "Wind") and some energy conservation measures ("Efficiency"). The summation of the 4 components gives the present total demand at the village. "Deficit" is the amount of energy that the system will import from the Salvaterra plant to cover the demand.

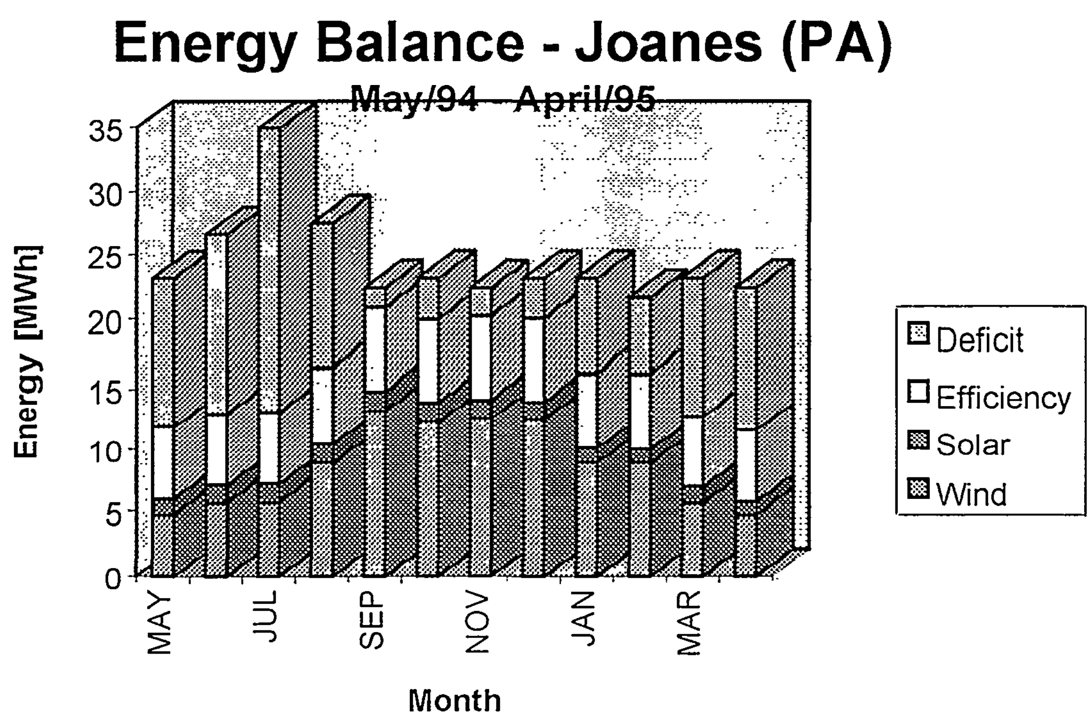

Figure 3. Estimate of the Monthly Energy Balance for Joanes Hybrid System

System Design, Configuration, and Grid Connection

This system is based on a rotary converter (shaft-coupled DC motor and synchronous alternator), rather than an electronic inverter, for power conversion. It comprises four 10-kW wind machines supplied by Bergey Windpower and 10 kW of PV modules from

Siemens Solar Industries. A system schematic showing the connection to the Salvaterra grid is given in Figure 4.

PV structures were designed to allow monthly manual adjustment of the slope by the operator. The battery bank was sized to carry the load during a typical daily peak period (6:00 p.m. to 12:00 p.m.) without any real time contribution from renewable sources. Control, data acquisition, fault detection, and diagnostics are primarily provided through programmable logic controllers (PLCs) connected via a serial link to a local operator interface (a computer running an algorithm based on the Wonderware Intouch software package).

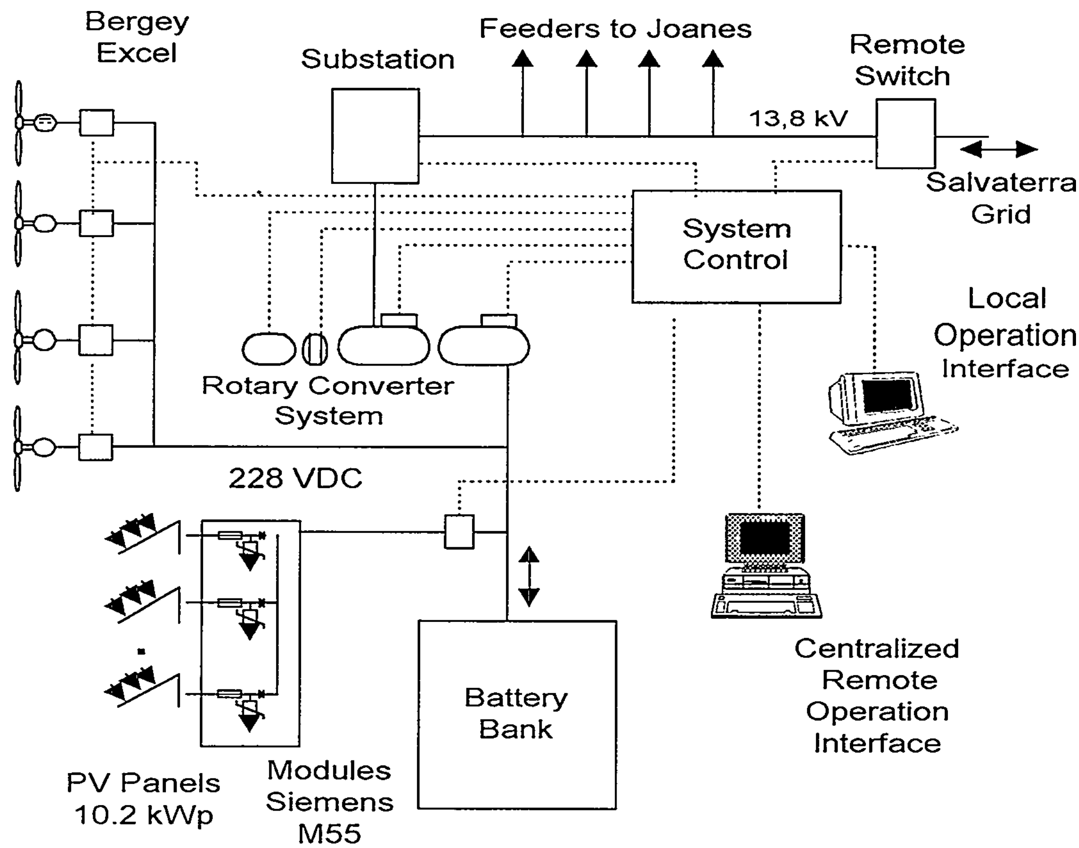

Figure 4: Simplified schematic drawing of Joanes hybrid system.

AC switches, PV contactors, and battery bank state-of-charge are controlled by the PLCs. Wind turbines have their own controllers and will be disconnected from the DC bus if the battery bank is fully charged or the system is off. Battery state-of-charge is assessed through terminal voltage monitoring, compensated by current and temperature. The battery will be recharged in a constant current/constant voltage sequence with temperature compensation. Equalization charges are also planned.

Specific charge/discharge parameters are programmed for the characteristics of the selected battery bank.

Regarding grid connection, Joanes is connected to the Salvaterra power plant, one of 41 utility owned and operated Diesel systems presently installed in Pará (with a total of 98 MVA). The plant has a nominal capacity of 1.2 MVA. Joanes receives its electricity from this system, through a 17-km line operated at 13.8 kV. The village has 170 regularly connected consumers, plus public lights. There are 4 transformers in Joanes with a total of 165 kVA, and distribution to consumers is at the line voltage, 110 V. Salvaterra's power plant is currently overloaded and the hybrid system will help to reduce peak load and avoid rationing at the village.

Operation Strategy

As envisioned, operation of the system is fundamentally driven by fuel displacement and peak load reduction at the Salvaterra power plant. The day is divided into key periods, as shown in Figure 5. Two operation windows are defined: "Supply Time" and "Charge Time." During charge time, the system will be connected to the grid and the battery will be recharged to a maximum preset level. During supply time, the system will be isolated from the grid, carrying the village load. The windows will be defined by the operator in both relative position to the load curve and duration. Outside the defined windows, the village will be supplied by the grid, with renewables charging the battery bank.

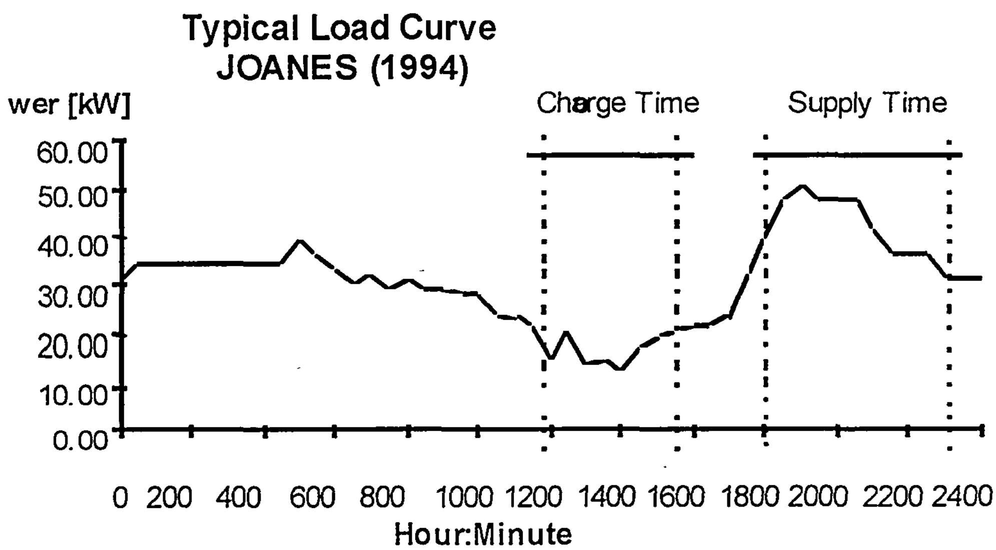

Figure 5. Operation of the Joanes hybrid system (adjustable operation windows over typical load curve).

Campinas

The second hybrid power system, a 50-kW PV-Diesel-battery hybrid, is being installed in the village of Campinas, about 100 km upstream from Manaus, in the state of Amazonas, between the Solimoes and Negro rivers (see Figure 1). System controls and power processor for the Campinas plant were supplied by Advanced Energy Systems Ltd. (AES - Australia), as a subcontractor to Bergey Windpower Corp. (USA). A 50-kW PV array was supplied by Solarex Corporation. Two existing 60 kVA Diesel units, currently supplying the village load, were modified to interface with this hardware: the first will interact with the inverter and the other will be used as a back-up unit.

One year of solar radiation (global horizontal, direct normal, and diffuse), ambient temperature, and wind (speed and direction) data at the site is available. During the period October 1995 to July 1996, the average wind speed was 1.46 m/s, and the daily average global-horizontal radiation was 4.23 kWh/m^2. The ratio of diffuse to global radiation ranged from 0.32 in July 1996, to 0.85 in December 1995. The average temperature was approximately 26^oC.

Figure 6 shows the estimated energy balance for Campinas considering the installation of the hybrid system ("Solar") and some energy conservation measures ("Efficiency"). The summation of the 3 components gives the present total demand at the village. "Diesel" is the amount of energy that the system will require the Diesel to generate in order to cover the demand.

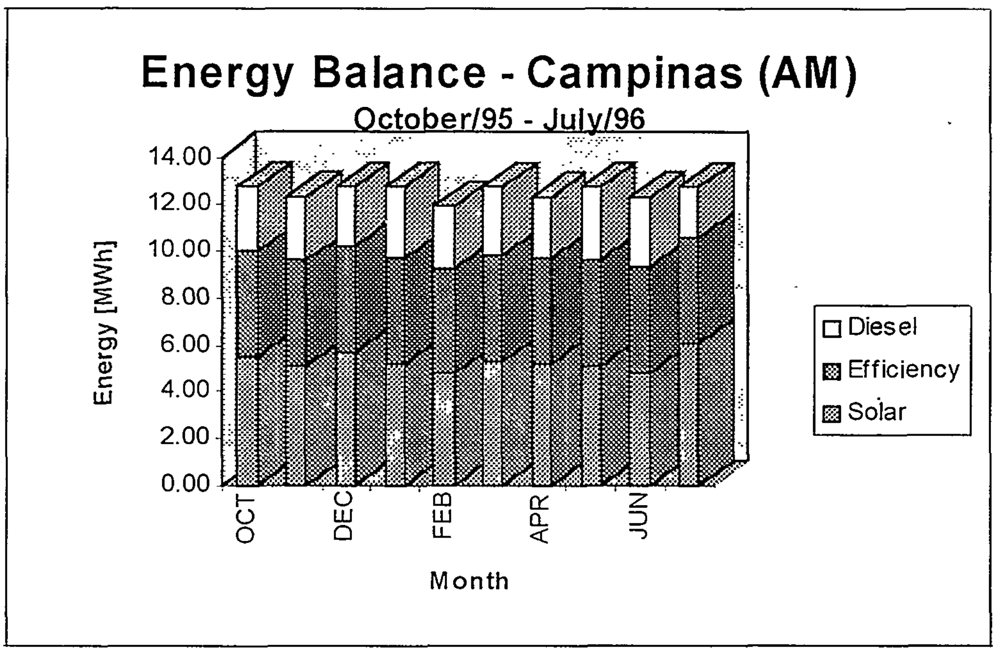

Figure 6. Estimate of the Monthly Energy Balance for Campinas Hybrid System System Design and Configuration

A system schematic is given in Figure 7. PV panels are fixed, tilted 8° toward the north. Control, data acquisition, fault detection, and diagnostics are primarily provided by the AES inverter's internal capabilities. A local operator interface is connected to the inverter via a serial link.

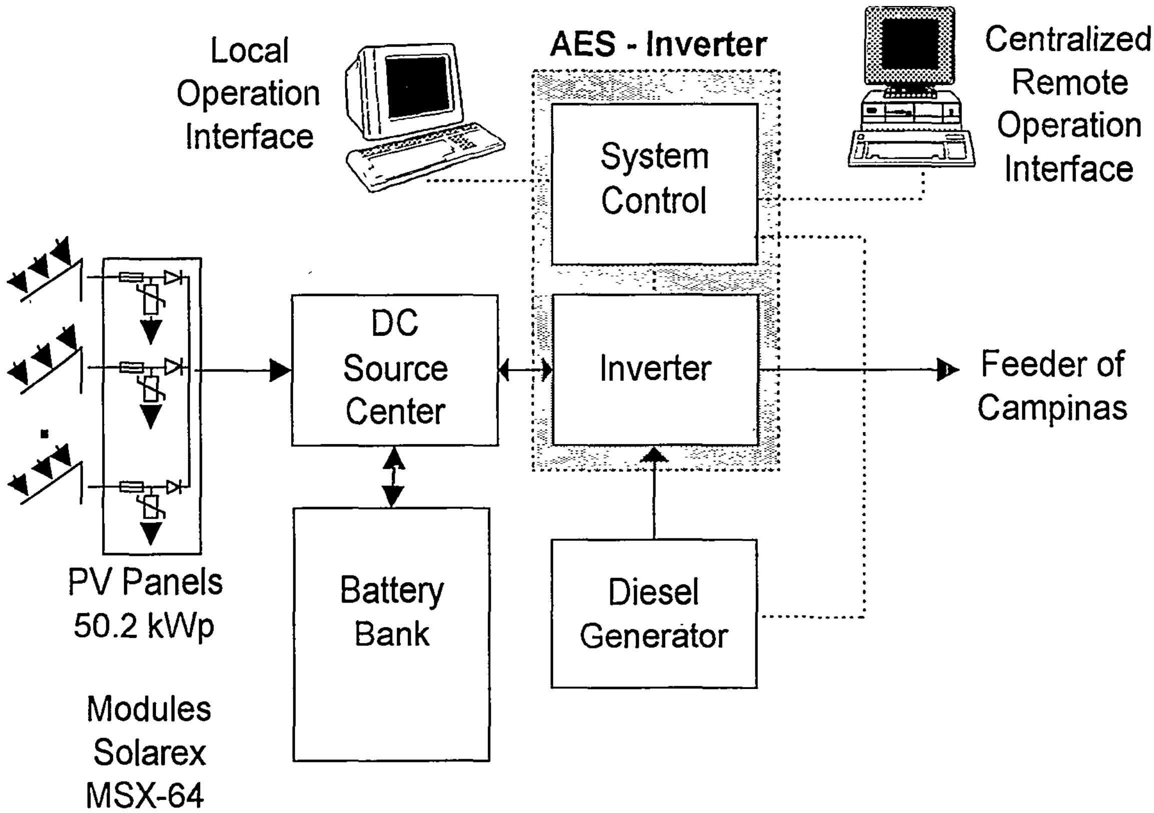

Figure 7. Simplified schematic of Campinas hybrid system.

Due to expected fuel consumption reduction, the local utility (CEAM) has authorized an extended number of hours for operation (from 6 to 18 hours per day). Campinas has 124 consumers regularly connected plus public lighting.

Operation Strategy

This system will try to keep the Diesel units from running, unless the battery bank state-of-charge is depleted. In this case, the Diesel will run to supply the load and recharge the battery bank to a preset maximum state-of-charge. While running, the Diesel generators will be operated close to the nominal power rating to achieve high operating efficiency and to avoid damage to the units due to underload conditions. If the load requirement is greater than the nominal power of the inverter, the Diesel generator will be turned on and the inverter will supply the remaining power requirement.The Brazilian state electric utilities (CELPA in Pará and CEAM in Amazonas) are responsible for site preparation, village grid connection, system installation, operation, and maintenance, as well as for supply of the battery bank. System performance will be remotely monitored using a satellite communication system supplied by Ascension Technology.

5. PRESENT STATUS OF PROJECTS

Both systems are very close to be operative. In Campinas a problem detected during its start up is being corrected and in Joanes site preparation is almost concluded. Both systems are expected to be definitively operating in May. A very impressive interest on this technology can be felt in Brazil at this moment and the success of these two pilot projects will undoubtedly create new opportunities.

6. COST EVALUATION

A summary of each major component cost for both systems is presented in Table 2.

Table 2. Cost of Major Components

Component	Unity	Campinas			Joanes		
		Capacity	Total [US$]	Unitary [US$/kWx]	Capacity	Total [US$]	Unitary [US$/kWx]
Solar Panel	kWp	51	$227,000	$4,434	10	$45,000	$4,422
Structure	kWp	51	$30,000	$586	10	$10,000	$983
Wind Turbines	kW	0	$0	$0	40	$58,000	$1,450
Turbine Towers	kW	0	$0	$0	40	$32,000	$800
Power Converter	kW	50	$58,000	$1,160	50	$27,000	$540
Control Panel	kW	50	$13,000	$260	50	$22,000	$440
Battery Bank	kWh	192	$83,000 *	$432	228	$44,000	$193
Total Cost			$411,000			$238,000	

* Purchased in Brazil

Analysis of data collected before hybrid systems installation show that generation plants have been operating with specific consumption of 0,35 l/kWh (Joanes-Salvaterra) and around 0,50 l/kWh (Campinas). Diesel cost to Eletrobras (which manages the CCC Diesel account) for these states is around 0,27 US$/liter [6] but a significant amount should be added due to transportation to the sites which is critical for Campinas, for example, due to remoteness and difficulty to be reached during dry seasons. Some places in Amazon can take up to 30 days to be reached by the utilities' boat.

Difficult figures to be evaluated are maintenance and operation costs and they are critical in energy cost calculation. However, with the data presented in this paper and the estimated lifetime for each component one can assess the energy cost for a economical analysis of the project, provided some assumptions are made.

7. PROBLEMS AND SOLUTIONS

- The main problems we have faced till now to deploy these systems are:
- delay to purchase complementary components and contract necessary service by Brazilian counterparts (funding and bureaucratic reasons);
- construction of the wind turbine towers by local munufacturers in the state of Para;
- changes in the Brazilian electric sector (privatization) with strong consequences to utilities;
- importing bureaucracy (which is changing now);
- integration of the hybrid system and the Salvaterra's power plant in the case of Joanes;
- difficulty to get skilled personel to install, maintain and operate the systems;
- technologies involved are not completely mature (a technical problem with the inverter in Campinas has delayed start up of the system and required the presence of specialized people in the field).

As a consequence several delays occurred. To overcome funding problems several funding sources were involved to support the projects. A good training and availability of spare parts at the field will help to avoid delays related to equipment failures.

8. CONCLUSIONS

The hybrid systems described here represent two significantly different approaches to the problem of remote power supply using renewable energy. Deployment of both systems is expected to provide the Brazilian utilities with installation and operating experience in hybrid power. Monitoring the performance of these systems will contribute significantly to the body of knowledge in hybrid power systems, influencing the design, implementation, and operating strategy of future projects.

Concurrent with this program, energy conservation measures are being implemented in both villages. Regardless of the specific design, energy costs are very high for these regions when compared to conventional, large grid connected systems. This high cost reinforces the need for aggressive energy conservation measures and appropriate use of electricity.

Necessary in-country training and manpower requirements for sustainable renewable-energy technologies, including hybrid village power systems, are being established.

A new project headed by CEPEL has been launched to further evaluate the wind and solar potential of the Amazon region, as a follow-on to the current program.

A very impressive interest on this technology can be felt in Brazil at this moment and the success of these two pilot projects will undoubtedly create new opportunities.

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PERFORMANCE OF A SMALL STAND ALONE PHOTOVOLTAIC-WIND SYSTEM AT "EL OYAMEYO" D.F., MEXICO

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ABSTRACT

"El Oyameyo", is an ecological site located to the South-West of the Topilejo town, D.F., 19° 25' North latitude, 99° 5' West longitude and at an altitude of 3100 m. At present, there are 10 families living at this place. They have energy generators to produce their own electricity by means of solar or wind energy using photovoltaic (PV) technology and eolic systems, respectively. There are three different configurations of energy generators: DC regulated PV systems, AC regulated PV systems and one PV-Wind hybrid system. The electrical power installed for the stand alone PV systems are from 48 W-p up to 768 W-p range. Among these, there are 4 PV systems that are configurated in DC regulated systems, and other 6 are AC regulated systems. All these systems use lead-acid battery (sealed or vented) banks to store the energy produced daily by the systems. The PV-Wind hybrid system is formed, at present, by a 5.0 kW wind generator, a PV array of 768 W-p, a 37.8 kW-h storage battery bank and a 5.0 kW DC/AC inverter. In this work, we report the electricity generated, load pattern and overall system performance of the photovoltaic-wind hybrid system. The technical characteristics, energy test on the hybrid system and the experience obtained from energy handling and system maintenance for all the systems are presented. We found that all the systems had shown good performance and users' satisfaction.

1. INTRODUCTION

Electrical generation by solar or wind energy using photovoltaic (PV) technology or eolic generators, respectively, represents an alternative to supply energy to small communities and even suburban areas far away from the electrical distribution network. Their characteristics are simplicity, reliability, low maintenance cost and above all, they are free of pollution. This technology is then a good choice among the different energy alternatives [1,2] . The eolic system is formed by a set of elements which generate electricity by wind. Wind energy follows seasonable patterns in a discreet way, showing a big potential use after the solar day. It is very punctual but influenced by the landscape and local phenomenon's; hence it depends on the particular site. On the other hand, solar energy can be transformed to electricity by mean of photovoltaic technology using solar cells; that is, PV systems transform sun light into electricity. The availability of solar energy is predictable during the year but it is available only during the day. The quantity of daily energy produced by a PV system depends on the power installed and the solar energy resource at the site of installation.

Since of wind energy is season dependent, it is worth considering to generate electricity by coupling an eolic system with a photovoltaic one. The resulting hybrid system can be more reliable, with operating periods longer than those of the single one (eolic or PV), having a more consistent electricity generation.

From these considerations it has been designed and installed several hybrid systems in our country, one of these is reported elsewhere [4]. Among these, "El Oyameyo" PV-Wind hybrid system can be considered in Mexico as the pioneer of these technologies. In 1980, a study on the wind energy potential was carried out in this place. In 1983, the Mexican company, Fuerza Eolica SA de CV, installed an eolic system whose components were a wind turbine, rated 5.0 kW mounted in a 25 m high steel tower, a battery bank of 6,480 Amp-h at 108 V and a 7.0 kW DC/AC square wave inverter with a drawing power of 600 W for no loads connected. The aim of this installation was to show the advantages of this kind of technology compared to the diesel generator and to produce electricity for a set of four households. The system was working for a period of five years with several problems. Among those it is worth: the inverter drawing power, lack of energy consumption policy, different electrical loads among all the users, short circuit at the electrical grid distribution and a lack of maintenance of battery bank, lead to a conflictive administration and in that period it was necessary to change the battery bank two times; as a result, the system was abandoned. Due to that, the owner of the eolic system (Fuerza Eolica SA de CV) sold it to the Instituto de Investigaciones Ecologicas AC.

On the other hand, the results of a solar energy potential study, carried out by Mr. A. Sanchez-Juarez of the former Solar Energy Laboratory IIM-UNAM (at present Energy Research Center-UNAM), from 1988 to 1989 in that place, showed the possibility to transform the eolic system to an eolic-PV hybrid system. In this way, an hybrid system was designed under the followings considerations:

a) The system must meet the electrical requirements for two households with daily energy consumption of 2.5 kW-h each.

b) The PV system would produce the 40% of the daily energy requirements.

c) The energy generated could be available only 8 hr. daily.

Under these considerations in December 1990 the eolic-PV hybrid system "El Oyameyo" was installed and put into operation. The two families were using the energy produced by the system from 1991 to 1994, but because of the increase in the daily energy requirements at the households, the energy balance of system became negative. Then, it was necessary that one of the owners sold his system shares to the other to keep the energy balance positive.

At present, the PV-Wind system is working and supplying the energy requirements for one household. On the other hand, neighbors of this place learned about PV systems and with special financial supports, some of them bought their own PV systems. In the "Oyameyo" place we can find PV systems starting from small DC regulated systems up to medium DC/AC systems. Depending of the peak power installed, the electrical appliances that we can find at the households are: DC and AC fluorescent lamps, DC water pumps, DC B&W TV's, AC color TV's, radios, VCR's, microwave oven, washing machines, computers, drills, blenders, etc.

2. TECHNICAL CHARACTERISTICS OF SYSTEMS

2.1 PV systems

2.1.1 Regulated DC systems .- These systems use batteries to store the electrical energy generated by the modules during sunny days, and deliver it whenever the modules cannot supply power. Their principal components are a PV array, a charge controller, a battery bank and electrical DC loads (see Fig. 1).

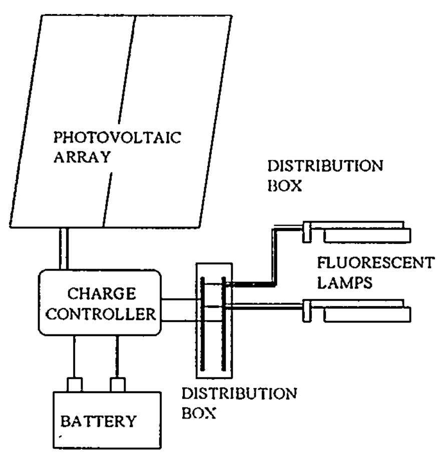

Figure 1. Schematic diagram for a regulated DC system

Since the electrical loads are rated at 12 VDC (fluorescent lighting, B&W TV and radio/stereo), nominal voltage of these systems is fixed at this value. The PV modules used in these systems are manufactured using single-crystal silicon solar cells (Siemens Mod. M75), rated at 48 W-p. They are mounted on the roof or on a pole, depending of the place and tilted at 19° face south. The charge controllers used are series-interrupting controller type manufactured by the Mexican company Condumex. The regulation set point was fixed at 14.8 V with a regulation hysteresis of 2.4 V. The low voltage disconnect set point was fixed at 12.45 V with a low voltage disconnect hysteresis of 1.4 V. These PV use shallow cycle lead-acid batteries, automotive type, to store the electrical energy. One can find vented and sealed batteries, depending on the owner. We found that the battery capacity size was fixed depending of how many 48 W-p modules were installed. The empirical rule was to use 13 plates battery for each one 48 W-p module. The electrical loads that are connected at these systems are: fluorescent lamps rated at 20 W (1.6 Amp consumption at 12.5 V) and 9 W (0.9 Amp consumption at 12.5 V); black and white television (1.0 Amp consumption at 12.5 V); and water pumps (5 Amp consumption at 12.5V, 6 l/min.).

2.1.2 Regulated AC systems.- These systems have the same configuration as that of the systems described above. Fig. 2 shows a schematic diagram of such systems.

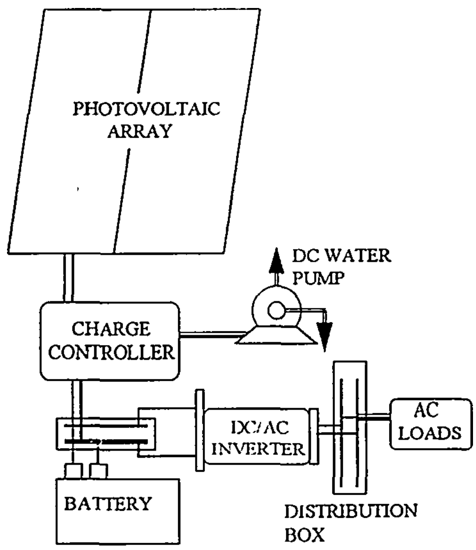

Figure 2.- Mixed AC/DC system

The additional components are the AC loads and the DC/AC inverters. All the inverters that we found in these systems are modified sine waveform type (Trace Engineering Co.). There are two different electrical configurations for these systems: 12V and 24V. The nominal voltage of them were fixed by the nominal voltage of the inverter. We classified the systems with respect to the inverter nominal power as follow:

a) 600W AC. This PV system is configurated at 12 volts with an array of 192 W-p. The battery bank is formed by 4 lead-acid shallow cycle batteries, automotive type, 12 volts with a total storage capacity of 360 amp-hours. The system has been operated since 1994 with a good performance.

b) 800W AC. This system is formed by 8 modules of 60 W-p from Solarex installed on the roof. System electrical configuration is 12 volts with a battery bank of 660 amp-hours of capacity. Batteries are lead acid deep cycle batteries, traction type, 6 volts 220 amp-hours each. The charge controller is series-interrupting, 2-step, constant current with a line protection unit (LPU) to prevent stroke of lightning. This system is the oldest in the Oyameyo place, and it has been operating since 1990.

c) 2500W AC. The system is configurated at 24 volts with an array of 768 W-p (16 modules, 48 W-p each, in a parallel-series array). The charge controller is series-interrupting, 2-step, constant current with a line protection unit (LPU) for to prevent stroke of lightning. The battery bank is formed by 16 lead-acid shallow cycle batteries, automotive type, 12 volts with a storage capacity of 85 amp-hours each. Operating since 1992, this system has the biggest PV power array in the Oyameyo place.

d) 2000W AC. There are two systems rated at this power configurated at 12 volts. The nominal peak power for the arrays are 300 W and 450 W, respectively. The charge controllers are of the same kind as that of the other described above. The batteries used to store the electrical energy are lead acid, deep cycle batteries, traction type, 6 volts @ 220 amp-hours. These two system were installed in 1996 and since then it has been showing good performance.

All these PV systems supply the electricity for one office, one restaurant, and four household. There, we found electrical loads like: photocopy machine, computers, 50 W quartz lamps, 20 W fluorescent lamps, stereos, blenders, 19" color television, etc.

2.2 PV-Wind hybrid system

The main components of the eolic-photovoltaic hybrid systems are: eolic generator, photovoltaic generator; two charge control units, storage battery bank and DC/AC inverter. Figure 3 shows a schematic diagram of the system and the position of monitoring points.

2.2.1 Eolic Generator. The eolic generator is a wind turbine called "COLIBRI" supplied by Fuerza Eólica SA de CV . The electrical and mechanical specifications of the eolic generator [5] are given in Table 1.

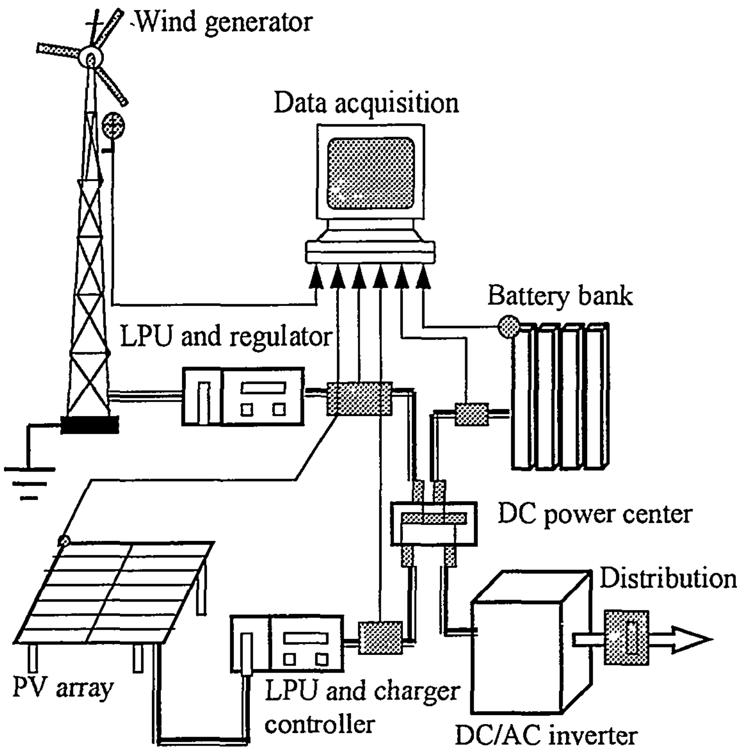

Figure 3. Schematic diagram of the hybrid system

Table 1: Wind turbine specifications

PERFORMANCE	MECHANICAL	ELECTRICAL
Star-on wind speed of 3.4 m/s	Type: 3 blade upwind	Generator: 3 phases permanent magnet alternator.
Star-up wind speed of 3.6 m/s	Rotor: diameter 5.0 m	
Rated wind speed of 11 m/s	Over speed protection:PE™	Controller: PE ™
Cut-out wind speed of 27 m/s	Tower: 25 m height	Output: 108 volts DC Rated power of 5.0 kW
Rotor speed of 160-250 RPM	Weigh: 225 kg	

The wind turbine was installed in a hill, about 100 m away from the household. In this location, the wind speed is not constant but there are many gusts of wind of about 8 to 10 m/s, producing 2.5 to 3.5 kW. Figure 4 shows the mean value of the power production and the extrapolated annual energy generated as a function of the wind speed, corresponding to data taken in 1994.

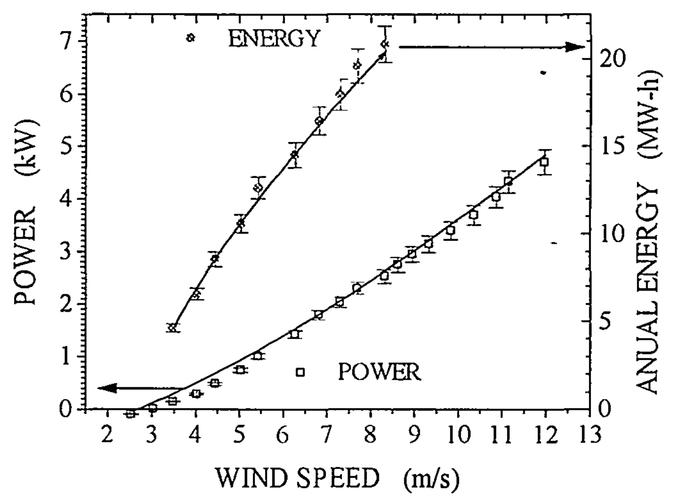

Figure 4: Mean values of the power production as a function of wind speed corresponding to data taken in 1994.

2.2.2 PV Generator.-The photovoltaic generator has the following characteristics: It is formed from 16 M75 single crystal silicon Siemens modules. These modules are arranged in two subarrays of 8 modules each, wired in series in order to charge the batteries at 108 V (nominal); both subarrays are wired in parallel. The two subarrays were installed at the garage roof, using aluminum structure with a tilt of 20°. The array is wired to a separate breaker in the DC power center.

2.2.3 Charger Control Unit.- The hybrid system has two charger control units: one for the wind turbine and another one for the PV array. The eolic generator has a box controller in which there is an automatic rectifying AC/DC regulator for 108V (nominal). Also, there are an automatic over speed and manual protection unit, which can stop the turbine motion when the wind speed reaches 20 m/s. The charge control unit has a voltmeter, an Ampere meter and a rpm meter. Due to the electrical storms, a Linear Protection Unit (LPU) with 6 surge arrestors was incorporated at the three output phases of the turbine. The PV charge control is series-interrupting, 2-step, constant current, with voltage disconnection point from 125 to 132 V DC [6]. This unit also has an analogical voltmeter and Amper meter which let to know the input power to the battery bank. A LPU with 4 surge arrestors was incorporated at the output of the PV array to prevent lightning problems.

2.2.4 Battery Bank .-The firsts storage system was formed by 36 units of 12 volts, 200 A-hr batteries LTH™ (rated at 20 hr discharge rate). From these, 9 batteries were connected in series for a nominal voltage of 108 volts and 4 strings of this were connected in parallel. Therefore, the capacity of this bank was 800A-h at a nominal voltage of 108 volts. The batteries are automotive type, lead-acid, flooded electrolyte. Every string of 9 batteries has a DC disconnect breaker for easy maintenance.

2.2.5 The Inverter.- The system has a 5.0 kW inverter from SINEMAX™. This inverter transforms the 108 volts DC in a pure sinewave, 120VAC, 60 Hz, which power the AC loads. It has an efficiency of 95% at continuos 4 kW output. The sinewave output of the inverter is stable and noise-free, allowing smooth operation of controls, electronic gear, computer systems and audio and video equipment. The inverter can shutdown by itself due to high power demand, low batteries voltage or high temperature. This can be done because the inverter has a built-in controller that it can limit the power drawn to the users in the case of the power demand exceeds the output of the inverter. It has a low voltage disconnect and reconnect feature and all theses functions are displayed by LED's. These LED's display the cause of the inverter shutdown.

3. SYSTEM MONITORING

The system began to operate on 4th December 1990 and the first monitoring processes started in January 1991. This monitoring was carried out in discreet mode due to the lack of data acquisition system and it has been reported elsewhere[6]. In December 1993 a pyranometer Eppley, a solar cell reference from Solarex Mod M10, two type T thermocouples, and an anemometer, was installed. We built a data acquisition system with a PCL™ computer card and using a PC. We also used a several calibrate-shunt-resistors and electronic hardware to readout DC currents for the PV array, wind power, battery charger, inverter draw and AC currents for the inverter output . It also provides DC voltages for the PV array, the wind generator, battery bank, as well as AC voltage. Measurements were taken using a Praire Digital data acquisition card model 812 (12 channels, 8 bits). This card has an 8 bit analog to digital converter, with a maximum measurement frequency of 500 Khz. Using a PC-AT computer (12 Mhz) and a program developed in Pascal, maximum frequency of measurements drop to around 10 Khz.

4. RESULTS

A typical daily behavior of the electricity generation and the load consumption is shown in Fig. 5 .

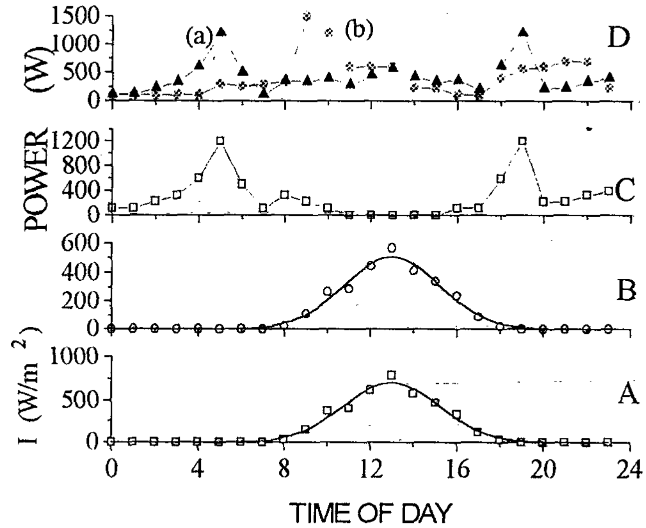

Figure 5: Typical daily behavior of the system. (A) the irradiation, (B) the PV generated power, (C) the wind generated power, and in (D) we show (a) the total generated power and (b) the power consumption.

The loads include some fluorescent and halogen lamps, microwave, clothes washer, refrigerator, audio and TV center, water pumps, pressing iron, telephone answering machine and computer. We can see from this curve that the energy consumed by the loads, in this particular day, was 8.0 kW-h, distributed as follows: 2.6 kW-h was provided by the PV, 5.16 kW-h was generated by the eolic, and the rest, 100 W-h was taken from the storage system. We found that there were electrical loads that were using a lot energy to work. After this, we made some recommendations to optimize the energy consumption: use of fluorescent lights instead of incandescent ones, use of LPG refrigerators, time of use for the iron, and so on. With respect to the system, we found two critical problems: 1) electrolyte leaks problems at the battery bank because of the high voltage sent by the wind generator under wind over speed conditions and 2) electrical storms which produce stroke of lightning. In the first case, voltage and current under critical conditions are 145 Volts @ 30 amps. Then we proposed a systematic sanitation of the battery bank every 15 days. In this way we reduced the corrosions problems on the battery terminals. Concerning the second case, as The Oyameyo is located in a forest area with strong lightning storms during rainy season, some electronic parts of the inverter as well as some equipments like a TV, computer, telephone, etc. were damaged during a lightning. We have tried to solve this problem with the use of surge arrestors. We connected these kinds of protections in the output of the eolic and PV systems and also in the input at the houses. Therefore, during the 1995 rainy season the problem was substantially reduced.

Figure 6 show the mean values for energy production and consumption, monthly, for the last four years. The house was maintaining consumption of 200 kW-h per month. With the experience of the first two years, it was necessary to use a 4.0 kW gas generator and a AC/DC rectification bridge, like a backup system, in the months of August and September, because the solar and wind resources·were low.

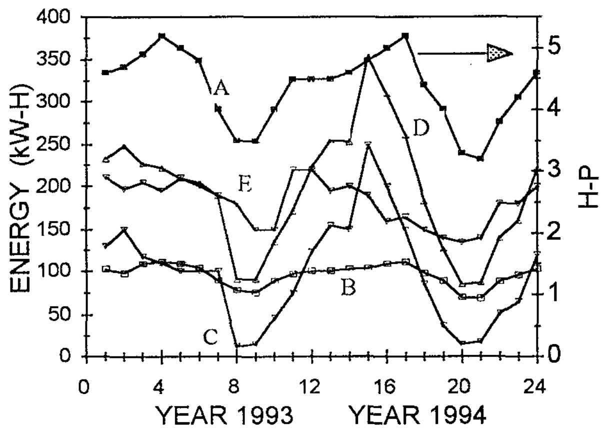

Figure 6: Mean values of energy production and consumption in "El Oyameyo" hybrid system. (A) the solar irradiation in peak-hours, H-P; (B) PV energy; (C) Wind energy; (D)Wind plus PV energy; and (E) energy consumption

5. CONCLUSION

We found that, when we began to monitoring the system, there were several problems about related to energy distribution and with electrical loads which were not working efficiently. After a few recommendations with respect to the network distribution we improved the efficiency of the system. The stroke of lightning problems was the biggest problem to solve and we hope that with the use of surge arrestors, the problem will be minimized. On the other hand, it is important to emphasize that lead-acid batteries had been shown excellent charge and discharge cycle in this system. At present, the system has a new battery bank formed by 18 lead acid, deep cycle batteries, traction type, 6 volts @ 360 amp-hours of capacity. Therefore, the hybrid system has performed very well.

6. ACKNOWLEDGMENTS

The authors would like to thank Instituto de Investigaciones Electricas (IIE), Mexico, for the financial support to attend this workshop.

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EVALUATION OF THE PV MINIGRID COMMUNAL SYSTEM PROJECT IN LA VENTUROSA COLOMBIA.

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ABSTRACT

A communal photovoltaic minigrid grid system had been operating for about two years in La Venturosa Village located at the Easter Plains of Colombia. The Institute of Nuclear Sciences and Alternative Energies, INEA, had been evaluating this system for about a year of operation in order to measure performance, level of satisfaction in users and sustainability of the project. The results of this evaluation concluded that the option of communal minigrid photovoltaic systems represents a good alternative, but that the human element can affect the sustainability for this type of projects.

1. INTRODUCTION

La Venturosa is a small Village located to 160 km at the West of the City of Puerto Carreño in the Eastern extreme of Colombia (Eastern Plains). In this site the solar isolation is characterized for an average of 5 kWh / m^2, an optimum level to develop energizing projects with solar energy.

This community is compose for about 80 inhabitants, its principal economic activity is cattle-raising. Also this village has a small confined school for about 25 children of Colombia and Venezuela and little health center.

This community had a small diesel gen. set, currently out of service. This generator operated about 120 days per year during approximately 2 hours per day with a high cost for the users because of the fuel expenses. By reason of this deficient electrical service the scholastic and the medical care labors were hindered.

Though this community does not have an economic importance, the region has guerrilla presence, therefore the Government needs to make presence by means of improving the way of living of their inhabitants.

2. TECHNICAL CHARACTERISTICS OF LA VENTUROSA SYSTEM.

This project was designed and built by the Colombian company, Solar Center for the Colombian Institute of Electrical Energy - ICEL - and with supervision of The Institute of Nuclear Sciences and Alternative Energies -INEA, during the first semester of 1995 with a total cost of US$ 35,000. The PV System of La Venturosa supplies with electrical energy to 13 users, a little health center and a confined school during 24 hours per day by means of a small single phase distribution grid.

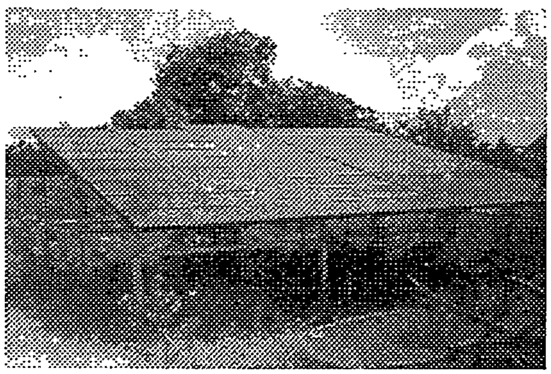

Figure 1. PV. Array of La Venturosa

The design load is 340 Ah, 24 V dc, the battery bank has an autonomy for 3 days with an 80% depth of discharge.

The equipment has the following technical characteristic:

The solar generator: 46 panels Solarex model MSX of 60 Wp each and 12 Vdc (total power 2760 Wp). The PV array is organized in three sub-arrangements to 24 Vdc. (Figure 1).

The Control Regulator: Power 3360 W, 24Vdc, INFINITY. It has 16 channels, 4 channels for direct measurement and a 4 channel datalogger,

(OMNIMETER) for record of information, this allows to supervise variables such voltage, current, energy and Amperes-hour for the solar generator, the battery bank and the users' load.

Inverters: Two TRACE Inverters, model DR15724, input 24 Vdc, output 120 Vac (modified sine wave) of 1.5 kW each.

Batteries: 12 Fulgor cells, with capacity of 1060 Ah, serial connection, for an output voltage of 24 Vdc (2Vdc by cell)

Distribution grid: The distribution grid has a length of 1000 m, single phase type, 120 Vac. The output is in two load circuits and two Public light circuits, the light and electrical poles are of wood .

Table 1

LOAD TYPE	No.	POWER (W)	TOTAL POWER (W)	TIME (h)
DOMESTIC LAMPS	35	18	630	3
TAPE RECORDER	11	20	220	8
COLOR TV	1	50	50	2
RADIO-TELEPHONE	1	20	20	8
REFRIGERATOR	1	55	55	10
VHS	1	50	50	2
PUBLIC LIGHTS	20	18	360	4

Grounding: With 5 cooper weld rods connected among them with nude copper cable.

SIMPLIFIED DIAGRAM OF LA VENTUROSA

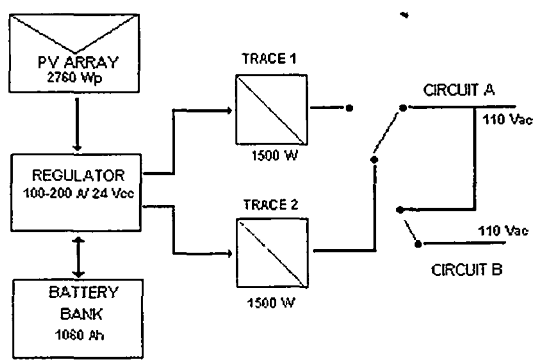

Figure 2 shows a simplified diagram of the system. The Table 1 shows the inventory design charges.

3. EVALUATION OF THE PROJECT

In consideration to the fact that the PV minigrid system of La Venturosa is considered by the ICEL, as an important alternative to the traditional energizing projects with diesel plants, the Solar Energy Group of the INEA considered important to evaluate the operation and level of satisfaction of the users of this small power plant, in order to apply the results to future projects.

The variables to explore are the following:

1. Charges and loads (consumption Load, Charge from the photovoltaic arrays, battery bank performance).
2. Meteorological Factors.
3. Maintenance and operation activities on the system .
4. Users' level of satisfaction .

The end of the evaluation stage will be in December of 1997. The results of the Evaluation could be use for the elaboration of a methodological guide for the design, implementation, follow-up and evaluation of solar systems with alike characteristic, adjusted to the Colombian case, as well as to evaluate the quality of the components (equipment, batteries, etc.), and compared them with the traditional diesel systems.

4. PRELIMINARY RESULTS OF THE EVALUATION

The analysis of the available information of generation and energy demand, was made for the not continuous records taken by the operator of the PV system during the first year of operation.
The daily average of generated energy is approximately of 4.21 kWh/ day or 175.5 Ah/ day.

In the figure 3, is observed that the maximum peak of the generated power, is presented to 9 AM with a mean value of 720 W.

The figure 4. shows the behavior of the average power demand. It shows a registered maximum value of 304W at 17:00 hours. Demand power average is of 162.3 W

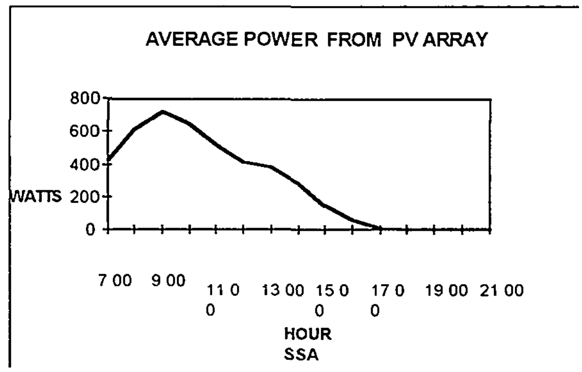

Figure 3.

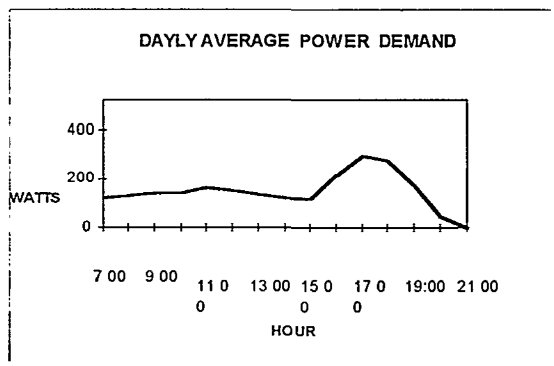

Figure 4.

The curve average of power demand presents a load factor of 0.53 and mean energy demand of 2.27 kWh (96 Ah) this demand is low due to the refrigerator (from the little health center) is not connected, and the public lights only work for about three hours.

With respect to the operation of the system, the more important outage has been due to faults in the control regulator as consequence of atmospheric discharges. The last occurred in August of 1996 and until now repair has not been carried out due to economic reasons. These atmospheric discharges also damaged 12 light bulbs (Phillips SL18).

Only routine maintenance type are accomplished by the system operator such us PV modules cleaning and water level control of the batteries. This is because the operator does not have enough technical knowledge and adecuated tools for more complex maintenance, such as the one needed for the regulator.

In the two operation years has been accomplished only one technical visit qualify by guarantee (first inspection of the regulator). Also there is a lack of spare parts such as fuses and light bulbs.

TECHNICAL PERFORMANCE OF THE "VILLAS CARROUSEL" PV-WIND HYBRID SYSTEMS

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ABSTRACT

Fifteen PV-Wind mini Hybrid Systems were installed at the Villas Carrousel Hotel. The first twelve were installed in December 1995. The remainder were installed during January 1997. The energy produced by the systems is used to provide the hotel illumination. Monitoring of the system's performance has been carried out since 1996.

Each system is integrated by a wind generator (Avispa) rated at 500 W, a PV array ranging from 150 to 320 Wp, an electronic control and a battery bank with capacities from 585 up to 780 Ah. The systems operate at 12 VDC and the energy produced is used through 12 V, 13 Watt high efficiency fluorescent lamps.

The systems were designed to produce 140-180 Ah/day. During the first months of operation. Some problems arised with the battery voltage measurement. This parameter was formerly measured at the DC bus bar of the control board. Some corrosion problems were detected there. This problem caused the undercharging of the battery banks, and in several cases abnormal operation of the wind generators were observed.

In general the systems produce the energy demanded by the load. This first experience is helping to promote the Mini Hybrid technology in other applications.

This paper presents some results from the system monitoring for the first year of operation that gives a general idea of the system performance.

1. INTRODUCTION

The use of small hybrid systems in applications where the preservation of the environment is a premise, like in the eco-hotel industry, can be benefits. In the Caribbean region there are many places where the lack of electricity has been a factor that stops the development of the tourism activity.

In the middle of 1995 Operadora Turistica Carrousel, ordered The Non Conventional Energy Resources Unit of the Electrical Research Institute a feasibility study for determining the availability of local energy resources (wind and solar) for supplying electricity to a hotel under construction, using renewables.

At that time the hotel was almost built. A data acquisition system was installed (DAS) with solar and wind sensors in order to know the potential of these resources for electric generation.. Using the information from the DAS, and historical information from the nearest weather stations to the site, a study was carried out for determining the type of power generation system based on renewables that could provide electricity for illumination.

Three alternatives were considerated. Photovoltaic systems, wind systems and hybrid systems. The last alternative seem to be the best choice from the technical and economical point of view. The data taken at the site showed a good complementarity between solar and wind resources.

There were some restrictions for the wind machine and solar panels installation. The hotel owners decided that the systems should not interfere with the building architecture. The wind machines were installed at the top of the buildings on self supported towers. Due to the lack of space in the hotel, the wind machines were installed at distances that are not according to the wind machine engineering practices.

The PV modules were installed on the sloping roof of the buildings. They are not facing the true south as it is recommended, and their inclination angle ranges from 35 to 30 degrees. The villages are not at the same front line. This fact brings some problems of early shadowing of some PV modules early in the morning and in the afternoon as well, during some seasons of the year. The first twelve systems started working at the end of December 1996 and the remainder three in mid January 1997.

2. SYSTEM CHARACTERISTICS

In this project PV modules of monocrystalline, policrystalline and amorphus silicon technologies were installed. The PV installed capacity for the systems ranged from 150 to 320 Wp. The Wind Machine has a nominal power of 500 W. The rotor diameter is 1.8 m. The generator is of the automotive induction type . The battery bank is built by 6V deep cycle flooded Lead-acid batteries. The hub height of the machines varies from 15.2 m to 16.5 m for the first systems installed, and 18m for those installed in 1997. Table 1 shows the main characteristic of the systems installed. Figure No. 1 shows a schematic diagram of the systems configuration.

Table .1 Characteristics of the hybrid power systems

System No.	PV Wp	Battery bank Ah	Wind generator Wn	Hub height m
1	150	585	500	15.3
7	225	"	"	16.5
13	320	"	"	18.0
15	300	"	"	18.0

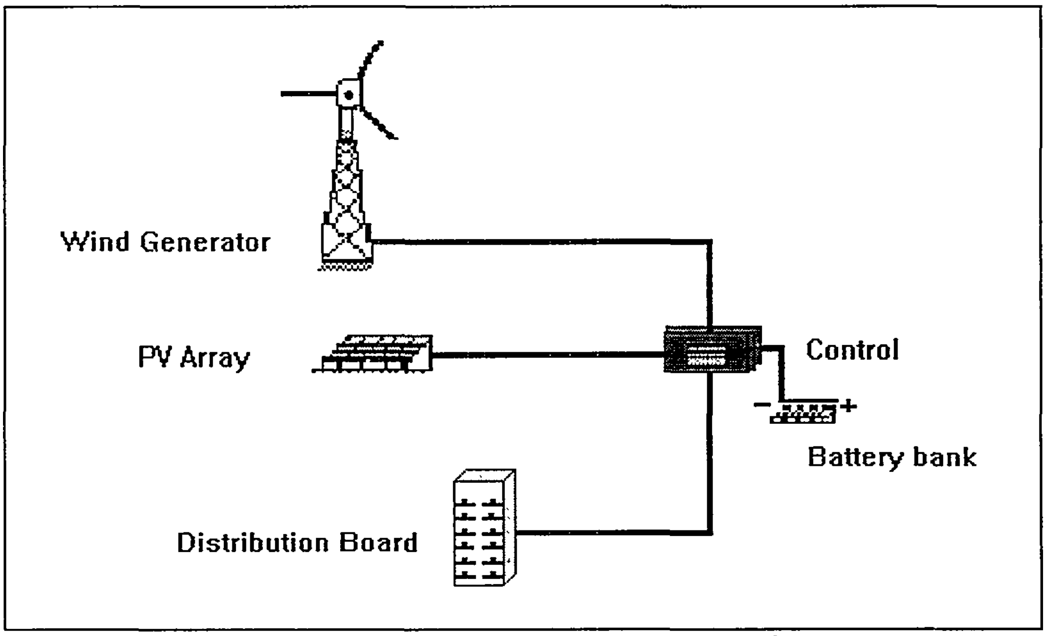

Fig. 1. Diagram of the mini hybrid (solar-wind) power systems

3. SYSTEMS MONITORING

In order to know the systems performance, two data acquisition systems (DAS) were installed. One was placed in Village No. 3 and the other one, in Village No. 6. Those villages were selected because it was believed that they could be representative for all systems. The main floor of Village No. 6 was formerly used as the hotel restaurant. Almost a year later the DAS was moved to one of the new systems that provides energy to the newly built restaurant.

Variables are sampled every second and then registered at ten minute intervals. Table 2 shows the variables registered in the DAS.

Table 2. Measured Variables at Villas Carrousel hybrid systems

Battery bank Voltage	(VDC)
Current from wind generator	(A)
Current from PV array	(A)
Current to the load	(A)
Logic state of control elements	(dimensionless)
Wind direction	(degrees)
Wind speed	(m/s)
Horizontal total radiation	(W/m^2)
Ambient temperature	(°C)

4. RENEWABLE ENERGY RESOURCES

The site can be considered with good availability of solar and wind energy resources. The annual mean of daily solar and wind speed at Playas Paraiso is 6.2 $kWh/m^2/day$ and 5.25 m/s respectively. In figure 2 the resources availability at the site is shown.

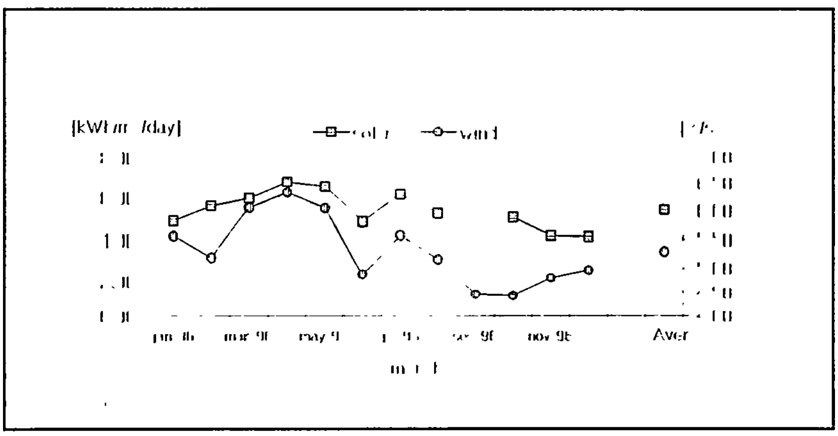

Fig. 2. Monthly means of average daily total horizontal insolation and wind speed

4.1 Energy contribution (solar and wind)

Up to now the biggest energy contribution have corresponded to the PV array. The main reason has been because the villages monitored have not had on energy demand as large as anticipated they were designed. Most of the energy produced by the system has been used to maintain the battery bank fully charged. Figures 3 and 4 show the energy contribution by the solar and wind subsystems.

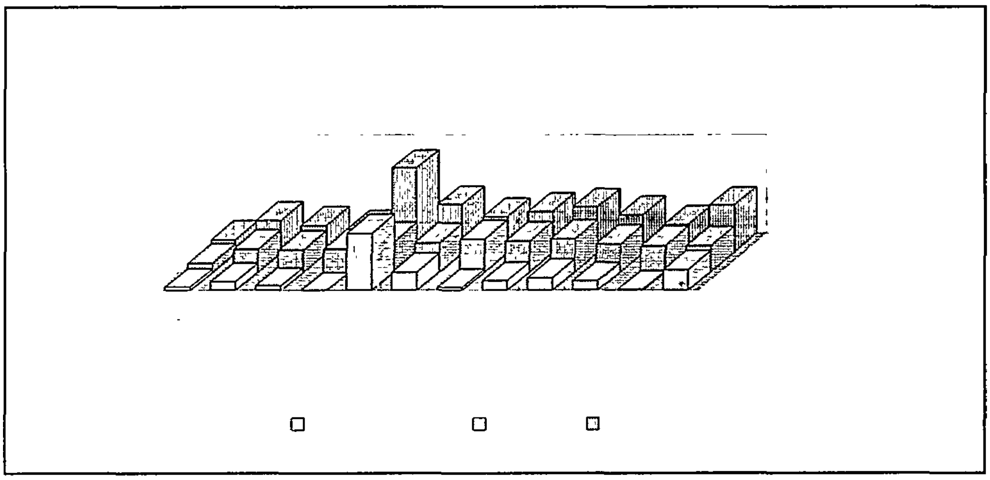

Fig. 3 Monthly energy contribution by source (Village Nu. 3)

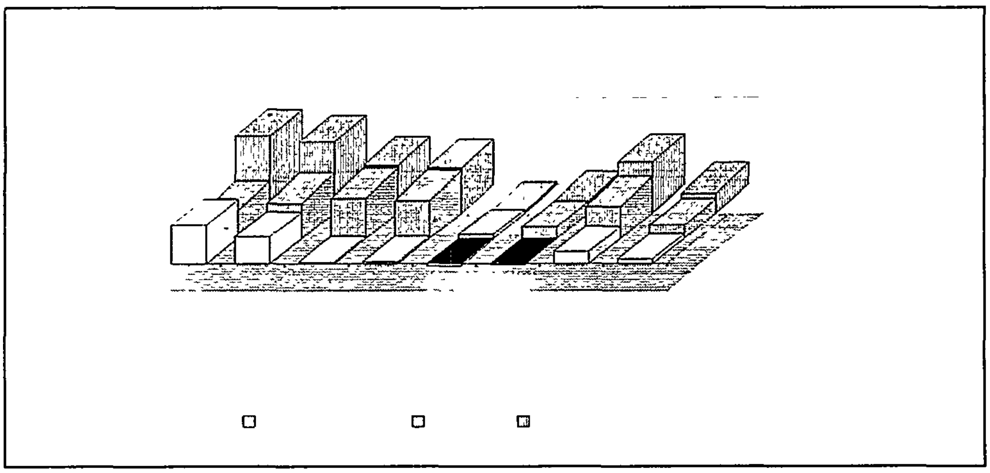

Fig. 4. Monthly energy contribution by source (Village No. 6)

One indicator of the energy usage in the system, is the amount of destillated water added to the battery banks of the systems 3 and 6. As the battery banks reach the high battery voltage disconnect, the excess of energy fed to the batteries is used to electrolyze the water which is finally lost.

5. THE LOAD

Figures 5 and 6 shows the monthly energy consumption for the monitored villages. It is clearly shown that the energy demand has been very low during the first year of operation. The design load was 57 kWh/month. The energy demand has been half of this during the few months for system 3 and even lower for system 6.

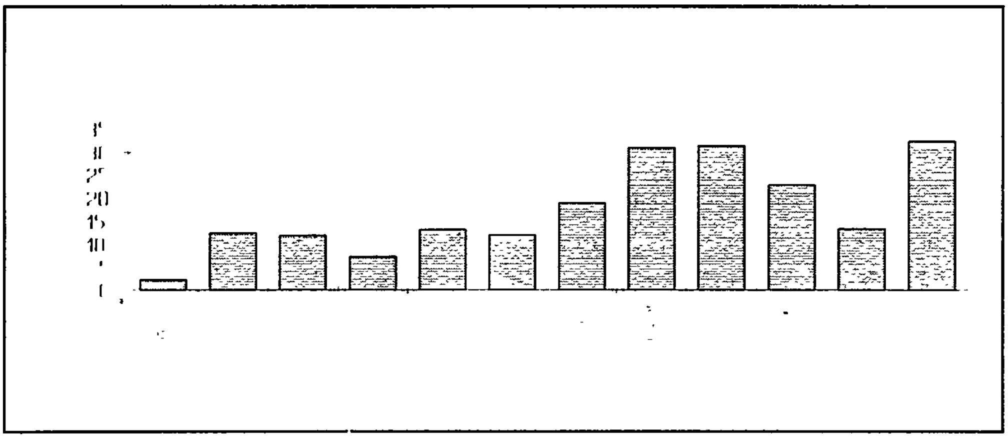

Fig. 5 Monthly energy consumption (Village No. 3)

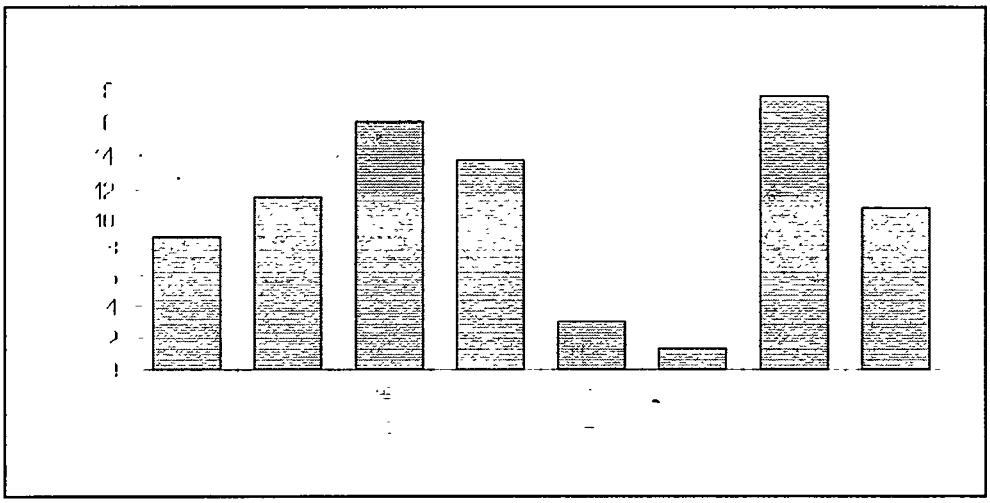

Fig. 6 Monthly energy consumption (Village No. 6)

As mentioned before three new systems were installed early in 1997. The DAS was moved from system No. 6 to one of the new systems that provides illumination to the new restaurant. Data from this system shows a more realistic operation. The daily load has reached 2 kWh/day. The electronic control has at times disconnected the load because of low voltage disconnect set point was reached. The need for a backup system had arised because the illumination of this hotel area is a priority.

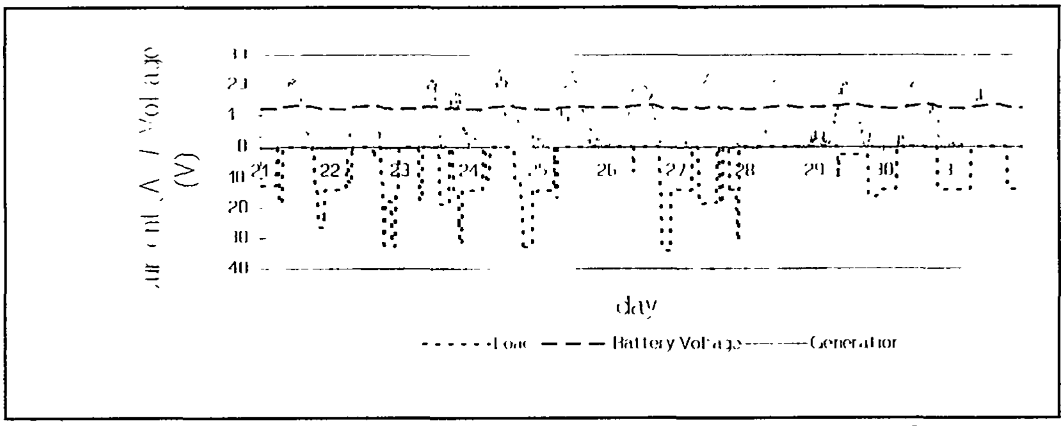

Fig. 7 Performance system No. 13 during some days of march 1997

6. CONCLUSIONS

System Reliability

The systems had performed almost continuously during their first year of operation. Only for a few days during the hurricane season the wind machines were put out of order for safety reasons. Four batteries had been replaced due to malfunctions and the control system had worked very reliably.

Problems

During the first months of operation some corrosion problems were detected and solved. Corrective actions were done and training was given to the hotel personal in order to make a better system's management.

Backup need

Information from the system's operational data shows a need for a backup system. One alternative has been considerated and that is to use the Utility distribution line. Another possible solution is to increase the PV arrays capacities. This alternative has the inconvenience of need for open areas that in this hotel are not available.

ELECTRIFICACIÓN DESCENTRALIZADA DE UNA POBLACIÓN RURAL AISLADA MEDIANTE ENERGÍA SOLAR FOTOVOLTAICA

Proyecto piloto: isla Taquile en el Lago Titicaca

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ABSTRACT

En la comunidad insular de Taquile en el Lago Titicaca se esta ejecutando un proyecto piloto de electrificación domiciliaria con sistemas fotovoltaicos. El Proyecto quiere evaluar la posibilidad de una electrificación rural básica con sistemas fotovoltaicos en base a iniciativas privadas, dentro del marco de la economía de mercado libre, vigente en el Perú.

1. ANTECEDENTES Y PREMISAS

El Centro de Energías Renovables de la Universidad Nacional de Ingeniería (CER-UNI, Lima) está ejecutando desde 1995 tres proyectos experimentales en el campo de las energías solar y eólica para el Proyecto de Ahorro de Energías del Ministerio de Energías y Minas del Perú (PAE-MEM). Estos proyectos están financiados íntegramente por el Gobierno Peruano (con aproximadamente US$ 100 000 para cada proyecto) y tienen el objetivo general de evaluar la viabilidad social, económica y técnica de la electrificación básica de zonas rurales remotas con el uso de las energías solar y eólica. Se espera que los resultados de estos proyectos permiten evaluar si este tipo de electrificación rural puede diseminarse basándose principalmente en mecanismos del mercado libre.

Particular interés tiene un proyecto iniciado a comienzos de 1996 para suministrar electricidad fotovoltaica a un poblado rural remoto en forma domiciliaria, es decir, suministrar electricidad básica a las casas de los habitantes de un poblado hacia donde es económicamente impracticable de extender una red eléctrica. Este proyecto había previsto fondos para instalar inicialmente 75 SFD, debiendo el proyecto elaborar mecanismos que llevarían a su sostenibilidad.

El proyecto ha asumido algunas premisas, con diferentes grados de comprobación previa:

Existe hoy en día una tecnología madura, todavía no muy difundida en el Perú /1/, que permite satisfacer las necesidades básicas de electricidad de la población rural en un país en desarrollo, que son para fines de iluminación y de telecomunicaciones (teléfono, TV, radio).

Diversos proyectos en el Perú y en otros países en desarrollo han demostrado que la tecnología fotovoltaica es fácilmente aceptada por la población rural y, donde es conocida, es considerada útil y es deseada /2/ - /3/.

Los gastos para iluminación (velas, kerosene para mecheros y lámparas de gas) y pilas y baterías para radios y TV son para una amplia parte de la población rural mayores que el costo de la electricidad fotovoltaica que suministraría un mejor servicio.

La experiencia de otros lugares ha demostrado que no es conveniente instalar sistemas fotovoltaicos centralizados para una electrificación rural básica domiciliaria, sino se debe instalar en cada casa un Sistema Fotovoltaico Domiciliario (SFD) en forma individual e independiente /3/.

El usuario debe desear adquirir un SFD. Para esto es necesario que el conozca previamente los SFD, sus beneficios y costos.

Salvo casos excepcionales, la mayoría de la población rural del Perú no tiene la capacidad económica de pagar un SFD al contado sino requiere una financiación que le permite adquirir su SFD con pagos a su alcance.

Es conveniente que una misma empresa se encarga del suministro, de la instalación y del servicio de posventa de los SFD, incluyendo la capacitación de los usuarios /4/.

Es posible hacer una electrificación rural básica en regiones remotas del Perú dentro del esquema de la economía de mercado, vigente en el Perú, donde el usuario debe pagar el servicio que está recibiendo.

La verificación de estos dos últimos puntos es el objetivo específico más importante del Proyecto.

Para este Proyecto se ha elegido la población insular de Taquile, perteneciendo al distrito de Amantanø, ubicado en el Lago Titicaca.

2. EJECUCION DEL PROYECTO

Taquile es una isla en el Lago Titicaca, a 3815 m s.n.m.. Junto con la isla vecina, Amantanø, forma el Distrito de Amantanø, perteneciendo al Departamento de Puno. Tiene una población de 1400 habitantes (380 familias), dispersada sobre toda la isla de 5,7 km2.

Una conexión a la red eléctrica con un cable subacuático tiene un costo de varios millones de dólares (la oferta más barata de una licitación pública en 1995 de un cable subacuático de la orilla hasta Amantanø, que se encuentra bastante más cerca a la orilla que Taquile, fue de 2 millones de dólares; la licitación fue declarada desierta). **Así** una electrificación de Taquile requiere la generación local de la electricidad, lo que, en la práctica, deja dos alternativas: fotovoltaica o grupo Diesel.

Un estudio de prefactibilidad de electrificación de Taquile, realizado en 1994 por el CER-UNI para el Ministerio de Energía y Minas concluyó que la mejor y más barata alternativa es una electrificación fotovoltaica. Independientemente, al mismo tiempo, por iniciativa de una ONG de Puno, se había formado en Taquile un comité de electrificación solar, con más de 120 familias Taquile como socios. Ambos esfuerzos quedaron sin resultado.

En marzo 1996 una comisión del CER-UNI visitó Taquile, explicó los alcances y la modalidad del proyecto a las autoridades y realizó una encuesta. En dos días 92 Taquile se inscribieron, expresando su **internos** en la adquisición de un SFD.

En mayo 1996 el MEM aprobó la propuesta del CER-UNI de ejecutar el proyecto en Taquile y una comisión del CER-UNI viajó nuevamente a Taquile para firmar con 75 personas de Taquile contratos de compra-venta para SFD. Después la UNI realizó una licitación pública para la adquisición e instalación y servicio de posventa de 75 SFD, en concordancia con la reglamentación vigente para la adquisición de bienes por entidades pública. Las bases de la licitación precisaron con mucho detalle la configuración técnica de los SFD y de los servicios a adquirirse y fijaron como plazo máximo 3 semanas para la instalación de los 75 SFD. La empresa ganadora, INTILUZ S.A., ha instalado los 75 SFD en 10 días en julio de 1996 bajo la supervisión del CER-UNI, que previamente había evaluado en el laboratorio los componentes de los SFD ofrecidos.

El Proyecto ha instalado también un Sistema Fotovoltaico Comunal (SFC) para fines sociales (educación, salud, etc.) y de promoción de la tecnología. Este SFC tiene un panel FV de 400 Wp, regulador de carga, 800 Ah/12V de batería, un inversor de 800 W de 12 VDC / 220 VAC, 8 fluorescentes compactos de 20 W, un televisor a color, antena parabólica (3,5 m) y una videograbadora. El SFC está instalado en un local comunal y está bajo la responsabilidad (operación y mantenimiento) de las autoridades municipales.

3. ASPECTOS SOCIO - ECONOMICOS

La actividad productiva principal en Taquile es la agricultura. Cada familia tiene, en promedio, aproximadamente 1 ha de tierra cultivada (casi todo en andenes), de secano (sin irrigación), que les permite producir los alimentos para su subsistencia: papa, cebada, habas, maíz, etc. Adicionalmente, todos Taquileños son artesanos, tejiendo los hombres con palitos y las mujeres con telares rústicos diferentes vestimentos y mantas con diseños muy tópicos y de alta calidad. Los Taquileños están siempre vestidos con sus trajes tópicos, tejidos por ellos. La venta de esta artesanía lanar genera el principal ingreso en efectivo. Algunos se dedican a la pesca en el lago, otros al transporte (lanchas) y últimamente se está iniciando un turismo, atraído por la belleza del lugar y el estilo tradicional de vida y de vestimento de los Taquileños, que fomenta la aparición de restaurantes y alojamientos (todos rústicos).

Una encuesta realizada en marzo de 1996 entre 93 de los aproximadamente 380 familias en Taquile ha indicado sus principales consumos energéticos:

para cocinar, todos usan leña, obtenido en la misma isla (existen escasos árboles de eucalipto) y algunas usan kerosene, sobre todo los restaurantes.

para iluminación todos usan velas y lámparines de kerosene; en ocasiones especiales, también usan lámparas de kerosene a presión, tipo Petromax. Todos usan linternas eléctricas con pilas.

todos tienen radio/tocacassette con pilas o conectados a una batería. 70% tienen un pequeño televisor b/n (se puede recibir la señal de un canal de TV nacional; en muchas partes de la isla en forma débil), operado con batería de 12 V. Esta batería es transportada cada 1 - 2 semanas a **Puno** para su recarga.

se estima que 20 familias ya tienen un módulo FV, de diferente tamaño (5 - 40 Wp) y procedencia y adquirido en forma individual y pagado al contado, algunos desde 10 años; los 7 encuestados se expresaron muy favorablemente sobre la tecnología FV.

según el testimonio de los encuestados, cada familia gasta mensualmente entre $4.- y $20.- para kerosene para iluminación, para pilas y recargas de baterías.

Estos gastos justifican económicamente para una gran parte de la población de Taquile el uso de un SFD, que les cuesta mensualmente una cantidad similar (el monto exacto depende de la suposición de varios parámetros, en particular el costo de la financiación), pero que les ofrece un servicio mejor.

Adicionalmente es de esperar que la mejor iluminación permitirá aumentar las horas de trabajo en artesanía, tal como fue expresado por muchos. Así se tendrá indirectamente un efecto productivo, generando ingresos.

Por otro lado, la ubicación y las características de Taquile indican que la mejor, si no la única, alternativa para el desarrollo económico de Taquile es el turismo ecológico y este puede aprovechar bien una energetización con energía solar, fotovoltaica como fototérmica.

4. ASPECTOS TECNICOS

Para satisfacer las necesidades básicas de iluminación y telecomunicaciones de una familia rural se consideró una necesidad de 180 Wh/día. Asimismo se consideró que se debe dar mucho énfasis a la calidad de todos los componentes y de la instalación del SFD y del servicio de posventa.

En base a lo anterior se elaboró las especificaciones técnicas de un SFD:

- 1 módulo FV que suministra, bajo las condiciones específicas del SFD en Taquile, un mínimo de 15 Ah/día, como promedio anual, a una batería de 12 V (180 Wh/día; 5,4 kWh/mes), con una vida útil garantizada mayor de 10 años.

- 1 controlador de carga de batería, de estado sólido, con una corriente mínima de módulo FV de 7 A (permitiendo la conexión de un segundo módulo FV) y de carga de 10 A, con regulación de gasificación y de igualización, con compensación de temperatura y desconexión automática de carga a bajo voltaje, protección contra inversión de polaridad, cortocircuito, circuito abierto y sobretensión, con vida útil garantizada mayor de 5 años.

- 1 batería plomo-ácido, abierto (tipo solar o automotriz), mínimo de 100 Ah (C20), con vida útil garantizada mayor de 3 años (80 % de capacidad inicial) bajo las condiciones locales (en /5/ se expone argumentos en favor de este tipo de baterías).

- 3 lámparas, completos con difusor de luz, con fluorescentes compactos de 7 - 11W, con balastros electrónicos para 12 V DC, con una luminosidad mínima de 1700 lumen y un consumo máximo de 4 A (las 3 lámparas juntas), una eficiencia luminosa mínima de 40 Lumen / Watt (incluyendo el consumo de los balastros electrónicos), protección contra polaridad invertida y operación sin fluorescente, sin interferencia para radio y TV, con una vida garantizada de los tubos fluorescentes mayor de 5000 horas.

- 1 caja de conexiones con 5 fusibles y LEDs indicadores, con salida para 3 lámparas, para TV (12V) y radio (conversor DC-DC, 3 - 9 V).

- 10 m cables 2x10 para exteriores y 30 m cables 2x14 para interiores, bipolares, 3 interruptores.

- 1 soporte metálico para módulo FV tipo pastoral (tubo de 2 m de longitud y 5 cm de diámetro), que permite una inclinación apropiada del módulo FV con respecto al plano horizontal y una orientación hacia el norte.

- manuales para el servicio técnico de mantenimiento y manuales para los usuarios, en lenguaje apropiado, para la operación de los SFD.

- mantener un stock de repuestos en Taquile, garantizar un servicio de posventa durante un año y capacitar 5 Taquileños en el mantenimiento de los SFD

5. COSTOS Y ASPECTOS FINANCIEROS

En base a los precios en Lima de los diferentes componentes de un SFD, se estimó que el costo de un SFD instalado en Taquile sería US$ 800 - 900. En este precio están incluidos aproximadamente 40 % de impuestos (mayormente: 15 % arancel para productos importados y 18 % IGV, impuesto al valor agregado).

Considerando lo anterior y las premisas del proyecto, se fijó los siguientes precios del SFD para el usuario, incluyendo la instalación y servicio de posventa:

- al contado: US$ 675.00

- diferentes modalidades de pago a plazo: US$ 700.00 - 750.00

con un mínimo de US$ 150.- como cuota inicial, al momento de la instalación, y el resto a pagarse en un plazo máximo de 3 años, con cuotas semestrales o anuales de un mínimo de US$ 150.-. Esto corresponde a un costo de financiación de 9% anual.

La mayoría de los usuarios ha elegido la financiación más cómoda: 5 cuotas de US$ 150.- cada una, a pagarse en 3 años. Después de haberse instalado los primeros 75 SFD (financiados con fondos del proyecto), las primeras cuotas pagadas sumaban US$ 13500.-

Por otro lado, como resultado de la licitación pública realizada, se ha obtenido los siguientes costos (incluyendo impuestos):

- un SFD, compuesto por los siguientes partes (en paréntesis se da los porcentajes del precio total): 1 módulo FV Kyocera 51 Wp (47 %), 1 controlador de carga Steca 10 A (10 %), 1 batería 100 Ah Toyo Solar (11 %), 3 lámparas fluorescentes compactos 11 W/12V Helios (16 %), 1 caja de conexiones (6 %), cables (7 %), soporte del módulo FV (3 %),

precio de venta de un SFD en Lima (incl. imp.):	US$	785.-
- transporte , instalación y servicio de posventa:		65.-
- Costo total de un SFD instalado:	US$	850.-

6. PERSPECTIVAS DE SOSTENIBILIDAD

Para poder evaluar la sostenibilidad del esquema de electrificación rural con SFD previsto en el presente Proyecto, se puede considerar varios escenarios con diferentes metas como indicadores de la sostenibilidad.

Sin embargo, una condición que se debe cumplir de todas maneras para obtener una sostenibilidad es que todos - o casi todos - los compradores de SFD paguen todas sus cuotas. Para lograr esto, es importante tener un eficiente y económico sistema de cobranzas de las cuotas. Se encargó la cobranza a una persona del lugar que recibe como pago un porcentaje de las cuotas cobradas (2 %). Hasta la fecha no hay morosidad: todos ya han pagado por lo menos su segunda cuota. En las diferentes reuniones con los usuarios se ha enfatizado que los SFD siguen propiedad del CER-UNI hasta su pago total y que la falta de pago conllevará un retiro de los sistemas. Esto es fijado claramente en los compromisos firmados por los usuarios y refrendados por autoridades de Taquile.

Como consecuencia de la instalación de los primeros 75 SFD en julio de 1996 se ha creado una expectativa en la población de Taquile y una demanda: muchos han expresado su voluntad de adquirir su SFD y en septiembre 1996 se ha instalado otros 25 SFD, con el dinero recaudado con la primera cuota. Con los fondos de la segunda (ya pagada) y tercera cuota (julio 1997) se proyecta instalar en agosto de 1997 otros 40 SFD.

Un escenario y una meta es que el Proyecto, que tiene un costo de US$ 100000.- para el Gobierno (que incluye todos los costos de estudios y de asesoría realizados por el CER-UNI) permite, sin apoyo o subsidio adicional, una electrificación básica de todo Taquile. Con los costos actuales (US$ 850.-/ SFD) y los pagos realizados por los usuarios (US$ 675.- al contado, ó US$ 750.- en 3 años), esto es realizable: los primeros 75 SFD, con un costo de $ 63750.-, fueron financiados por el proyecto, creando un fondo rotativo, y con las cuotas de los usuarios se puede instalar otros 300 - 550 SFD en un plazo que dependerá de la velocidad de pago. En el caso más lento (todos pagan 5 cuotas de $ 150.- en 3 años), se puede ofrecer en aproximadamente 5 años SFD a todas las familias de Taquile.

Se obtendría así una electrificación de todas las casas y posteriormente de los locales comunales. (El primer Sistema Fotovoltaico Comunal (SFC) , con un costo de $ 8000.-, fue pagado con fondos del proyecto.) Considerando que el costo actual de $ 850.- incluye aproximadamente $ 300.- de impuestos, en realidad el Gobierno recuperá toda su inversión inicial.

Hoy, un año después de haberse iniciado el Proyecto, consideramos que esta meta será alcanzada.. También consideramos que el logro de esta meta significará que el proyecto será éxitoso, habiéndose demostrado que se puede lograr en el Perú una electrificación básica rural prácticamente con el esfuerzo exclusivo de los usuarios e usando empresas privadas para la diseminación.

Otro escenario posible es que una masificación de los SFD conlleva a una reducción de sus costos. Si bien no se puede esperar una reducción significativa en los próximos años del costo del panel FV o de la batería, los otros componentes, con una mayor integración de materiales nacionales, pueden reducir el costo de un SFD instalado a $ 700.- - 750.-, incluyendo impuestos, a corto plazo. Si adicionalmente el Gobierno subsidie a cada campesino de regiones remotas que instala en su casa un SFD con US$ 200.-, equivalentes a parte de los impuestos pagados por el SFD, el costo para el campesino se reduciría a $ 500.- - 550.-. Consideramos que esto llevaría a una electrificación rural FV masiva, sin apoyo adicional del Gobierno, sino en base a iniciativas netamente privadas de financiación como de promoción e instalación de los SFD.

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HYBRID 95: SOFTWARE DE DISEÑO DE SISTEMAS HÍBRIDOS, POTRERILLO DE SANTA TERESA

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RESUMEN

Este trabajo describe el software Hybrid 95 y como se utiliza a los efectos del diseño de sistemas híbridos. Como ejemplo de aplicación se recorren algunas de las etapas del diseño (determinación del recurso eólico, simulaciones para el dimensionado de generación/acumulación y topología) de la instalación de Potrerillo. Teniendo en cuenta las claras connotaciones ecologistas del lugar, durante el diseño se tiene presente el impacto visual que representa el eventual aerogenerador por lo que se estudian diversas ubicaciones y alturas de aerogenerador, llegándose incluso a estudiar la eliminación de la generación eólica.

1. INTRODUCCIÓN

En el marco de un Convenio con el Programa de Conservación de la biodiversidad y desarrollo sustentable en los humedales del este. (PROBIDES) financiado por el Programa de las Naciones Unidas para el Desarrollo (PNUD) se realizó el diseño de un sistema híbrido para generación de energía eléctrica en el predio El Potrerillo, una reserva de fauna y flora autóctonas, que está alejado de la red eléctrica nacional y donde se deseaba en lo posible preservar el medio ambiente. Como ayuda para este diseño se usó el programa "HYBRID 95" que es una aplicación del simulador de sistemas energéticos SIMENERG [1], [3]elaborado por el Grupo de Trabajo en Energías Renovables. Esta herramienta permite además de dar resultados acabados de la prestaciones de un cierto sistema, obtener rápidamente un costo estimativo de los sistemas a implementar teniendo en cuenta la demanda de energía solicitada por el cliente. por lo que ya en las etapas de anteproyecto se puede ir adaptando las necesidades del cliente con los recursos disponibles.

2. DESCRIPCIÓN DEL HYBRID 95

El programa Hybrid 95 es una implemantación particular de un sistema híbrido con energías provenientes del viento y sol construido con la herramienta Simenerg.

El menú principal del programa presenta la posibilidad de administrar los diferentes escenarios confeccionados, permitiendo salvarlos o leerlos de disco o crear uno nuevo. Una vez seleccionado el escenario, es solamente necesario determinar los años a simular y se procede a la simulación misma. Para este tipo de sistemas se ha elegido un paso de simulación fijo de una hora.

2.1. Entrada de Datos: Escenario

Este programa permite armar el sistema híbrido seleccionando los actores y sus respectivos parámetros de funcionamiento en forma muy simple.
Los elementos a definir son: recurso eólico, recurso solar, aerogenerador, placas fotovoltaicas, baterías y demanda.

Recurso Eólico: selecciona un archivo en donde están almacenados los datos de viento en el lugar. En dicho archivo está la información día a día horaria de viento en valores medios a 10 m de altura. Si se tienen datos a otra altura se deberá determinar el correspondiente coeficiente de speed-up. [5]

Recurso solar: en este caso existen diversas posibilidades de definir este recurso.
El caso más básico es disponer de información de irradiación diaria acumulada para cada día de simulación. Por tanto se simulará en base a series históricas de datos.

En un caso mas general, cuando se quiere simular numerosos años y obtener así información estadística del sistema se ha desarrollado un fuente continua de irradiación solar basada en la información de 8 años de datos registrados en un determinado lugar del país, la cual es modulada por los datos meteorológicos de nubosidad para todo el país. A esta fuente de datos de irradiación se le ha dado el nombre de anillo ruidoso y es en esencia una fuente sintética de datos [4].

A los efectos de poder realizar pasos de simulación menores, como en este caso de una hora, se dispone de un método para obtener la distribución horaria basado en la información histórica de la zona. Asimismo, para obtener la energía en el plano inclinado del panel es necesario realizar la correspondiente transformación para lo que se utilizan diferentes métodos como ser Liu-Jordan, Pérez o HDKR [4]. Estos métodos utilizan la misma información histórica de la zona para obtener la distribución horaria en el plano inclinado.

En todos los casos se utiliza la transformada antes mencionada para pasar al plano inclinado del panel fotovoltaico.

Aerogenerador: Permite seleccionar un archivo con la curva de velocidad-potencia a determinada altura (especificada en el archivo) de diversos eologeneradores. A los efectos de obtener la potencia del generador se toma el dato de viento, se corrige por el coeficiente de speed-up del lugar, se corrige por altura y se interpola la potencia que el molino entrega en esas condiciones.

Placas fotovoltaicas: En este caso se selecciona la cantidad de unidades con determinada potencia pico de generación. También se determina el ángulo de inclinación del panel respecto a la horizontal.

Acumuladores: El modelo de batería adoptado considera a la batería como un reservorio de energía en donde la misma entrega energía solo limitado por su máxima corriente de descarga y admite energía con determinado rendimiento de carga y limitado por la máxima corriente de recarga. Asimismo se efectúan modificaciones de la capacidad por temperatura [4].

Los datos del ciclado admitido por la batería son utilizados para estimar la vida de la batería y por tanto el periodo de recambio de la misma [6]. Como salida del programa se da el histograma de ciclado que recibió la batería durante la simulación.

El programa solicita la máxima profundidad de descarga a la que se le permitirá llegar a la batería, no permitiendo durante la simulación que la misma supere tal límite. Asimismo se especifica las máximas corrientes de carga y descarga admitidas.

Demanda: La demanda energética del sistema (el consumidor) se introduce mediante el perfil de demanda diario hora a hora el cual es afectado por los coeficientes estacionales mensuales que es necesario suministrar como dato de entrada. El programa permite salvar o recuperar los datos de demanda.

2.2 Salidas del programa

Durante la corrida del programa se visualiza en pantalla, el estado de carga de baterías y su evolución hora a hora. Se muestra además como van evolucionando los histogramas de déficit y el de exceso energético. En el extremo inferior izquierdo se observa la proporción de corriente entregada a la batería respecto a la máxima admisible y la proporción de descarga de batería respecto a la máxima admisible, gráficas que permiten visualizar rápidamente si los sistemas de bancos de batería o paneles esta sobre o subdimensionados.

Al finalizar la simulación se obtiene la pantalla que muestra los resultados como se indica en la figura 1. Se destaca que la gráfica del extremo inferior izquierdo vista durante la simulación se sustituye por la del ciclado final de la batería .

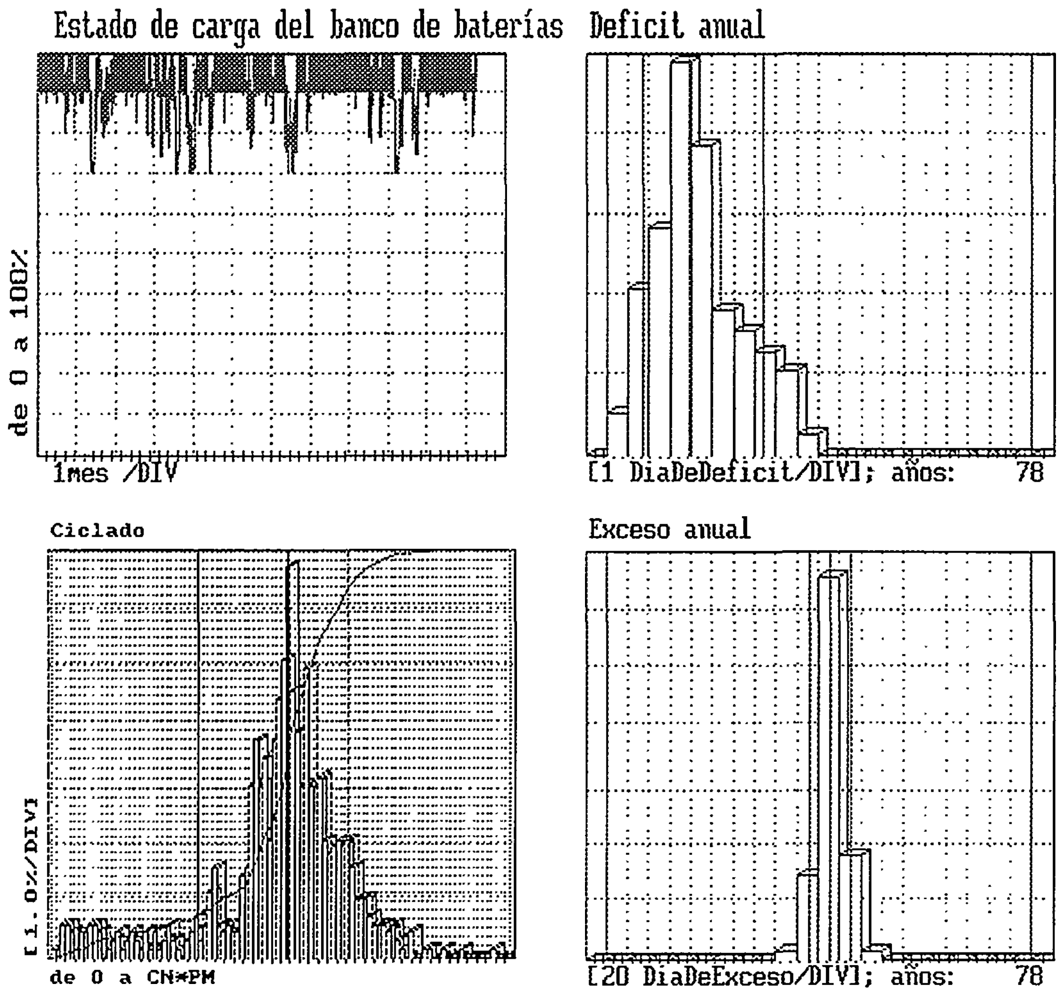


Figura 1. Vista de la pantalla al final de la simulación

Finalmente en un archivo se guardan resultados varios destacándose el "Déficit 90% en días". "Degradación anual de la batería: en [p.u.]" y los "Años que dura la batería [u]"

El "Déficit 90%" es la cantidad de días con una confianza estadística del 90% en que el sistema se quedará sin suministro de energía. Este factor será el que determinará la calidad del suministro energético.

A los efectos del calculo de mapas de sistemas posibles, se utiliza una versión sin salida gráfica que calcula dicho déficit energético para cada escenario. A los efectos de generar los mapas capacidad-panel, se simulan matrices de estos valores en donde se deja fijo el aerogenerador y su altura, la demanda y los recursos eólico y solar.

3. ALGUNOS ASPECTOS DEL DISEÑO DE POTRERILLO

3.1 Selección del lugar del aerogenerador y datos de viento.

En primera instancia se eligió la ubicación optima del aerogenerador de acuerdo con la geografía del lugar y los vientos predominantes. En este lugar se instalo a 12m de altura un registrador que midió los datos de vientos durante dos meses. Luego, en base a estadísticas históricas en estaciones meteorológicas cercanas y a registros de dichas estaciones en simultaneidad con los registrados durante los dos meses en el sitio, se generó por correlación un archivo anual de viento esperado en el lugar inicialmente seleccionado y a 12m de altura.

Finalmente, el lugar de instalación adoptado, de acuerdo a criterios de impacto visual, determinó una perdida de 13% de velocidad de viento a la misma altura (en base a un estudio de rugosidad aguas arriba del aerogenerador), por lo que se debería subir el molino de 12m en el lugar original a 18m en el lugar adoptado para recuperar la energía perdida.

Se analizó para a 12m y 18m, con coeficientes de speed-up de 1 y de 0.87 respectivamente.

3.2 Demanda energética

En esta etapa del diseño de debió determinar el perfil de carga a adoptar. Se itero con diversas pretensiones del usuario y el costo asociado. Finalmente se acordó el perfil de consumo de la tabla 1, en donde la discusión se centro en la eliminación de refrigeración, reducción del consumo y eliminación de la integración al sistema de la casa del guardaparque.

	Centro de recepción			Servicios					Bombeo	Bombeo	Subtotales		
				Oficina		Cafetería	Baños	Depósito	al tanque	al aljibe			
Hora	Luz vitrinas	Luz emerg.	220 Vac	Luz	220 Vac	Luz	Luz	Luz		220 Vac	Wh/hora	220 Vac	DC
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	60	0	100	0	0	0	0	0	0	62	289	214	75
11	0	0	0	0	0	0	0	0	0	62	89	89	0
12	0	0	300	0	0	0	0	0	0	62	464	464	0
13	0	0	0	0	0	0	0	0	0	62	89	89	0
14	60	0	300	0	0	0	0	0	40	62	596	464	132
15	0	0	0	0	0	0	0	0	40	62	146	89	57
16	0	0	300	0	0	0	0	0	40	0	432	375	57
17	0	0	0	0	0	0	0	0	40	0	57	0	57
18	60	0	100	15	0	30	15	0	40	0	332	125	207
19	0	0	0	15	0	30	15	0	0	0	75	0	75
20	0	0	0	15	0	30	15	0	0	0	75	0	75
21	0	15	0	15	0	30	15	15	0	0	113	0	113
22	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0
mu	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7			
Wh/d	225	19	1375	75	0	150	75	19	286	531	2755	1906	848
%	8.20%	0.70%	49.90%	2.70%	0.00%	5.40%	2.70%	0.70%	10.40%	19.30%	100.00%	69.20%	30.80%
											Máximos	464	207

tabla 1. Perdil de carga simulado (otro archivo)

En el mismo se observa la gran proporción de consumos en alterna a proveer (70%). Asimismo se hace notar que la mitad del consumo es en 220VAC en el Centro de Recepción (equipo multimedia, TV y video).

Para el perfil de carga anual, teniendo en cuenta el uso estacional del lugar, se previó durante tres meses de verano y en los meses previo y posterior al mismo consumo nominal y del 10% de este durante el resto del año.

3.3 Sistema de generación, acumulación y servicios

La figura 2 muestra la configuración adoptada la cual surge de utilizar en la misma equipos estandard del mercado. En particular se busca el uso de reguladores de probado desempeño en los cuales se trate a las baterías en forma racional. Como se ve los sistemas de generación eólico y solar son independientes y se utiliza para cada uno de ellos sus salidas estandard como suministro de energía para el usuario.

El tablero general de distribución mostrado en la figura 3, se diseñó para dar las máximas prestaciones del sistema incluso ante eventuales roturas parciales.

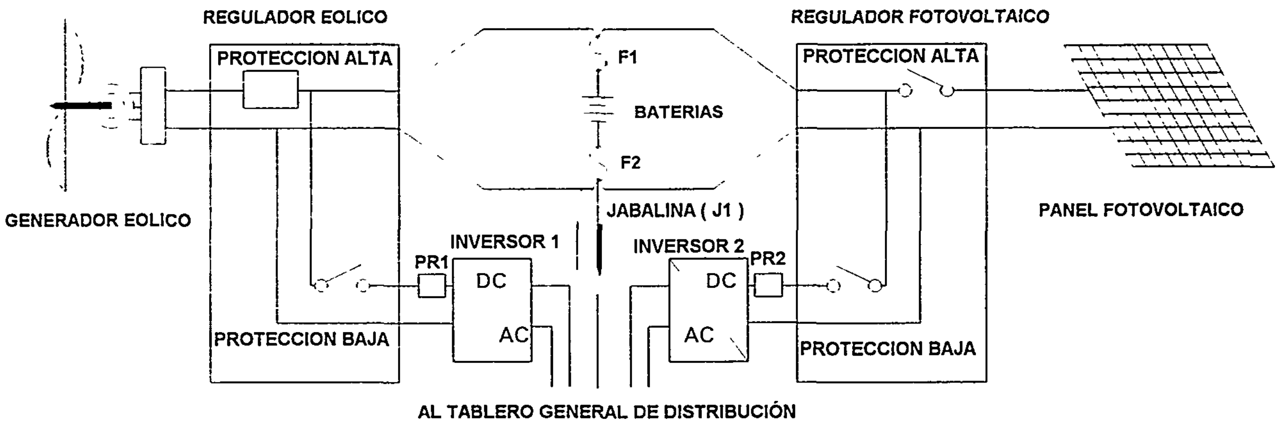


Fig 2. Esquema general de generación, acumulación y servicios

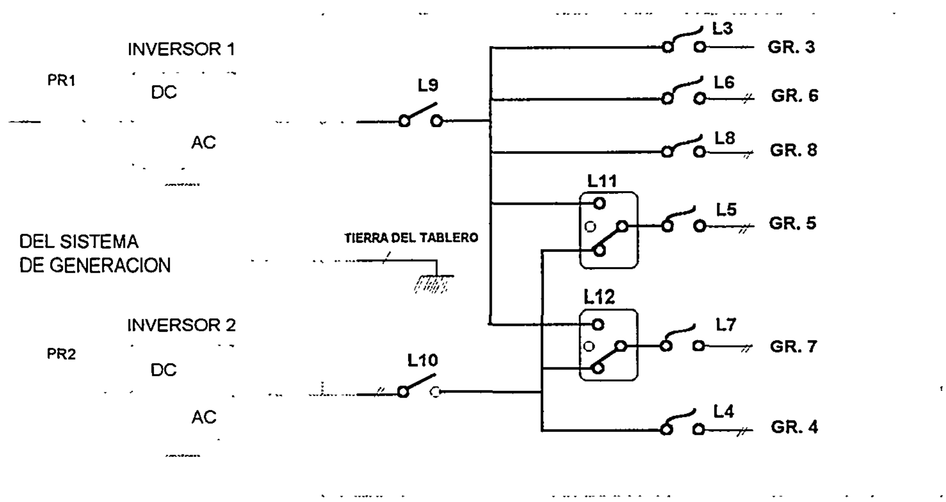


Figura 3. Tablero general de distribución.

3.4 Simulaciones

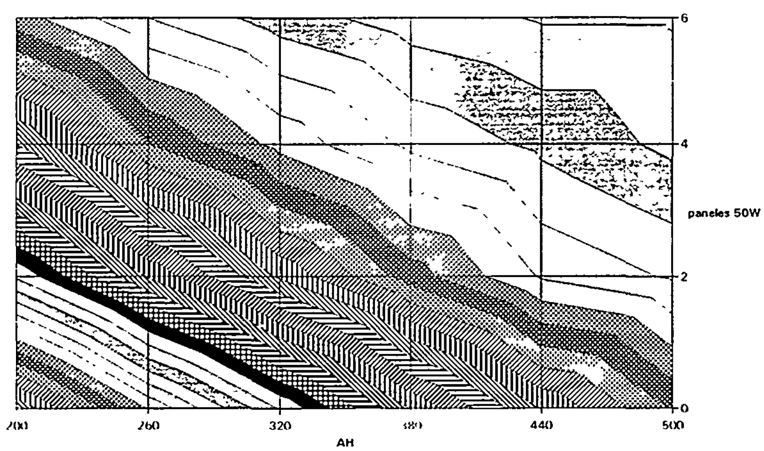
Los aerogeneradores y alturas simuladas fueron los mostrados en la tabla 2.
La matriz capacidad-paneles que se utilizo fue de 200 a 500 AH 24V cada 40AH, y de 0 a 6 paneles cada 2 paneles de 50W pico (por ser un sistema de 24V son de 2 en 2 paneles).

Whisper 1000	18m
Whisper 1000	12m
Whisper 600	18m
LMW 1003	18m
LMW 1003	12m
LMW 600	18m
BWC 1500	18m
sistema sin aerogenerador	SOLO PANELES

Tabla 2. Simulaciones

Por ejemplo para el sistema Whisper 1000 a 18m de altura se tiene el resultado mostrado en la figura 4.

Cada zona avanzando del extremo superior derecho hacia abajo representa un día de déficit energético anual arrancando de 0-1 día. Por ejemplo, tanto el sistema con 2 paneles y 500AH (punto B) tendrá el mismo déficit de 3 a 4 días anuales que el sistema de 6 paneles y 260AH (punto A).



En la figura 5 se muestra los costos del equipamiento de generación y acumulación para el sistema particular con el Whisper 1000 y a 18m de altura.

En este caso cada zona avanzando del extremo inferior izquierdo hacia arriba representa un sistema de costo con incrementos de 500U$ arrancando de 5000 a 5500 U$. Por ejemplo, tanto el sistema con 4 paneles y 500AH (punto D) tendrá el mismo costo de entre 8500 y 9000 U$ que el sistema de 6 paneles y 260AH (punto C).

Superponiendo la zona de 3 a 4 días de déficit en la matriz de costo, resultaría evidente la selección de un sistema 2 paneles, 500AH (punto F) dado su menor costo. La dificultad que se presenta en esta zona de la gráfica es la alta sensibilidad a los paneles que resulta el déficit, por lo que es conveniente alejarse, a pesar de tener costos superiores de la zona asintótica de las curvas isodéficit [4].

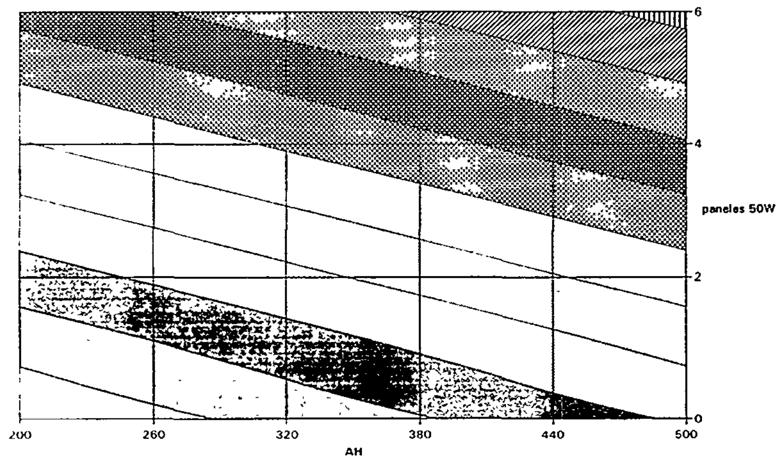


Figura 4. Zonas de costo constante: Whisper 1000, 18m

En este sistema en base al Whisper 1000 a 18m, se seleccionó el sistema de 4 paneles y 380 AH con un costo estimado de 8400 U$ (punto H).

Aplicando este procedimiento para los sistemas propuestos en la tabla 2 y con la consigna de 3 a 4 días de déficit resulta la tab 3.

Aerogenerador	Altura de la torre del aerogenerador	Wpico de paneles @ 24V	AH batería @ 24V	COSTO U$D
Whisper 1000	18	200	380	8400
Whisper 1000	12	300	440	9900
Whisper 600	18	300	440	9400
LMW 1003	18	100	260	10500
LMW 1003	12	100	440	11400
LMW 600	18	300	500	14100
BWC 1500	18	300	380	14300
sistema sin aerogenerador		1000	440	14700

Tabla 3. Resultados obtenidos en la simulación.

Por ejemplo se puede ver que si se quiere disminuir el impacto visual de tener el eologenerador a 18 m y ponerlo a 12 m con un Whisper 1000 cuenta 1500 U$ adicionales.

Si se quiere eliminar el eologenerador, el costo adicional será respecto a la opción mas económica de 5300 U$.

Es de destacar que los costos listados corresponden al sistema de generación y acumulación, restando para este sistema considerar los costos de instalación eléctrica, protecciones, inversores, bombeo, reguladores, lámparas, luminarias y mano de obra. Estos costos se estudiaron en detalle dando un estimativo de 5500 U$.

4. CONCLUSIONES

El diseño de sistemas híbridos presenta diversos aspectos a tener en cuenta: Sociales, culturales, económicos y ecológicos. El programa Hybrid 95 contribuye en obtener criterios técnicos objetivos para poder evaluar el desempeño de sistemas, permitiendo comparar sistemas diversamente constituidos. Es medular en este sentido la selección de como se mide la calidad de un sistema. y el criterio adoptado de días de energía equivalente deficitaria anual ha resultado ser de muy fácil comprensión gracias al uso de la información en forma estadística mediante histogramas adecuados. Asimismo la visualización gráfica al simular el desempeño del sistema permite acelerar el ajuste del diseño permitiendo rápidamente converger al sistema o matriz paneles-AH a estudiar.
Sin embargo, a los efectos de obtener un sistema ajustado a la necesidad precisa del usuario, es indispensable tener en cuenta muchos otros factores. En este proyecto fueron los factores determinantes los ecológicos y económicos ya que el aspecto sociocultural no presentó dificultades mayores.

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OPTIMAL EXPANSION PLANNING OF STAND-ALONE SYSTEMS WITH STOCHASTIC SIMULATIONS

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ABSTRACT

Stand-alone systems in the range of 1 kW - 10 MW are taking relevance in the new (global) liberal concept of energy market. State and private investors are becoming increasingly attention on the use of renewables for these systems, but it must be shown that this non-conventional solutions are competitive with the established conventional ones. The high investment costs and the technical and economic uncertainties coupled with the use of time-dependent energy sources are the mainly inhibiting factors for the decision agents to choose this systems instead of conventional ones.

In this paper a new model for optimal expansion planning of hybrid stand-alone generating systems under consideration of uncertainties is presented. This model is at present in "development state". Results already obtained in the first steps of this research are promising and some of them are here presented.

1. INTRODUCTION

Normally the expansion planning of conventional generation systems is made over an horizon of 10-15 years [1,8]. As a consequence of the high investment costs and the relatively high life-time of hybrid-systems components (PV-panels, wind and hydric micro turbines - figure 1), this planning process should be made over a period longer than 20 years. This long-term planning is thus influenced by *long-term uncertainties* such as:

- error of load-growth forecasts and

- future (uncertain) evolution of interest rates and fuel prices.

Otherwise, there are relevant stochastic variables to be considered as *short-term uncertainties*:

- the use of time-dependent energy sources (TDES) and the correlation appearing when load and generation units with TDES are not dispersed
- the fluctuation of the energy demand and
- the probability of unit fails.

The knowledge of the behavior of this uncertainties and their influence over the final energy costs can assure the achievement of the incorporation of this new concept for energy supply in isolated regions. Through this knowledge it will be possible to assure maximal *quality of energy supply* with minimal *costs and ecological impacts.*

2. OPTIMAL EXPANSION PLANNING

The aim of the expansion planning of a generating system is to find the evolution of the system configuration (sizing) over the planning period [1,16]. This evolution is made in order to meet the corresponding (normally increasingly) power and energy demand. The *optimal expansion plan of an hybrid system* like shown in figure 1 is such, that in a long-term planning horizon (20-30 years) the energy production costs and the ecological impact is minimized, while the reliability of the energy supply is maximized. From this point of view, to find the optimal configuration for a *one-year-horizon* could not be the optimal solution for a *long-term-horizon*. Due to the short and long-term uncertainties (see figure 2), the "expansion planning problem" leads to a "stochastic decision problem", which can be solved by means of a *hierarchical optimization procedure based on stochastic simulations.*

3. HIERARCHICAL OPTIMIZATION

To solve this decision problem the hole period is subdivided into subperiods of 1-5 years. These subperiods are determined in such a way, that for each of them the boundary conditions (i.e. power and energy demand, interest rates, fuel price) have similar behaviors. Thus, each subperiod can be represented by a *reference year*. A number of different system configurations fulfilling the quality and technical restrictions with minimal operating costs, the so called *system variants*, should be found for each reference year.

From this set of variants, one of them should be selected in each reference year, so that the *expansion alternative* built with the selected variants leads to minimal energy production costs and minimal emissions.

It can be recognized, that short-term uncertainties influence the process of evaluation and comparison of variants while long-term uncertainties act on the decision process for building the expansion plan. Thus, the hole problem lets be subdivided into two stages: *evaluation of variants* and *evaluation of alternatives*. This stages are not independent each other, because the optimality of the final solution (the optimal alternative or optimal expansion plan) strong depends on the available set of variants.

3.1 FIRST STAGE: EVALUATION OF SYSTEM VARIANTS

The aim of this first stage is to find a number *N* of variants for each reference year, so that:

- under consideration of:

  the fluctuation of renewable energies and power demand (stochastic variables),
  the correlation between these stochastic variables,
  the probability of unit fails;

- following aims are reached:

  the minimal required loss of load probability is assured,
  the operating cost are minimized,
  the contaminant emissions are minimized or kept under a required value.

In order to do that, for each reference year following tasks should be carried out:

T1- stochastic evaluation of the system to find the wanted operating & reliability values,
T2- selection of a representative number *M* of variants to be compared,
T3- comparison and selection of the best *N* variants for the expansion planning process.

<u>Stochastic Correlated Simulation</u>

Because the possible number of variants to evaluate and even those fulfilling the technical and reliability requirements could be very large, it is necessary to find an efficient way for the evaluation of such systems.

Task **T1** is made for conventional systems through stochastich simulations using probability analysis [1,17,21]. Some extensions of this approach have been made in the last years for including TDES [5-8,19,20]. The main problems to sort are the *commitment of storage units with low autonomy* (lower than a week) and the *avoid of chronological approaches* in order to decrease the computation time without loosing the information of the correlation between TDES and load. In hybrid-systems this last point is of importance, because a suitable combination of different TDES could match the load in an optimal way [10]. For all this reasons a new approach of stochastic simulation was developed in order to manipulate correlated random variables using only probabilistic methods [14]. The so called *stochastic correlated simulation* (SCS) was validated using theoretical and empirical tools, resulting in an expected probability of error of 20% versus 80% for the conventional (uncorrelated) approach [12]. The SCS is schematic presented in figure 3.

A mathematical probabilistic model for the commitment of electrical energy storage units (batteries and water-pumping) with autonomy lower than a week was also developed. This model allows the use of weekly simulation intervals (or greater) for the SCS, without loosing accuracy on the expected values of the reliability indices [13]. The method was validated for a small hybrid-system in the German Alps. Some results of this simulation are presented in figures 5 to 10.

Random Local Search:

Task **T2** is carried out using a special local search randomization algorithm developed for optimal sizing of hybrid-systems [11]. The main idea is to minimize the following objective function:

$$\textbf{OF1} = \textbf{cost of energy production + cost of unserved power and energy}$$

$$= (\,Inv + kc\ C_{(Ef)}\,) + ke\,(EUE + Pdef \cdot LOLP \cdot Tn)\ /\ 2 \qquad (1)$$

The investment costs are calculated using dynamic annuity methods [4,9] and the expected life-time of the components. For the second term the probability function of the unserved power is used. The expected life-time and fuel consumption, and the probability function of the unserved power are results obtained from the SCS for the one-year-horizon simulation. Note that in equation (1) not only the unserved energy is considered but also the maximal unserved power and expected unserved time [22]. The local search is done for several initial conditions, so that a representative part of the solution space is reached. Thus, the optimal and the nearest M-1 suboptimal solutions are chosen.

Probabilistic Multiobjective Analysis:

At least, the comparison of the M selected variants (task **T3**) is made using a combination of probability [22] and multiobjective [3,9] analysis under uncertainties. The aim is to find the best N ($< M$) variants in regard to the uncertainty of the operating costs and the quality of the energy supplied (i.e. reliability and emissions).

To each variant $\mathbf{v}_i$ is given a value a_{ij} as a measure of the disadvantage to choose it in stead of variant $\mathbf{v}_j$. Thus, the *out-ranking-relation matrix* **A** is constructed:

$$\mathbf{A} = \begin{pmatrix} a_{11} & \cdots & a_{1M} \\ \vdots & \ddots & \vdots \\ a_{M1} & \cdots & a_{MM} \end{pmatrix} \qquad \text{with} \quad a_{ij} = 1 - \alpha_{ij} \qquad \text{and} \qquad a_{ii} = 1 + \varepsilon_i$$

for

$$\alpha_{ij} = \Pr(p_j - p_i \geq \Delta\overline{P}_{ij}) \qquad ; \qquad \Delta\overline{P}_{ij} = \left|\overline{P}_i - \overline{P}_j\right|$$

$$\varepsilon_i = \frac{1}{3}\left(\frac{COX_i}{\max\limits_{j\in M}(COX_j)} + \frac{NOX_i}{\max\limits_{j\in M}(NOX_j)} + \frac{SOX_i}{\max\limits_{j\in M}(SOX_j)}\right) \qquad (0 \leq \varepsilon_i \leq 1)$$

By means of a *weight vector* $\mathbf{w} = (w_1, w_2, \cdots, w_M)$ the *preference vector* $\mathbf{g} = (g_1, g_2, \cdots, g_M)$ can be obtained as $\mathbf{g} = \mathbf{A} \cdot \mathbf{w}$ with:

$$g_i = \sum_{j=1}^{M} a_{ij} \cdot w_j \qquad ; \qquad \sum_{j=1}^{M} w_j = 1 \qquad ; \qquad w_j = \frac{Inv_j + kc \cdot C_{(Et)_j}}{\sum\limits_{i=1}^{M} Inv_i + kc \cdot C_{(Et)_i}}$$

Thus, a *preference value* g_i is obtained for each variant $\mathbf{v}_i$, so that best N variants are those with lower values of g_i.

3.2 SECOND STAGE: EVALUATION OF EXPANSION ALTERNATIVES

The aim of this second stage is to find the optimal expansion plan that minimizes the total energy production costs. Because the operating costs of the system variants have intrinsic uncertainties, this stochastic decision problem is solved using concepts from the *Decision Theory* and *Stochastic Dynamic Programming* (SDP) [2,18].

However the *long-term uncertainties* can not be considered in this optimization procedure, because the influence of this uncertainties is reflected on a change of:

- the solution space (due to the error of load-growth forecasts) and

- the energy costs (due to the uncertain evolution of interest rates and fuel prices).

This second stage is then carried out by means of the following tasks:

T4- modeling of the decision problem under uncertainty of operating costs,
T5- solving the decision problem by means of SDP, and
T6- evaluation of the optimal and sub-optimal alternatives in regard to the long-term uncertainties.

Expansion planning as a stochastic decision problem

Figure 4 shows the decision problem and the influence of the uncertainties. It is clear that the long-term uncertainties influence the observation of the decision agent. For the above mentioned reasons, this uncertainties are neglected in the optimization model.

The components of the stochastic dynamic decision problem of figure 4 are:

1. The *state* $\mathbf{z}_k$ at k-th reference year (k = 0, 1, 2, ... R). The state $\mathbf{z}_k$ (for $k > 0$) is the variant $\mathbf{v}_i$ (i = 1, 2, ... N) belonging to the *state space* $\mathbf{Z}_k = \{\mathbf{v}_1, \mathbf{v}_2, \dots \mathbf{v}_N\}$ of the best N variants for the k-th reference year. The *initial state* $\mathbf{z}_0$ is zero (no existing system) or equal to the generating system to be expanded.

2. The *decision* $\mathbf{u}_k$ at time k (k = 0, 1, 2, ... R-1) is the next variant to be selected for expanding the system given by $\mathbf{z}_k$ ($\mathbf{u}_k = \mathbf{z}_{k+1}$). Thus, $\mathbf{u}_k \in \mathbf{Z}_{k+1}$ and the *decision space* is equal to $\mathbf{U}_k = \mathbf{Z}_{k+1}$.

3. The *perturbation* $\mathbf{r}_k$ at time k (k = 0, 1, 2, ... R-1) is the operating cost uncertainty (γ_{OP}) of the next system to be selected ($\mathbf{u}_k$). Thus, $\mathbf{r}_k = \gamma_{OP\,(\mathrm{uk})}$

4. The *objective function* to be minimized is given by the total production costs over the hole planning period:

$$G = E\left[\sum_{k=0}^{R-1} G_{k(z_k, u_k, r_k)} \cdot q^{-k}\right] \rightarrow min$$

The *short-term uncertainties* are represented by the possible deviation of the operating costs to the expected values and can be calculated as follows [15]:

$$\gamma_{OP} = \gamma_{kc} + \left[\gamma_g + \gamma_{def\,0} \cdot (1 - \gamma_g)\right] \cdot (1 - \gamma_{kc}) \qquad (2)$$

The value of the *operating cost uncertainty* given by eq. (2) allows to find the standard deviation of this costs: $\sigma_{OP} = m_{OP} \cdot \gamma_{OP}$. The decision problem is then solved by means of stochastic dynamic programming [2,18].

Sensitivity analysis to evaluate alternatives:

The SDP finds an optimal solution and also sub-optimal ones. In this optimization was not considered the influence of the *long-term uncertainties*. Because they modify the solution space, it is not possible to insert these uncertainties in the optimization procedure. For the above mentioned reasons, the long-term uncertainties are considered attributes of the expansion alternatives. This uncertainties grow with longer planning periods and should be evaluated in order to choose the best alternative (task **T6**).

In order to do that, a sensitivity analysis is done for *the error of load-growth forecasts* and for the "economic factors" (the uncertain evolution of *interest rates* and *fuel prices*).

No matter which mathematical expression is used to describe the load growth ϖ , following relation will be always fulfilled:

$$\varpi_k = 1 + s_k = \frac{E_{L(k)}}{E_{L(k-1)}} \leq 1 + \left(1 + \gamma_L\right) \cdot s_k \qquad (k = 1,2,\cdots) \qquad (3)$$

Using eq. (3) and SCS for each expansion alternative can be found the *critical uncertainty value* $\gamma_{L,\max}$, so that for $\gamma_{L,\max}$ the load grows in such a way that the reliability restrictions cannot be more satisfied. Larger values of $\gamma_{L,\max}$ assure that the alternative is weakly dependent on errors of load-growth forecast.

The *sensitivity* [4,9] of energy production costs to different parameters can be also found:

$$S_L = \frac{G_{(\gamma_{L,\max})} - G_{(\gamma_L = 0)}}{\gamma_{L,\max}}$$: sensitivity to load-growth deviations

$$S_{OM} = \frac{\partial G}{\partial a_{kc}} = \sum_{t=0}^{P-1} OM_t \cdot t \cdot (1 + a_{kc})^{(t-1)} \cdot q^{-t}$$: sensitivity to O&M costs

$S_I = \frac{\partial G}{\partial a_I} = \sum_{k=0}^{R-1} I_k \cdot t_k \cdot (1+a_I)^{(t_k-1)} \cdot q^{-t_k}$: sensitivity to Investment costs

$S_q = -\frac{\partial G}{\partial q} = \sum_{t=1}^{P-1} OM_t \cdot t \cdot q_{(i)}^{-(t+1)} + \sum_{k=1}^{R-1} I_k \cdot t_k \cdot q_{(i)}^{-(t_k+1)}$: sensitivity to interest rates

Thus, from all expansion alternatives proposed A_i, the **optimal expansion plan** will be the *pareto-optimal solution* A_{opt} [3]:

$$A_{opt} = A_i \Big/ d_{(A_i)} = \min_{\forall j}\left[d_{(A_j)}\right]$$

with

$$d_{(A)} = \sqrt{(1-\gamma_{L,\max})^2 + S_L^{\ 2} + S_{OM}^{\ 2} + S_I^{\ 2} + S_q^{\ 2}} \qquad (4)$$

Note that a different number of parameters can be considered in eq. (4) for finding the optimal solution.

4. STATE OF THE RESEARCH

This complex optimization problem is at present not complete implemented as a computational tool. Only the first stage of the hierarchical optimization has been implemented.

A great effort has been made in developing the SCS, which is the *heart* of the hole optimization process. The SCS has been successfully implemented in a C++ programmed computational tool (ARIADNA System 2.0) and validated with measured data. This tool allows stochastic correlated simulation of wind, photovoltaic and micro-hydro generators, secondary storage units (electrochemical and water-pumping) and diesel generators. For input data of temperature and primary energies (solar radiation, wind and water flows) the program accepts either hourly times series or probability functions. The load demand can be given by hourly times series, probability functions and also daily typical curves with weekly max. and min. values.

By means of this tool a small stand-alone system in the German Alps was simulated: the *Rotwandhaus*, which consists of a 5 kW PV-unit, a 20 kW Wind turbine, a 30 kW Diesel-unit, and a 66 kWh electrochemical storage unit, with a (maximal) daily load demand of 64 kWh. This test-system was chosen because:

1. it is a small hybrid system with high correlation between TDES and load,

2. there exists a reliable set of intensive measurements of TDES and energy flows,
3. there is a strong dependence between energy supplied for unconventional units and storage.

The system was simulated for a one-year-horizon using intervals greater or equal than a day. Note that the storage unit has **daily autonomy**. Results obtained using SCS show high accuracy for the reliability indices, even for very large periods in the annual simulations (see figures 5 to 10). For very large periods (compared with the battery capacity) the probability distribution of the state of charge becomes inaccurate (see fig. 5) but the total energy transfer remains with lower errors (see fig. 6). Thus, when no optimization of such storage units is needed to minimize operating costs, greater periods of simulation can be chosen in order to accelerate the computation without significant errors in the remaining indices. Particularly the expected value of the energy generated with the diesel E_t -basis for the calculation of the operating costs- remains independent of the simulation intervals (fig. 7). For weekly simulation intervals *all results are obtained with high accuracy*.

5. CONCLUSIONS

From the experimental side, the results already obtained with SCS are promising, since this methodology allows the accurate and efficient realization of the complex optimization procedure here presented.

From the theoretical approach, some interesting results have been obtained. For example the mathematical formulation of the decision problem with stochastic dynamic programming shows, that the simplification of the stochastic problem to a deterministic is equivalent to consider that the uncertainties of the operating costs are **dependent stochastic variables** and this fact leads to a (theoretical) *non-optimal solution* [15]. It is also an interesting result the formulation of the planning process for an undefined planning horizon ($P \to \infty$), which allows to find an *optimal decision strategy with independence of the time*: the so called **optimal policy**.

Also the different methodologies for comparison and evaluation of hybrid generation systems are new proposals, which can be implemented in diverse instances of the optimal operation and planning processes.

Next steps are the computational implementation of the developed methodology and the validation with real systems in different ranges of installed power and capacity.

6. ACKNOWLEDGMENTS

The author wishes to thank the Fraunhofer Institute for Solar Energy Systems for supporting this research.

Symbols

kc : specific fuel price [$/lt.]
ke : cost of unserved energy [typically: 1 - 1.5 $/kWh]
Inv : annualized investment costs
OM_t : annual operating & maintenance (O&M) costs for the t-th year
I_k : investment costs for the k-th reference year
G_k : total costs (operation, maintenance and investments) for the k-th ref. year
$C_{(Et)}$: fuel [lt.] of diesel generators required to generate Et [kWh] in one year
Et : expected generating energy from diesel generators [kWh]
E_{um} : energy transfer from and to storage units
E_L : annual energy load for the k-th reference year
$E_{def.i}$: expected unserved energy after commitment of the i-th diesel generator
EUE : expected unserved energy [kWh]
$Pdef$: maximal unserved power [kW]
$P_{def.i}$: expected unserved power after commitment of the i-th diesel generator
p_i , $\overline{P_i}$: instantaneous and expected unserved power of variant $\mathbf{v}_i$
$LOLP$: loss of load probability
$\Pr(p > x)$: probability that the random variable p is greater than a value x
COX_i : emissions of CO_2 for variant $\mathbf{v}_i$ (Kg / year)
NOX_i : emissions of NO_x for variant $\mathbf{v}_i$ (Kg / year)
SOX_i : emissions of SO_2 for variant $\mathbf{v}_i$ (Kg / year)
N_T : number of diesel generators
N_S : number of storage units
P , R : number of years and reference years of the planning period
Tn : one year (8760 hours)
t_k : cumulative years up to the k-th reference year
ν : stochastic availability
s_k : load growth rate (time dependent) for the k-th reference year
$q = (1 + i)$: interest factor (i = interest rate)
a_{kc} , a_I : rate of variation of fuel and investment costs
m_x , σ_x : expected value and standard deviation of the variable x
$\gamma_I = \frac{\Delta s_k}{s_k}$: load-growth uncertainty (time independent)

$$\gamma_{kc} = \frac{\sigma_{kc}}{m_{kc}} \quad ; \quad \gamma_{def} = \frac{\sigma_{def}}{\overline{P}_{def}}$$: fuel price and deficit (unserved power)

uncertainty

$$\gamma_g = \frac{4}{N_T + N_S}\left(\sum_{i=1}^{N_T}\frac{(1-v_i)\cdot E_{t,i}}{E_{def,i}} + \sum_{i=1}^{N_S}\frac{(1-v_{s,i})\cdot E_{um,i}}{E_{def,0}}\right)$$: generation uncertainty

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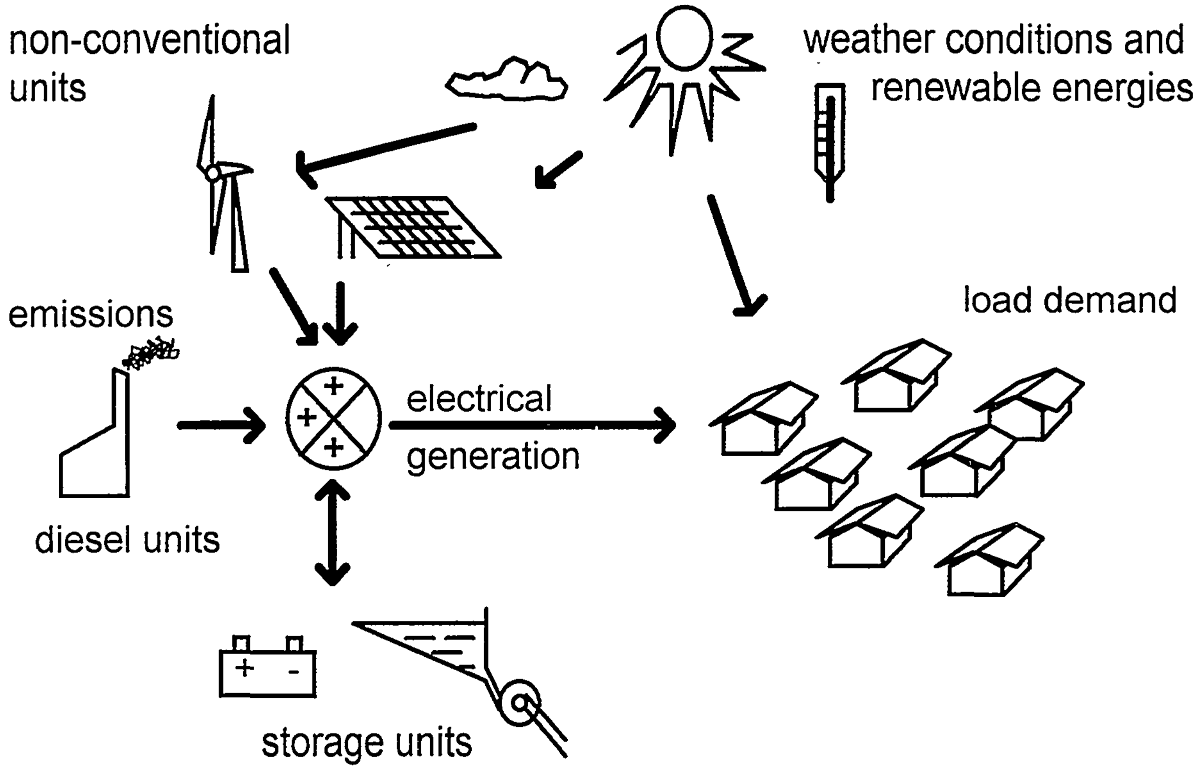

Fig. 1 Stand alone hybrid generation system

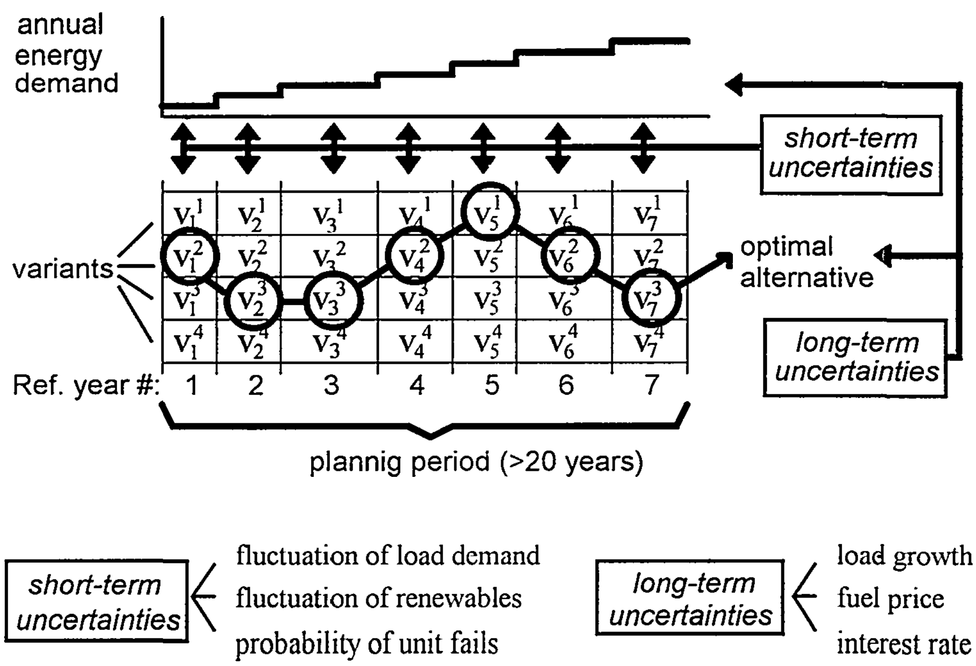

Fig.2 Expansion planning under uncertainties

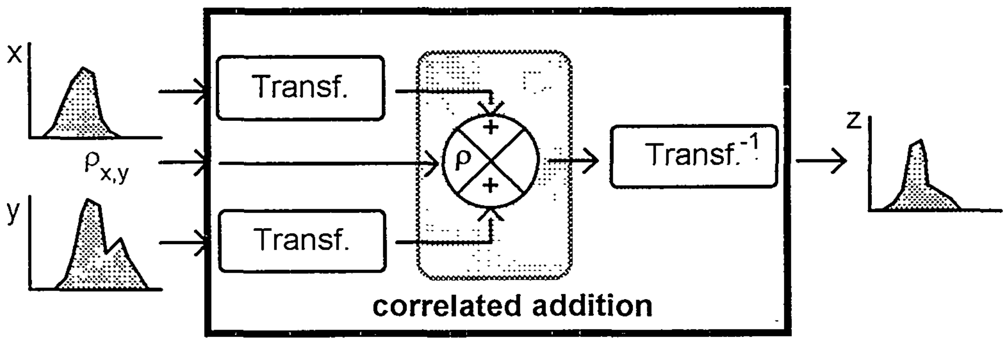

Fig. 3 - Correlated addition of random variables by means of a special transformation.

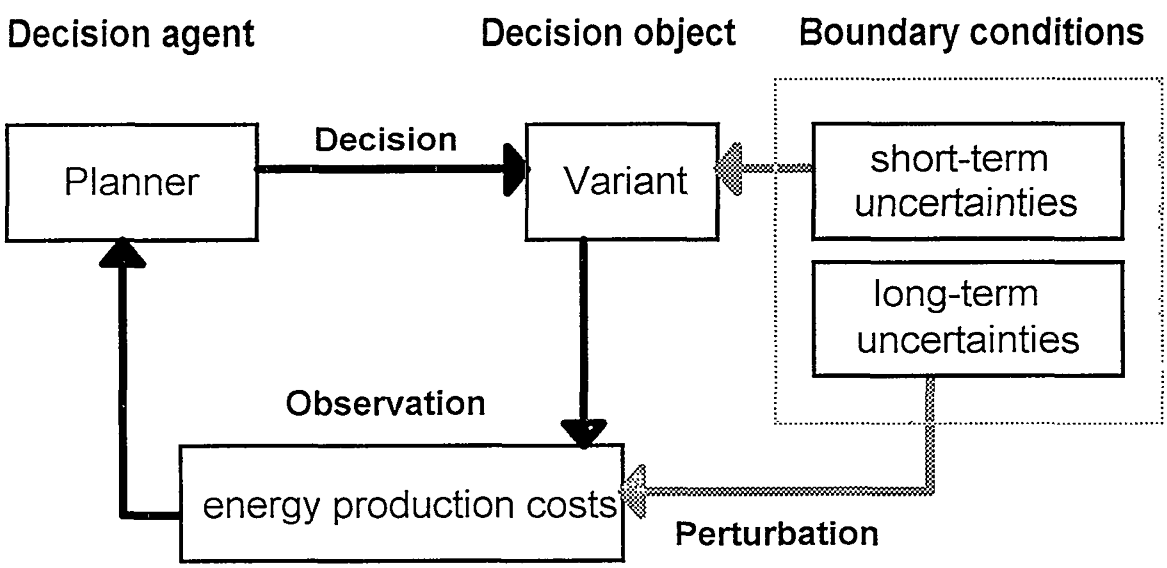

Fig. 4 - Expansion planning process modeled as a stochastic dynamic decision problem.

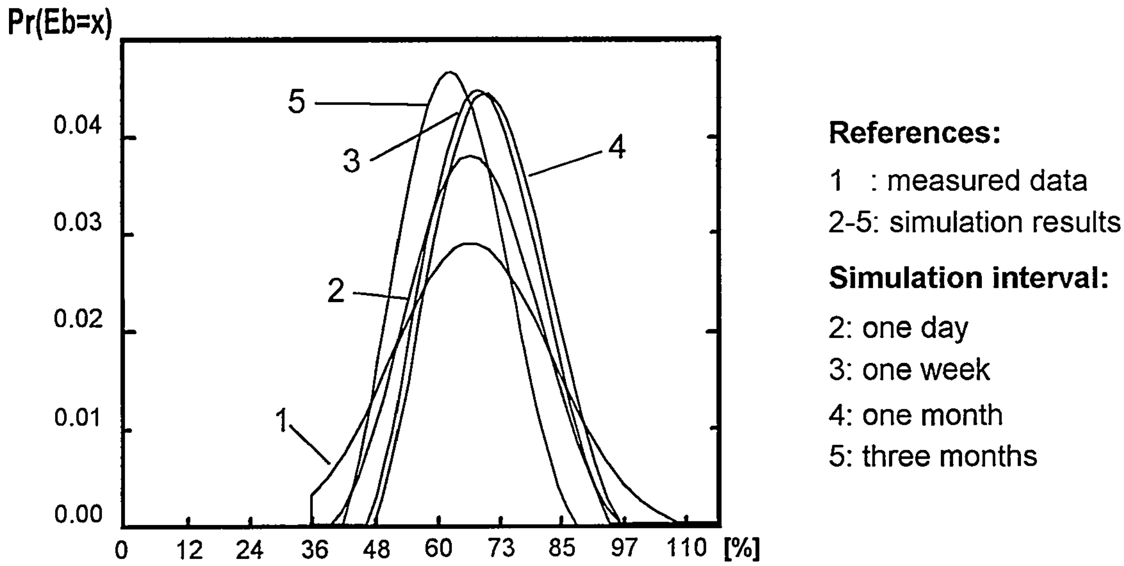

Fig. 5 - Probability function of the battery state of charge

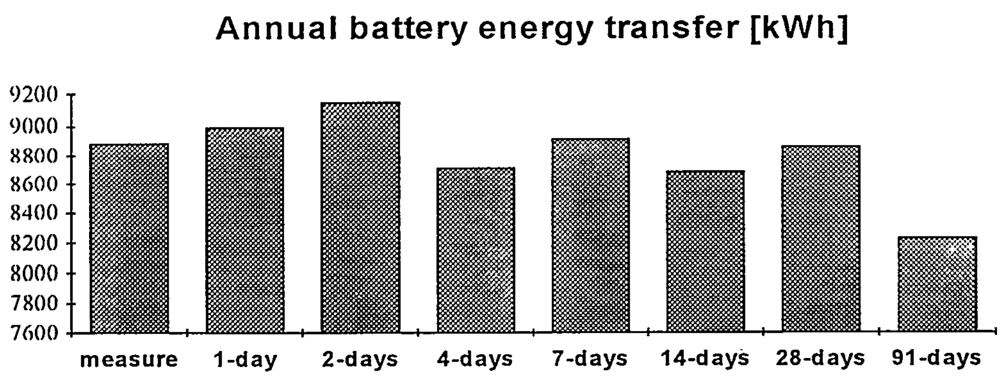

Fig. 6 - Expected energy transfer for different simulation intervals

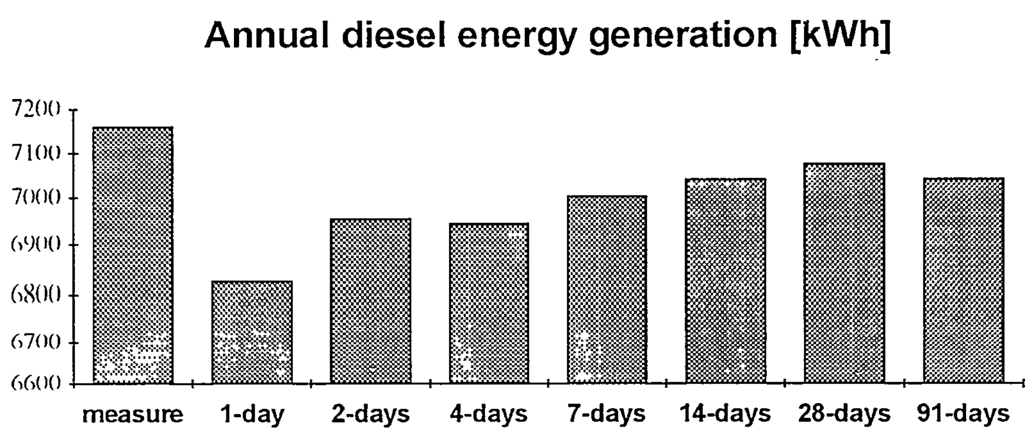

Fig. 7 - Expected energy generation for different simulation intervals

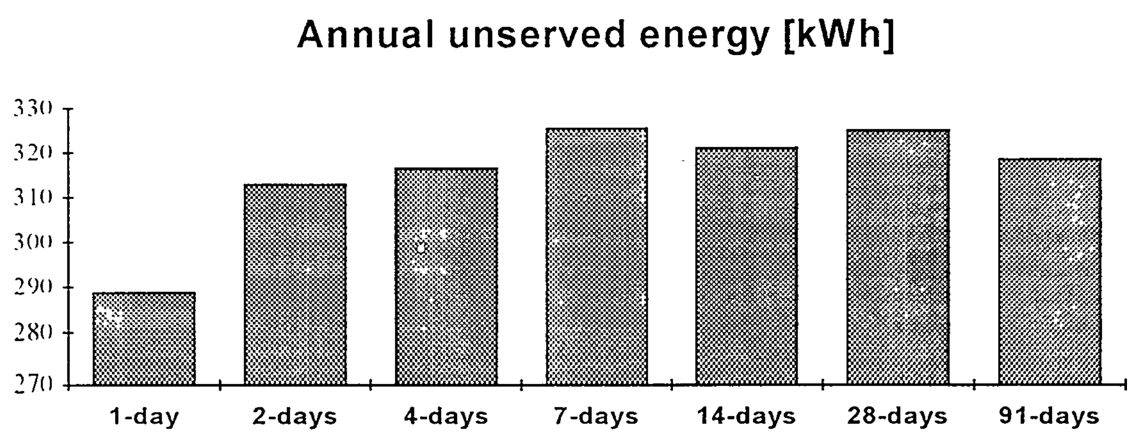

Fig. 8 - Expected unserved energy for different simulation intervals.

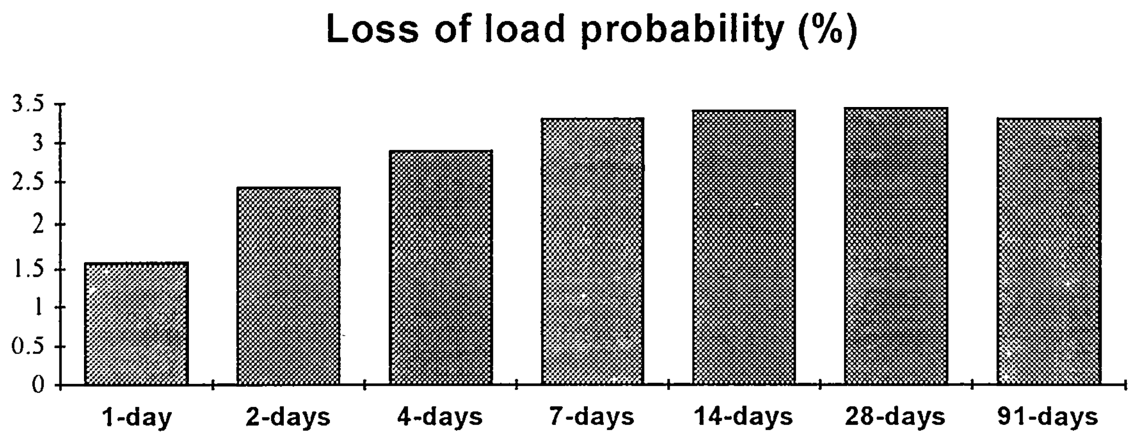

Fig. 9 - Expected LOLP for different simulation intervals

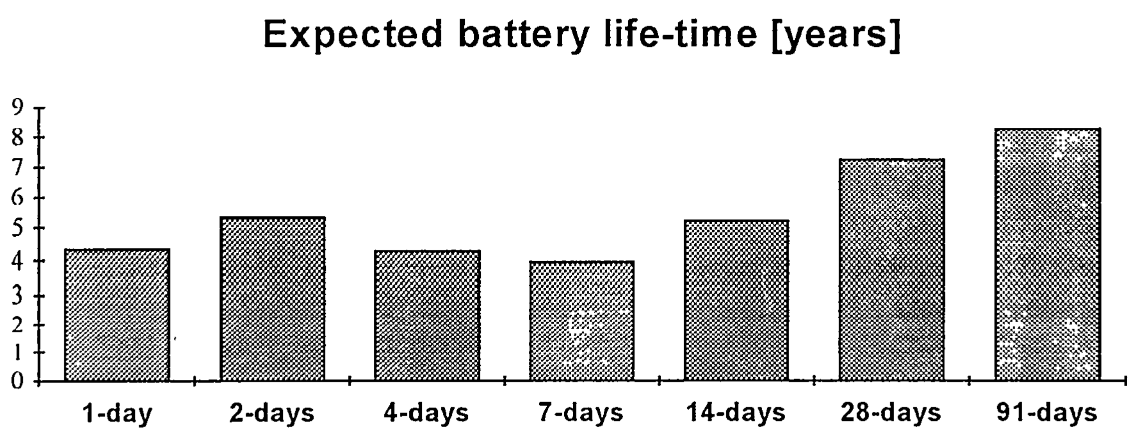

Fig. 10 - Expected battery life-time for different simulation intervals.

RESOURCE CHARACTERIZATION FOR HYBRID POWER SYSTEMS

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ABSTRACT

Assessment of available renewable energy resources plays an important role in the deployment of all renewable energy technologies. In particular, it is critical to the success of hybrid power systems, which draw typically upon two or more renewable energy technologies. Selection of the most appropriate temporal and spatial scales for resource characterization may be the result of considering many, often competing, criteria. For example, an assessment that achieves the desired level of uncertainty may be too costly an undertaking compared with the scope of the entire project. If the desired scale of resource analysis is site-specific to an area where regional assessments are sparse, it may be necessary to acquire data that are essentially unavailable without launching an unacceptably costly and lengthy resource measurement program.

While local-scale assessment can be key in verifying resources which are predicted to exist at a particular site, the focus of this paper is on the regional-scale characterization of renewable energy resources, a scale that can be valuable in "prospecting" for hybrid system deployment opportunities. Compelling reasons to invest time in regional-scale resource characterization include facilitation of feasibility studies and performance prediction analyses, evaluation of resources in the context of other geospatial information that could influence projects such as demographics, political boundaries, transmission grid, topography, etc., and reduction in the time needed to build investor or project partner confidence in a renewable energy project. Simply put, a cost-effective characterization of renewable energy resources can improve the prospects for project success.

At NREL, we have been tackling the problem of resource characterization for nearly two decades. During 1995, we began developing an automated wind mapping technique for regional-scale assessments using Geographic Information Systems (GIS) software. Previous to that time, we employed wind mapping techniques that were limited by labor-intensive, often subjective analysis methods. Because the distribution of the wind resource for a particular region depends on topographic variation, maps were hand-drawn to account for features such as ridge crests, elevated plateaus, and coastal areas. Our computer mapping technique substantially increases the objectivity

SITE CHARACTERIZATION FOR HYBRID SYSTEM CONSTRUCTION

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ABSTRACT

The basic reason to use alternative systems for electricity generation, in most cases, is the lack of electricity services, such as isolated rural communities which are located far away from the electric distribution line, and the cost of its extension is too expensive, while decentralized power systems can be an economic and appropriate solution to providing these services.

Up to now there are several technological options for rural electrification using PV modules, windplants, water-powerplants, anaerobic digesters, or a combination of some of them, according to the availability of energetic resources. The applications include centralized or decentralized systems, autonomous or hybrid systems, isolated or interconnected to the electric line, etc.

A particular hybrid system design can be done considering two general aspects, first it is necessary to know the electric consumption that will be supplied, taking into account present and future necessities and how local energetic resources are present in a selected site. Finally, also it is necessary to carry out an economic analysis to determine the cost of kilowatt-hour generated using local energetic resources and compare it with the cost of electricity produced by conventional power systems.

1. INTRODUCTION

The electrical generation by a hybrid system represents a technological combination that can be in some cases a suitable solution for the lack of electricity. In Mexico there are many communities without electrical service where exists the possibility to harness local energetic resources like solar, wind, biomass or small waterfalls.

The configuration of a hybrid system depends on the availability of the local resources. To decide on the system configuration it is necessary to identify all possible

There are some examples of the use of these kind of systems all over the country, nevertheless some of them were not successful due the deficiency of correct preliminary studies. These studies must include socio-economic factors, the potential consumptions of electricity and availability of local energetic resources.

2. EVALUATION OF SITE CHARACTERISTICS

2.1 Evaluation of electric consumptions

The basic needs for inhabitants of communities located in remote rural areas which do not have access to electricity are: lighting, water supply, health services, education, communication and entertainment.

To evaluate the electricity needs it is necessary to take into account:

- Number of houses
  - i) Number of inhabitants per house
  - ii) Number of rooms
- Dispersion of the houses
- Availability of services (schools, roads, health care, churchs, public halls, powerplants, etc.)
- Distance from possible water supplies to storage tanks
- Services and/or activities that can be promoted with the use of electricity

Other important factors are:

- Access to the site
- Distance to the nearest electricity distribution circuit
- Distances to state roads and commercial centers
- Verification of existence of governmental programs of electrification or introduction of other kind of services (communication, education, health care, etc.)

2.2 Evaluation of energy resources

In order to evaluate the local energetic resources at a selected site, it is necessary for the cases of solar and wind energies, to carry out a measurement and/or an inventory program, to determine the amount of solar radiation received and the distribution of wind speeds and directions, and their degree of complementarity. Another way can be to use models to estimate the frequency of wind speeds and levels of solar radiation. In the appendix some theoretical distributions to estimate the wind and solar resources are described, although it is necessary to have some knowledge of these resources, maximum solar radiation received, maximum wind speeds, windy periods, and type of circulation developed at the site.

In order to evaluate other local energetic resource such as biomass and waterfalls in the appendix some simple cases are presented.

3. CONCLUSIONS

A solution to fight the poverty at isolated rural communities is to promote local productive activities using local power supplies.

The use of a hybrid system using renewable sources of energy depends on the availability of these resources and of course of the cost of energy that is possible to produce. It is necessary to make previous studies focused to evaluate the demands of electricity and to establish a variety of reliable solutions, in order to choose the most convenient considering the real benefits for the community. It is necessary to consider too that a hybrid system must be designed case by case, taking into account that in some cases the best solution is not that which its cost is lower. This latter assumption considers for example other associate aspects just as countryside care, diminution of pollutant emissions, etc. These considerations are very difficult to take into account in a common economical analysis.

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APPENDIX

A.1 The Weibull distribution

The Weibull distribution can be described using two parameters; k called "shape parameter" and c called "scale parameter". The probability density function is

$$f(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} \exp\left(-\left(\frac{u}{c}\right)^{k}\right) \; ; \quad (k > 0, u > 0, c > 1)$$

where

u is the wind velocity, m/s

The cumulative density function is

$$F(u) = 1 - \exp\left(-\left(\frac{u}{c}\right)^{k}\right)$$

A.2 The Normal distribution

The normal distribution also called Gaussian distribution depends on the mean and the standard deviation. The probability density function is

$$f(u) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(u-\overline{u})^2}{2\sigma^2}\right) \; ; \quad (-\infty < u < \infty)$$

where

$\overline{u}$ is the mean wind velocity, m/s

σ is the standard deviation, m/s

When the random variable u is expressed in terms of standard units:

$$t = \frac{(u - \overline{u})}{\sigma}$$

then equation for the probability density function turn into the standard form

$$f\,(t) = \frac{1}{\sqrt{2\pi}}\,\exp\,(-\frac{t^2}{2})$$

A.3 The Rayleigh distribution

The Rayleigh probability density function is a special case of the Weibull function when the shape parameter k=2. Thus, the Rayleigh distribution only depends on the mean windspeed. If k=2 is used in the Weibull function the following expression is obtained for the Rayleigh probability density function

$$f\,(u) = (\frac{2\,u}{c^{\,2}})\,\exp\,(-(\frac{u}{c})^2)$$

A.4 Estimation of the instantaneous solar radiation on the earth surface

The instantaneous global solar radiation $\overline{G}$, is the total amount of radiation received on a horizontal per unit of area and unit of time, and it can be estimated with the following expression:

$$\overline{G} = \overline{G_m}\,\cos^{\alpha}\,(180\,\frac{\theta}{N})$$

where

$\overline{G_m}$ is the mean maximum global radiation received per month at noon

α is an empiric exponent. For the global radiation its mean value is 1.2 and for the direct radiation is 1.5

θ is the true solar hour of the day, measured from the noon, it is positive during the morning and negative in the afternoon

$$N = \frac{2h_s}{15}$$

N is the duration of the solar day and h_s in the hourly angle at dawn.

To calculate N it is necessary to know h_s , this is possible using the following expression:

$$h_s = \cos^{-1} (-tg\,\phi\; tg\,\delta)$$

where

ϕ is the latitude

δ is the solar declination

Solar declination can be obtained from

$$\delta = 23.45 \sin (360 \frac{284+n}{365})$$

n is the Julian day (n=1, 2, ..., 365).

A.5 Anaerobic digesters

Human excreta, animal manures, garbage, wastes of raw materials and sewage can be digested under suitable conditions, resulting in the production of bio-gas and fertilizer.

A digester is a container which holds organic wastes in a manner which allows natural bacterial degradation of the organic matter to occur in the absence of oxygen. This process produces bio-gas, sludge and effluents, both excellent fertilizing materials.

Bio-gas consists of methane mixed with carbon dioxide, approximately two parts methane to one part carbon dioxide by volume, and with very small additional amounts of oxygen, nitrogen, hydrogen, carbon monoxide and hydrogen sulfide. Any appliance that runs on natural gas, which is primarily methane, runs well on bio-gas. Butane and Propane appliances also have been run on bio-gas, and it can be used to operate steam and internal-combustion engines, both of which can operate electrical generators.

Tables A.1 and A.2 can be used to get a rough idea of the potential production of bio-gas (60 percent methane and 40 percent carbon dioxide).

Table A.1.- Gas production as a function of volatile solids

Material	Proportion (%)	ft^3 of gas[a]	Methane content of gas
Chicken manure	100	5.0	59.8
Chicken manure & paper pulp	31/69	7.8	60.0
Chicken manure & newspaper	50/50	4.1	66.1
Chicken manure & grass clippings	50/50	5.9	68.1
Steer manure	100	1.4	65.2
Steer manure & grass clippings	50/50	4.3	51.1
Steer manure & chicken manure	50/50	3.4	61.9
Steer manure & sewage sludge	50/50	5.0	63.9
Grass clippings & sewage sludge	50/50	7.8	69.5
White fir (wood) & sewage sludge	10/90	9.3	68.9
White fir (wood) & sewage sludge	60/40	4.3	69.7
Newspaper & sewage sludge	10/90	9.9	67.1
Newspaper & sewage sludge	20/80	8.8	69.0
Newspaper & sewage sludge	30/70	7.5	69.5

Note: Per pound of volatile solids (VS) added.

Table A.2.- Gas production as a function of total solid

Material	Bio-gas (ft^3)[a]
Pig manure	6.0-8.0
Cow manure	3.1-4.7
Chicken manure	6.0-13.2
Conventional sewage	6.0-9.0

Note: Per pound of total solids (TS) added.

A.6 Energy from water

A stream contains two forms of energy: by virtue of its velocity, it has kinetic energy; and by virtue of its elevation it contains potential energy. The kinetic energy in most streams is not great enough to be useful; it is the potential energy between two sites of differing elevations that is more convenient to exploit. The idea is to divert some of the water from a site upstream, transport it along an elevated conduit, and then let it fall through a waterwheel or hydraulic turbine located at a lower elevation downstream. The turbine (or waterwheel) turns a generator which produces electricity. The water then returns to the stream.

In a powerplant installation the central structure is the dam which causes the stream to back up, creating a pond or reservoir to store energy and elevate the surface of the water (which increases the obtainable power). The dam may include a spillway, which allows the stream to overflow when the pond is full, thus protecting the dam from overtopping floods.

Water can be transported from the dam to a waterwheel or a turbine in an open channel and/or in a pressure conduit called penstock. The power house (where the electricity is generated) may be either next to the dam, or further downstream. In the latter case, more power can be developed since the water drops further, but the increase in conduit distance is costly and some energy is lost in the conduits themselves.

The amount of power obtainable from a stream is proportional to the rate at which the water flows and the vertical distance which the water drops (called the head).

The basic formula is:

$$P = \frac{Q\,H\,e}{11.8} = \frac{A\,V\,H\,e}{11.8}$$

where

P	is the power obtained from the stream, kW
Q	is the flow of water, ft^3/s
A	is the average cross-sectional area of the stream, ft^2
V	is the average velocity of the stream, ft/s
H	is the height the water falls (head), ft
11.8	is a constant which accounts for the density of water end the conversion from ft-lb/s to kW
e	is the overall conversion efficiency

A.7 Methodology to evaluate the leveled cost of electricity generation using hybrid systems

The leveled cost of generation (LCG) is a way to evaluate the yield of a project, this method takes into account the value of the money in the time. The LCG is an indicating that synthesizes the economic information available regarding a project. Its value express the mean cost of the energy produced and it is useful to compare two or more generation systems.

Some economic parameters that must be considered to evaluate the LCG are: initial capital investment, O&M cost, fuel cost, retrofit cost, salvage value, installed capacity, plant factor, economic lifetime and discount rate. The costs during the lifetime of the project, normally are obtained from fabricants and dealers quotations; the salvage value for small hybrid systems is neglected; the installed capacity depends on the demand and design characteristics; the capacity factor depends on the availability of natural energetic resources in the installation zone; the economic lifetime is estimated on 20 years and the discount rate on 10 %.

$$LCG = \frac{NPV_C}{NPV_{EP}}$$

where

NPV_C	is the net present value of costs
NPV_{EP}	is the net present value of electricity production

The net present of costs and electricity production fulfill the following expressions:

$$NPV = S_0 + \sum_{t=1}^{n} \frac{S_t}{(1+i)^t}$$

where

S_0	is the initial investment
S_t	are the expenses at the period t
n	is the economic lifetime
i	is the discount rate

S_t includes operation and maintenance costs, fuel costs and equipment replacement at period t.

The net present value of electricity production is calculated using the following expression:

$$NPV_{EP} = \sum_{t=1}^{n} \frac{EP_t}{(1+i)^t}$$

where

EP_t is the electricity production at period t obtained from the product of rated power and plant factor.

Previous analysis can be used to evaluate a generation system, in which participates just one technology, in the case of a hybrid system the expressions change as follows:

$$NPV_c = \sum_{\beta=1}^{m} S_{0,\beta} + \sum_{t=1}^{n} \left(\frac{\sum_{\beta=1}^{m} S_{t,\beta}}{1 + i^t} \right)$$

where

$S_{0,\beta}$ are the inversion costs for each one of the technologies used in the system

$S_{t,\beta}$ are cost per period for each technology

m technologies that participate in the hybrid system

The production net present value by means of a hybrid system can be expressed by:

$$NPV_{EP} = \sum_{t=1}^{n} \left(\frac{\sum_{\beta=1}^{m} EP_{i,\beta}}{(1 + i)^t} \right)$$

Thus the LCG por hybrid systems can be expressed using the following expression:

$$LCG = \frac{\sum_{\beta=1}^{m} S_{0,\beta} + \sum_{t=1}^{n} \left(\frac{\sum_{\beta=1}^{m} S_{t,\beta}}{(1+i)^{t}} \right)}{\sum_{t=1}^{n} \left(\frac{\sum_{\beta=1}^{m} EP_{t,\beta}}{(1+i)^{t}} \right)}$$

OPERATIONAL PERFORMANCE OF THE AVISPA-IIE WIND GENERATOR IN MICROHYBRID SYSTEMS

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ABSTRACT

The purpose of this paper is to make a general analysis over the operational performance of the Avispa-IIE wind generator in an Solar-Eolic hybrid installation, at an eco-tourist resort. This work was performed through the monitor of the wind generator and the system itself throughout a year, for the acquisition taking the variables of interest and operational parameters that might allow to characterize and to evaluate the general behavior of the system. Herein are the principals characteristics of the wind generator; its performance curve, the basic configuration of the installation and the control philosophy; Likewise, some technical and human problems which arise during the operation of the system are included, the implementation of improvements in the wind generator and the general results acquired during the time of operation of the wind generator in the cited installations.

1. INTRODUCTION

In December of 1995 the installation of twelve microhybrid systems in the eco-tourist resort "Villas Carrousel" was carried out, these systems (to 12 VCD) are conformed basically by a Avispa-IIE wind generator, a group of fotovoltaic panels, a lead-acid battery bank and an electronic control. The load connected to the systems are high efficiency type PL lamps, which provide the interior illumination required in each one of the villas. Due to lack of space and the hotel arquitecture, the wind generators were placed in line in the high part of the construction, over self supported tubular towers and anchored to the burden walls, to offer a common front to resist the dominant winds of the place. The installation highness oscillates between the 15.3 and 16.5 m. (in towers of 3.5 and 5.9 meters) and the lateral separation between wind generators is of approximately 6.5 m. (5 m. the nearest [1]). These systems were dimensioned for a load of 132 and 155 Ah/day in versions A and B; adding a fotovoltaic panel over 75 Wp to the version B. The battery bank capacity is of 570 Ah (2-3 days of autonomy) per system. The electronic control realize the functions of connection and disconnection of the wind generator, the fotovoltaics modules and the load, in accordance with the state of charge of the battery bank; Through an algorithm and that senses the voltage at the terminals of the battery bank.

2. CHARACTERISTICS OF THE AVISPA-IIE WIND GENERATOR

The wind generator "Avispa" is a wind energy conversor system developed by Instituto de Investigaciones Electricas, with a nominal power of 500w at 12 VCD; It is a high-yield equipment, elaborated by optimized manufacturer procedures and specifically developed to contribute and or to satisfy electrification needs between the low consumption load, for applications in isolated places where the eolic resource exists.

The appropriate places for the installation of the wind generator "Avispa" are those whose annual media velocity speed is of 4 meters per second (approximately 15 km/h) or higher.

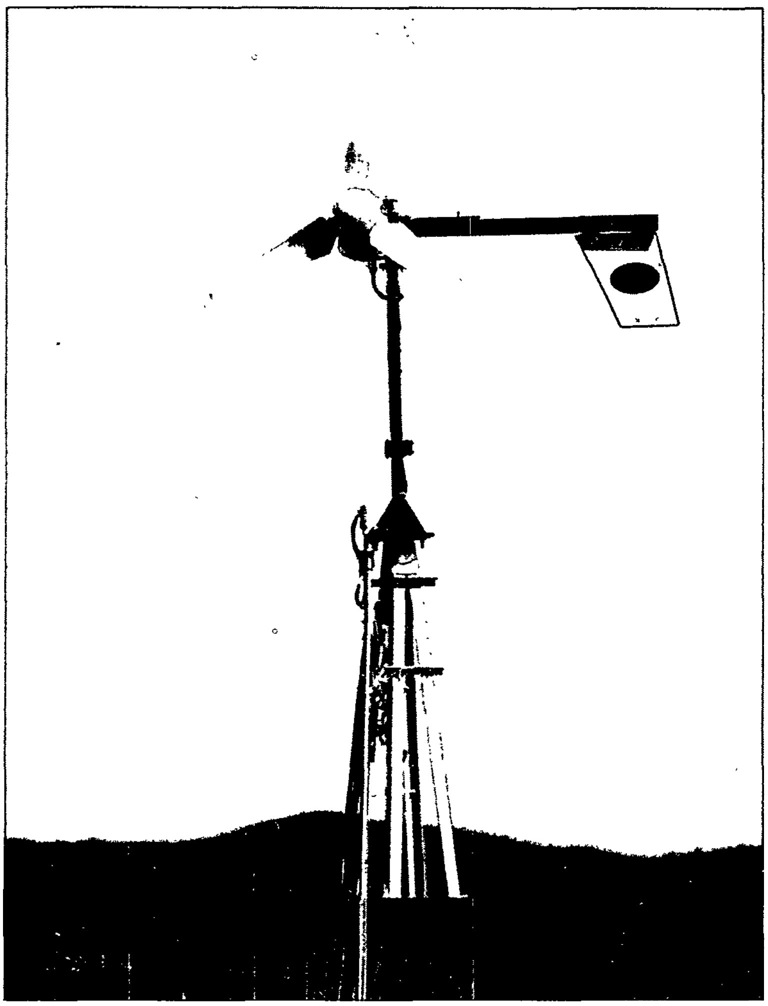
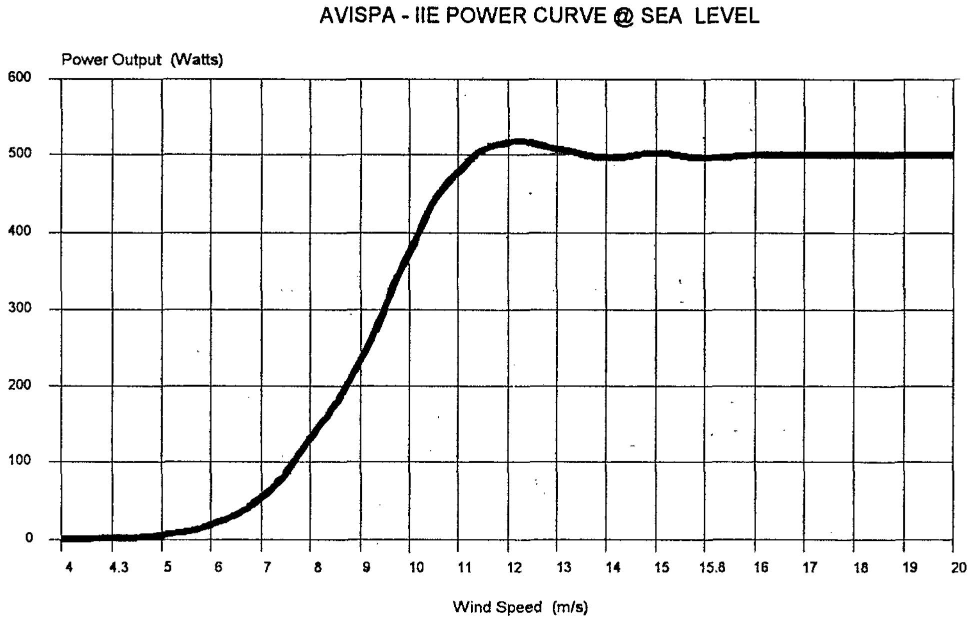


Fig. 1 Avispa-IIE wind generator

This wind generator (figure 1) is a conversor system with an horizontal axis with a wind up orientation, a three blades of fixed pass, variable speed, with a speed design of 11.5 m/s for 500 w. of nominal power; Configured with a transmission relation 1:2.5 and a automotive type trifasic alternator, with 75 amp. nominal capacity and exit voltage of 14 VCD. The wind generator is provide with an orientation system and a control speed based in a lateral tail rudder of an articulate vane and, a shut down mechanism through devices for braked manual-automatic rotor (mechanical and/or electric) in combination with a total deject lateral orientation rudder. To protect the machine is provided with mechanisms that, acting over the orientation system, it protects the system against excessive vibration, angular rotor overspeed and wind overspeed; Likewise, the design provide means to realize the automatic control shut down of the machine, from the control electric board to protect the battery bank against overload. The wind generator can be interconnected to a battery bank to integrate a system of isolate generation and/or in a hybrid configuration. The main characteristics of the wind generator are:

Rated power:	500 watts
Rotor configuration:	3 blades Horizontal axis Up wind
Rotor diameter:	1.80 m.
Blades material:	Reinforced fiber glass
Rated wind speed:	11.5 m/s.
Cut-in wind speed:	3.5 m/s.
Cut-in wind speed of control speed:	11 m/s.
Nominal Lambda:	5
Transmission relation:	2.5
Survival wind speed:	20 m/s
Electric generator:	Automotive type alternator
Orientation system and control speed:	Rudder tail an articulate vane.



3. OPERATIONAL PERFORMANCE

Figure 2 shows the measured performance curve of the wind generator as function of the wind speed, considering an air density of 1.225 kg/m3 (air density at sea level). The curve is obtained by Bins method from 10 minutes averages, measuring wind speed to the highness of the axis of the rotor and, the voltage and power of the wind generator in the battery terminals.

Figure 3 presents an schematic configuration of the hybrid system. This is conformed by the wind generator, the photovoltaics panels, the battery bank, a security general switch for the disconnection of the batteries, the boards of control and protection, and the resistor for the dynamic brake of the wind generator. The electronic control monitors the voltage at the battery terminals and, through an algorithm of voltage and time, performs the functions of connection and disconnection of the wind generator, the photovoltaic panels and/or the load, to avoid conditions of overcharge or overdischarge in the battery bank.

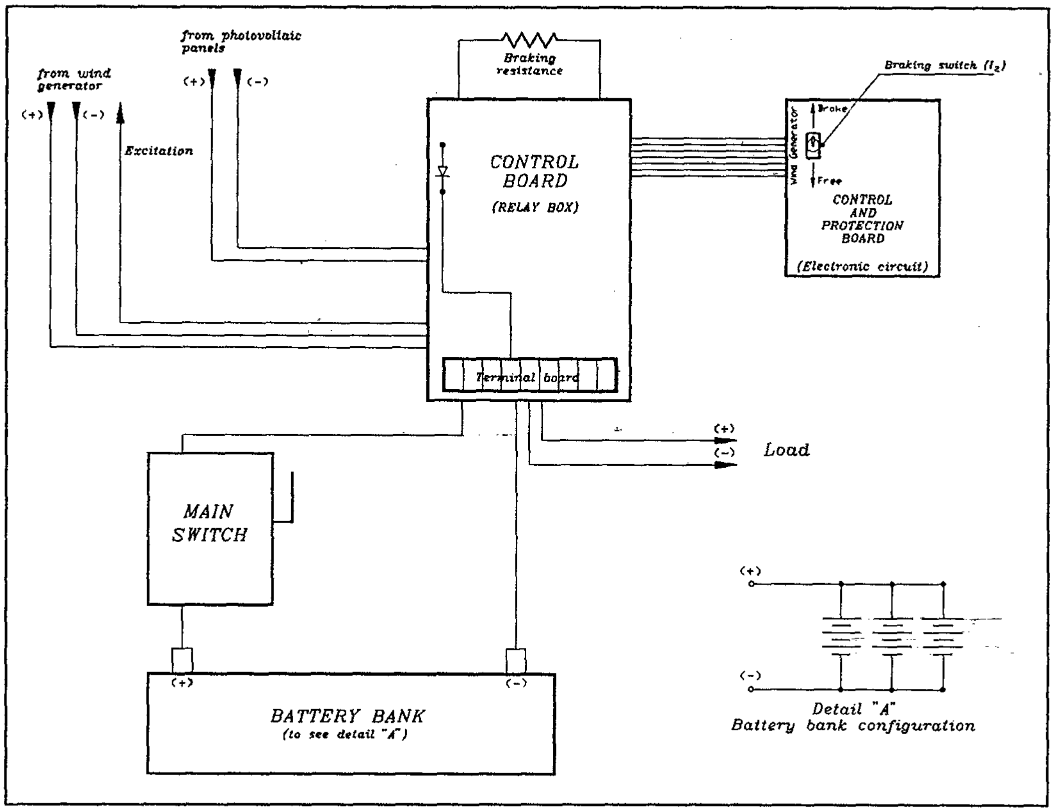


Figure 3. Configuration of the microhybrid system

Table 1 summarizes the information on the wind regime at this place and the energy produced by the wind generator in the hybrid system during the period analyzed. In practice, this energy, may or may not to be utilized depending on the size of the load as determined by electronic charge control.

The overall measured efficiency, defined as the ratio of the useful electric energy (available to supply the load) divided by the energy produced by the wind generator in a given period, is around 70%. This number is valid for a conductor with a voltage drop no larger than 1 V (6% allowed energy lost) at 70% of the nominal generator current, at 12 V DC.

This system efficiency accounts for the energy utilized in the control system the joule losses in the feeders and the efficiency of the battery bank. Variability in the charge and discharge requires is also considered.

This system efficiency is extremely important at the moment of making forecasts of the energy production for a particular place, using local wind data and the characteristic power curve of the wind generator; in order to not over estimating the system and adequately dimention this, to actually satisfy the requirements of each application.

Table 1. Available energy in the wind generator

Month	Wind speed (m/s)	Standard Deviation	$P_{average}$ (watts)	E_{month} (kWh)	Capacity factor (%)	$E_{ave.daily}$ Ah@12V
January	5.73	2.09	53.84	40.06	10.77	107.7
February	5.35	2.28	47.39	32.98	9.48	94.8
March	6.23	2.88	109.82	81.70	21.96	219.6
April	6.51	2.23	90.31	65.02	18.06	180.6
May	6.19	2.56	86.85	64.61	17.37	179.5
June	5.02	2.00	26.40	19.01	5.28	52.8
July	5.74	2.43	66.26	49.30	13.25	132.5
August	5.31	2.72	57.77	42.98	11.55	115.5
September	4.60	2.19	23.12	16.65	4.62	46.2
October	4.57	2.68	43.81	32.59	8.76	87.6
November	5.45	2.80	74.47	53.62	14.89	148.9
December	5.11	2.24	40.14	29.86	8.03	80.3
Average annual	5.48	2.42	60.01	528.38	12.00	120.5

4. INSTALLATION, OPERATION AND MAINTENANCE

The operation of the wind generator Avispa-IIE has been reliable, safe and silent. The wind generator design gives the user a great convenience in the operation. Once installed it will operate in an almost autonomous way, while the wind blows with speeds greater than 3.5 m/s.

During the first year of operation of the wind generators installed at Villas Carrousel, some problems were experimented due to the siting of the machine and the wind direction during certain periods. Strong shading problems arouse, that caused severe oscillations in the machine orientation, with the consequent fatigue of the blades and other elements; This problem was solved decreasing the sensibility of the orientation system, through a frictional element, in conjunction with an additional structural reinforcement of blades.

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BATTERY MONITORING IN MEXICAN HYBRID POWER SYSTEMS

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ABSTRACT

Hybrid power systems for an autonomous power supply are based on different renewable and fossil energy sources. They are considered as a good option for the power supply of remote areas. In these systems an energy storage is a vital necessity and very often this storage will consist of batteries which are generally conected in series and parallel arrays, or both. In Mexico as in other countries, the most extensively use batteries used for this application are the stationary and electric car type deep cycle batteries. However the experience with them in these systems is generally not very good.

One way to overcome this problem is to maintain a regular monitoring or installing monitoring equipment, in order to make preventive actions before a developing fault can have serious consequences and in this manner increase the practical lifetime of the batteries.

Unfortunately, battery bank monitoring is not easy task becuase most of the hybrid power systems are installed in remote areas which makes it difficult and expensive. In Mexico it has been not possible to maintain a regular monitoring of all hybrid power systems instaled, due to the high cost of this work and the lack of founds. The hybrid power systems instaled in the state of Quintana Roo are the only systems that have been continuosly monitored since their installation.

This paper gives an overview of the hybrid power systems instaled in Mexico,focusing in the battery banks, the way they are being monitored, the main parameters used to detect possible premature problems and the method used to evaluate the battery bank conditions. Finally some results from the battery banks monitoring activities are presented.

1. INTRODUCTION

Battery storage is a critical component of renewable energy systems (PV, Wind and Hybrid power systems), especially in stand-alone applications. For these applications lead-acid batteries are the most extensively used type because it is a well known energy storage technology. However in contrast with other applications (electric cars, fork-lifth trucks, uninterruptible power supplies, etc.) batteries usually fail much earlier than expected in these systems, which generally results in total system failure. One manner to reduce this problem is to maintain a continuous monitoring to detect the possible premature problems and carry out corrective actions in order to extend battery's life.

However in Mexico like in others countries the monitoring of these systems is not easy task because most of them are instaled in remote areas which makes it difficult and expensive. This paper gives a generall point of view of the hybrid power systems instaled in Mexico, the principal caracteristics of the battery banks, the way they are monitored, the main parameters used to detected possible premature problems and the method used to evaluate the battery bank conditions. Finally some results derived to from the monitoring of the battery banks are presented.

1.1 Hybrid Power Systems Installed in México

Hybrid power systems for autonomous power supply are based on different renewable and fossil energy sources. They are considerated as a good option for remote areas power supply. In Mexico the installation of hybrid power systems started in 1991 and lastest ones built at the begining of 1996. In all, twenty four hybrid power systems have been instaled.

Most of them have been instaled in the state of Quintana Roo (16 systems), four in the Zacatecas state and one each in Coahuila, the Federal District, Hidalgo and México State. Nine of these systems, supply electricity to rural communities, one supplies electricity to a private house and 15 supply electricity to an eco-tourist resort. Nineteen hybrid systems are of the PV-wind type, three are PV-wind-diesel, one PV-wind-gasoline and one PV-diesel. The main caracteristics of the hybrid systems are shown in table I.

2. BATTERY BANKS CHARACTERISTICS

In all hybrid systems the energy storage is a vital necessity and very often this storage will consist of batteries generally conected in series or parallel arrays. Of the battery storage

Installation Year	Site	Type of System	Installer Company	PV (kW)	Wind (kW)	Diesel (kw)
1991	Nueva Victoria/Coahuila	PV-diesel	CIEDAC	8.700		28.00
1991	Sta. Ma. Magdalena/Hidalgo	PV-wind-diesel	IPC and LyFC	4.320	5.000	18.40
1991	El Oyamello/Distrito Federal	PV-wind-gasoline	INAINE	0.770	5.000	
1992	Xcalak/Quintana Roo	PV-wind-diesel	CONDUMEX	11.200	60.000	125.00
1992	La Gruñidora/Zacatecas	PV-wind	ENTEC	1.200	10.000	
1992	El Calabazal/Zacatecas	PV-wind	ENTEC	0.800	10.000	
1992	I. Allende/Zacatecas	PV-wind	ENTEC	0.800	10.000	
1992	El Junco/Zacatecas	PV-wind	ENTEC	1.600	10.000	
1993	Sn. Antonio Agua Bendita/ Estado de México	PV-wind-diesel	IPC	12.390	20.000	50.00
1995	Playa Paraíso/Quintana Roo	PV-wind (3 systems)	IIE	0.150	0.500	
1995	Playa Paraíso/Quintana Roo	PV-wind (9 systems)	IIE	0.225	0.500	
1997	Playa Paraíso/Quintana Roo	PV-wind (2 systems)	IIE	0.300	0.500	
1997	Playa Paraíso/Quintana Roo	PV-wind (1 system)	IIE	0.320	0.500	

Note: data were from of reference 1.

Table I. Caracteristics of the hybrid power systems instaled in Mexico.

technology which is available, the lead-acid type is the most extensively used for this kind of aplications in Mexico and others countries. In the hybrid systems instaled in Mexico the stationary and electric car deep cycle type are the lead-acid batteries most commonly used. Due to the different generating capacities of the hybrid systems, the battery banks capacities vary from hundred up to thousand of A-H. The voltages most commonly used are 120 V, 220V and 12 V. The caracteristics of the battery banks of the hybrid systems instaled in Mexico areshown in table II.

3. BATTERY BANKS MONITORING

Batteries are one of the most vital parts in all PV and hybrid systems, however the experiences with them, are generally not very good. One way to overcome this problem is to maintain a regular monitoring program, either mannually or installing a monitoring equipment, with the objective to of taking preventive actions before a developing fault can have serious consequences and to increase the practical lifetime of the batteries. In the automatic monitoring, the system performance data are collected and stored by means of a data acquisition system. The data are later retieved via modem or the memories are sent by regular mail for their analysis. However in the manual monitoring, personnel is necessary to make the measurements directly in the field. In the automatic monitoring the variables are measured continuously, while in the manual monitoring the variables must be measured at least once a month. Generally these measurements are made during the charging process of battery banks. The most commonly used parameters utilized for monitoring the battery banks are: voltage, current, temperature and specific gravity measurements (only in vented lead-acid batteries).

In Mexico only 5 hybrid systems are monitored using a data acquisition system and the remaining are monitoring manually. Unfortunately a regular manual monitoring has not been possible to maintain in most of the hybrid systems because the majority of them are instaled in remote areas, a lack of founds, the high transport cost, and the man hours required. Of the several methods existong to know battery bank condition, the one most commonly used in Mexico is by monitoring the state of charge of the battery banks, obtained from measurements of specific gravity. Other parameters like voltage and temperature are commonly used to detect short circuited and reversed polarity cells, in order to optimize the performance of charge controllers.

4. MONITORING RESULTS

In this section results of the monitoring results carried out at differents battery banks of some hydrid systems are presented. As mentioned before, it has not been not possible to maintain a regular monitoring in most of the hybrid systems instaled in Mexico due mainly to the high cost of this activity. Most of the time the inspections carried out to the hybrid systems are made upon request from the users and, generally, this happens mostly when problems have araised. The most common problems found during the inspections of battery banks are: low state of charge, terminals corrosion, dry cells, high temperature of the electrolyte, cells with reverse polarity and poor maintainance.

The figures 1 and 2 shown the specific gravity and voltage values obtained during two inspeccions carried out in 1993 and 1995 to the San Antonio Agua Bendita hybrid system. The states of charge shown in these figures were detected trough specific gravity measurements. It can be seen that in both inspections, the battery banks were found in a low state of charge. This situation may be caused by a low set point value for the load disconnect, an inadequate performance of the charge controller or/and incorrect battery bank sizing. However the exact reason could not be determined due to a lack of battery bank performance history. From both figures it can be infered the need for an equalization charge in order to reduce the marked variations between voltage cells. This important corrective acction could be done more easily in systems that have diesel or gasoline back up generators.

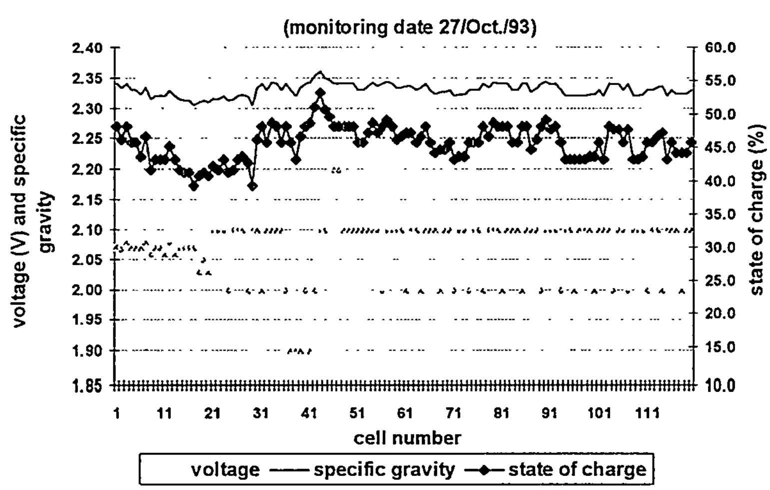

Figure 1. Battery bank conditions found during the inspection carried out on 1993 at Antonio Agua Bendita hybrid system.

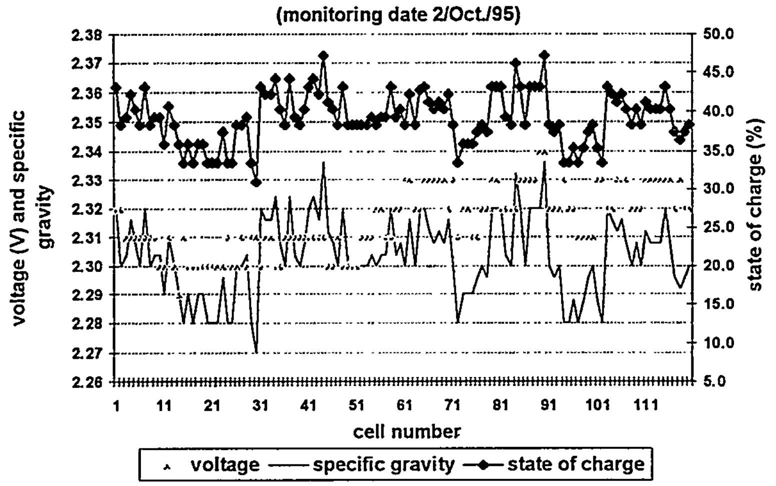

Figure 2. Battery bank conditions found during the inspection carried out on 1996 at San Antonio Aguas Benditas

In the figures 3 and 4 the results obtained during the inspections carried out at Sta. Maria Magdalena hybrid system in 1993 and 1996 are presented. Figure 3 shows the battery conditions during a normal operation day in September 1993, while figure 4 shows the battery bank condition after several months of system inactivity. The system was to inverter and diesel generator problems. At the moment of the last inspection the battery bank had four months without recharge. This situation affects the battery efficiency due to thetransformation of the smaller sulphate crystals into larger crystals, which are difficult to reconvert into reacting material during charge. For this reason the batteries should be recharged as quickly as possible after discharge.

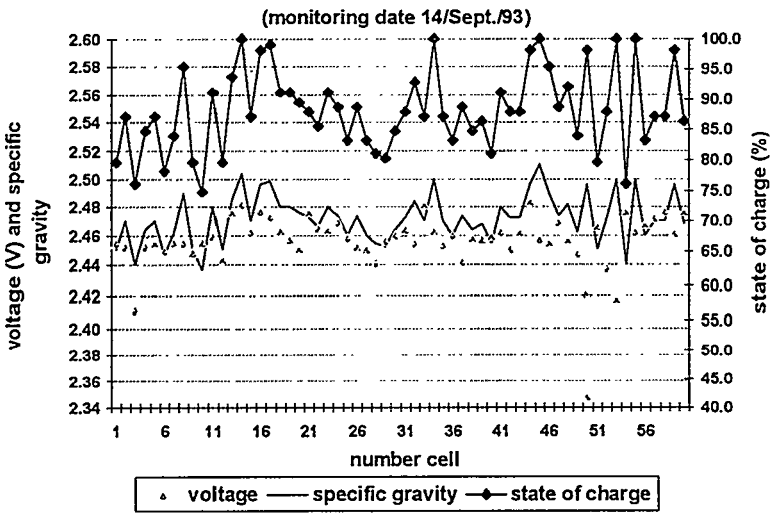

Figure 3. Battery bank conditions found during the inspection carried out on 1993 at Santa María Magdalena hybrid system.

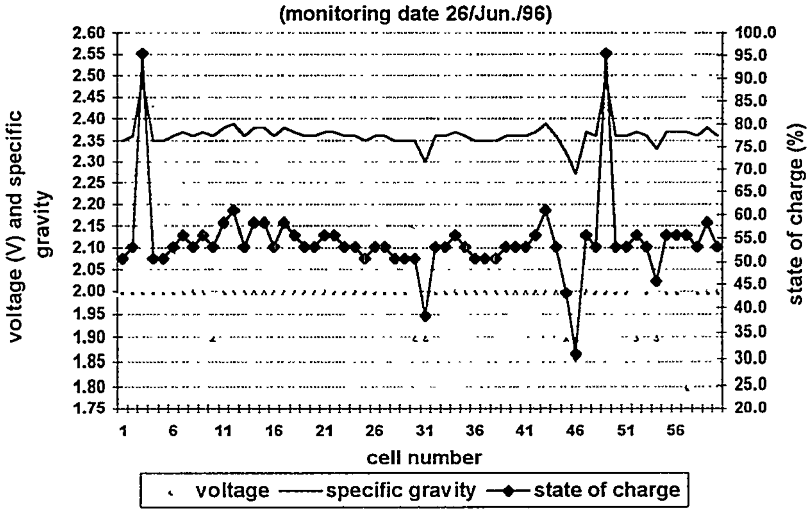

Figure 4. Battery bank conditions found during the inspection carried out on 1996 at Santa María Magdalena hybrid system.

On the other hand, voltage monitoring can help detected bad cell and maintain them in a safe operating condition. Figure 5 shows a problem of the battery bank due to marked voltage variation, which was detected in two batteries of the battery bank of hybrid system number 4, installed at Playas Paraiso. Due to the continous monitoring it was possible to detect the problem on time. The two batteries were disconected from the battery bank and tested separatly. After the test had been performed, it was decided to replace these batteries for new ones (2). The battery temperature is another important parameter by means of which it is possible to detected dangerous temperature increases and to optimise the performance of the charge controller. During the first inspection to the hybrid systems at Playas Paraiso

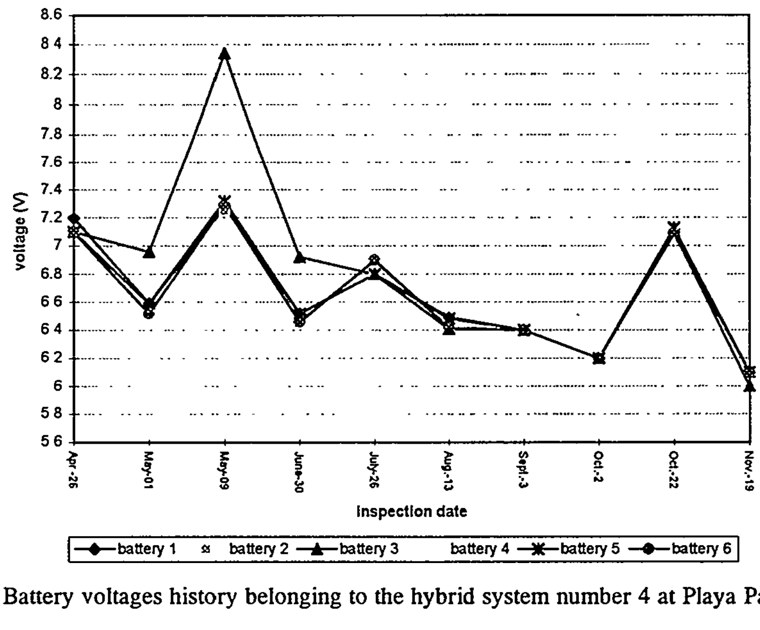

Figure 5. Battery voltages history belonging to the hybrid system number 4 at Playa Paraíso.

Antonio Agua Bendita hybrid system.

one problem detected was the high set point value for the high voltge disconnect. That causes excessive gassing and temperature raise up to 40 °C inside batteries. This problem is shown in the figure 6. The problem was solved lowering the high voltge disconnect set point from 14.8 V to 14.5 V. However, the most battery problems were found at the hybrid systems installed in the state of Zacatecas (La Gruñidora, El Calabazal, El Junco and Ignacio Allende) as shown in figures 7 to 11.

In June 1993 personal of the Electrical Research Institute carried out an inspection at Ignacio Allende hybrid system but at that time they could not be able to measure the specific gravity because all battery bank was found totally discharge. Figure 7 shows the results obtained during the second inspection carried out at the same system two years later from the first inspection. In this inspection 6 cells were found seriously

damaged without voltage and specific gravity readings and probably with irreversible damage. Anhother cells were found with states of charge less than 50%.

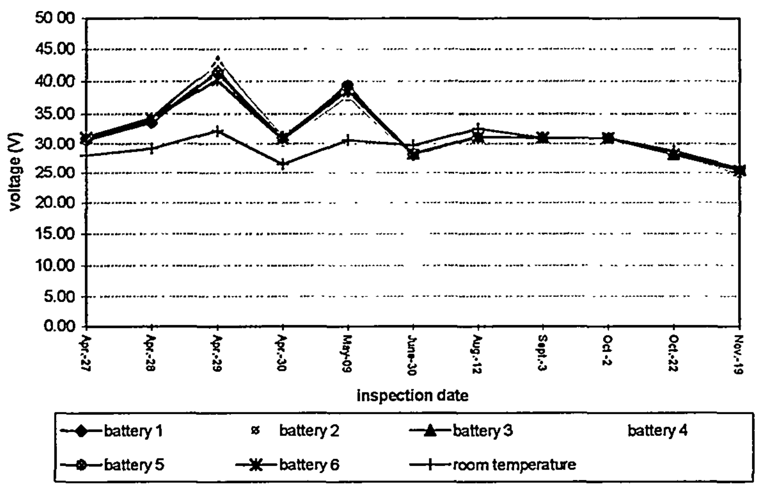

Figure 6. Electrolyte temperature history belonging to the hybrid system number 1 at Playa Paraíso

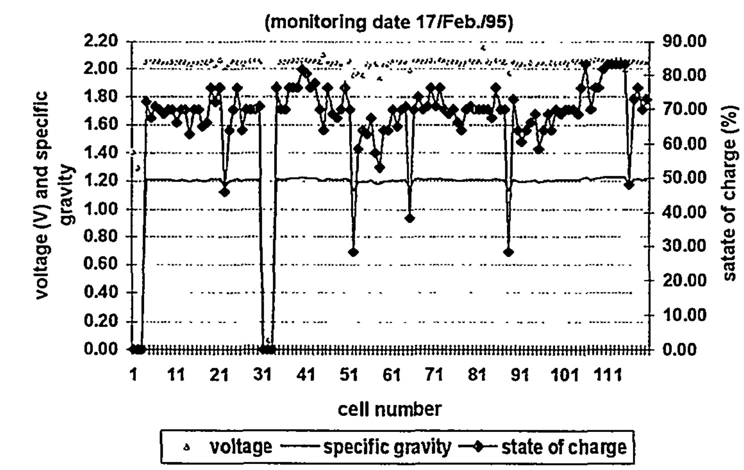

Figure 7. Battery bank conditions found during the inspection carried out on 1995 at Ignacio Allende hybrid system.

In similar conditions was found the battery bank of the Calabazal hybrid system as can be seen in figure 8. Here most of the cells had states of charge less than 40%, and 5 cells were found seriously damaged. On the other hand, in June 1993 the first inspection carried out to the Junco hybrid system. There was not taken voltage measurements, the only parameter measured at that time was the specific gravity as shown in figure 9. In this figure is possible to see the low state of charge found at the battery bank (approximately 15%) and how some cells didn't give specific gravity readings.

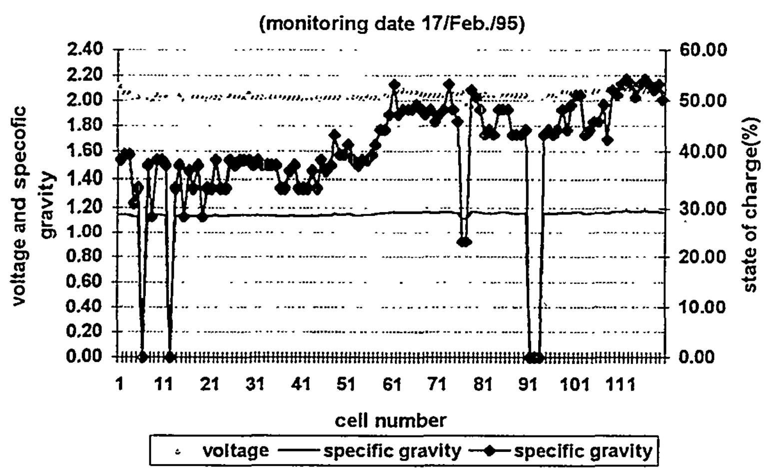

Figure 8. Battery bank conditions found during the inspection carried out on 1995 at Calabazal hybrid system.

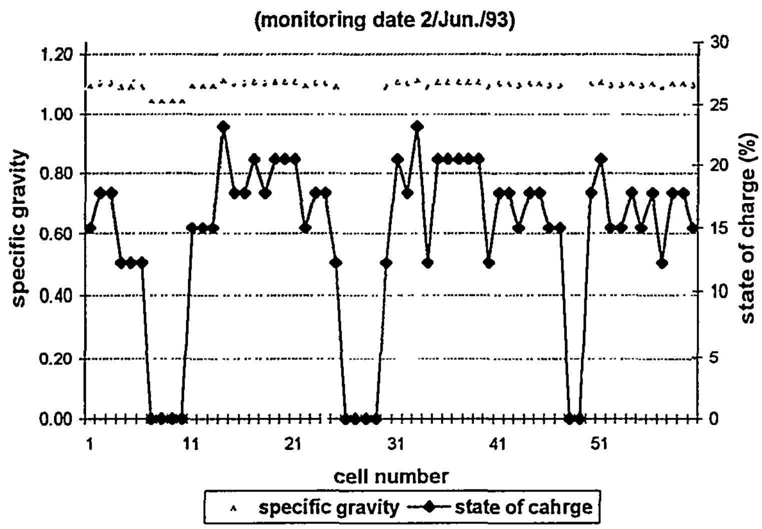

Figure 9. Battery bank conditions found during the inspection carried out on 1993 at the Junco hybrid system.

In the figure 10 the results obtained in the second inspection carried out to same system are shown. This figure shows a better state of charge of battery bank with respect to the inspection carried out tow years later. However some of the same cells that two years before didn't give specific gravity readings had the lowest reading of specific gravity in the battery bank. Probably these cells have been developed sulphation problems.

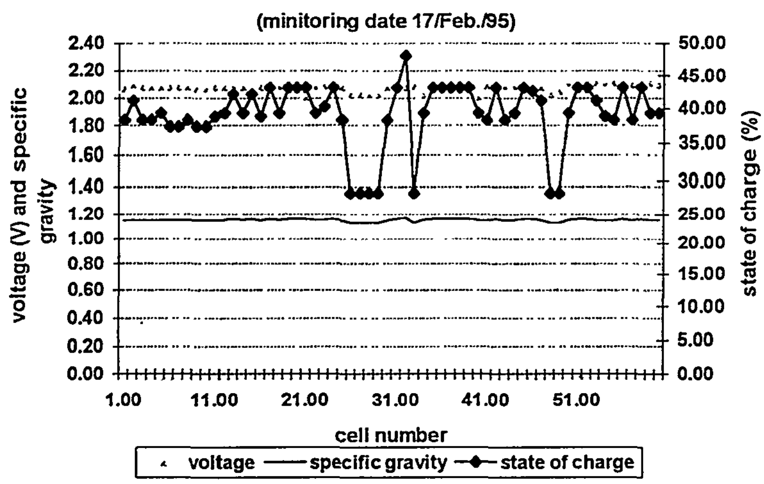

Figure 10. Battery bank conditions found during the inspection carried out on 1995 at the Junco hybrid systems.

DEVELOPMENT OF ANELECTRONIC CHARGE CONTROLLER FOR MICRO-HYBRID SYSTEMS

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1. INTRODUCTION

In the last quarter of 1995, the Electrical Research Institute of México (IIE) developed a micro-hybrid system (wind-photovoltaic) aimed to supply electricity for lighting purposes in a tourist development known as "Villas Carrousel" in the state of Quintana Roo, México [1].

Twelve micro-hybrid systems were integrated with a 500 Watts windturbine, which is a previous design of the IIE (known as "Wasp.IIE"), and with commercial available photovoltaic modules and batteries.

In order to achieve system integration with these components, an electronic charge controller was developed, which was endowed with functional features required by the components and with some innovations useful in systems of bigger capacity.

The electronic charge controller (CTR-1) is a digital electronic system based in an 80C31 microcontroller chip, a 12 bits analog to digital converter, a 16 Kbytes Eprom memory, analog amplifiers, optocouplers, voltage regulator, a watch dog, relay drivers, some logical circuits, and electromechanical relays (Fig. 1).

Major functions of the CTR-1 are:

- Battery bank charge / discharge cycle control.
- Windturbine's generator excitation supply.
- Windturbine dynamic braking.
- System malfunction events detection.

This paper describes the major requirements found for the electronic charge controller development and the chosen solutions.