THE SOLAR HOUSE OF CRESESB / CEPEL
SEVEN YEARS OF SUCCESS

Marco Antônio Galdino[(1)] e Hamilton Moss de Souza[(2)]
[(1)] CEPEL - Centro de Pesquisas de Energia Elétrica
[(2)] CEPEL / CRESESB - Centro de Referência para Energias Solar e Eólica Sérgio de Salvo Brito

ABSTRACT - The Solar House is located in the facilities of CEPEL - Centro de Pesquisas de Energia Elétrica (Electric Power Research Centre) at Fundão Island, Rio de Janeiro, Brazil. It is powered by a stand-alone PV system and is operated by CRESESB – Centro de Referência para Energia Solar e Eólica Sérgio de Salvo Brito (Reference Centre for Solar and Wind Energy Sérgio de Salvo Brito) and CATE – Centro de Aplicação de Tecnologias Eficientes (Efficient Energy Application Center) as a demonstration centre.

The Solar House was built in 1997, and during seven years of operation it received circa 9.000 visitors (up to middle 2004).

The present paper shares some aspects of the experience gained with the Solar House, including technical details of the systems installed, the experience in operation and maintenance, and the divulgation and training of personnel so far obtained.

KEY-WORDS: Photovoltaics; PV Systems; Stand-Alone PV Systems; Solar Energy.

1- INTRODUCTION

The CRESESB – Centro de Referência para Energia Solar e Eólica Sérgio de Salvo Brito (Reference Centre for Solar and Wind Energy Sérgio de Salvo Brito) is an institute supported by MME – Ministério de Minas e Energia (Brazilian Ministry for Mines and Energy) and located at the facilities of CEPEL – Centro de Pesquisas de Energia Elétrica (Electric Power Research Centre) at Fundão Island, Rio de Janeiro, Brazil.

The main objective of CRESESB is to foster the development of solar and wind energy in Brazil though the dissemination of information. It includes not only technical information aimed at professionals, but also general information aimed at the public, students and teachers.

To reach this goal, CRESESB has been publishing books, newsletters, CD-ROMs, promoting basic and advanced courses and supporting research and events in subjects related to solar and wind energy. It also maintains a specialised library and a website (www.cresesb.cepel.br).

As one more step to attain its objectives, CRESESB designed and built the Solar House in 1997 together with CATE. Other institutions also participated in this project: ELETROBRÁS (Brazilian Electric Utilities Holding Company), PROCEL (Brazilian National Programme for Energy Efficiency) and the Physics Department of PUC- RJ (Catholic University of Rio de Janeiro).

There are still millions of people living in remote places located far from the electric grid in the brazilian outback. The official estimates mention a total of 12 million people. One of the technologies suitable to meet this demand is the stand-alone PV system. The Solar House (Figure 1) is a prototype of a rural house powered by a stand-alone PV system and self-sufficient concerning energy and water, intended to be applied for rural electrification in the brazilian outback.

Figure 1 - Solar House.

Section 2.0 describes the technology, section 3.0 discusses some technical aspects. Section 4.0 presents a conclusion.

2- DESCRIPTION OF THE TECHNOLOGY

The Solar House is a low-cost pre-fabricated wood house, which suffered minor modifications [1] to become adequate for the project. It received the following equipment:

- PV electric energy generation system;
- PV water pumping system;
- two PV public lighting systems;
- solar water heating system;
- efficient appliances;
- data acquisition system.

Technical considerations about these equipment, maintenance and performance are addressed in the following subsections 2.1 to 2.7.

2.1- PV electric energy generation system

The configuration of the system is:

- PV array [2] comprising 44 Kyocera LA45 modules (45Wp), associated 4 in series and 11 in parallel (4s * 11p), with a nominal voltage of 48Vdc;
- battery bank with 24 Concorde PV12105 batteries (12Vdc – 105Ah @ C_{20}), connected 4s * 6p;
- Trace C40 charge controller (40A – 12/24/48Vdc);
- Trace SW4048 inverter (48Vdc/120Vac – 4kW).

An electric diagram is presented in Figure 2 below.

[1] It was modified in order to have a classroom.
[2] The PV modules, the charge controller and the solar tracker were donated by the MME, within PRODEEM – Programa de Desenvolvimento Energético de Estados e Municípios, the brazilian national programme for rural electrification using photovoltaics (Galdino, 2002).

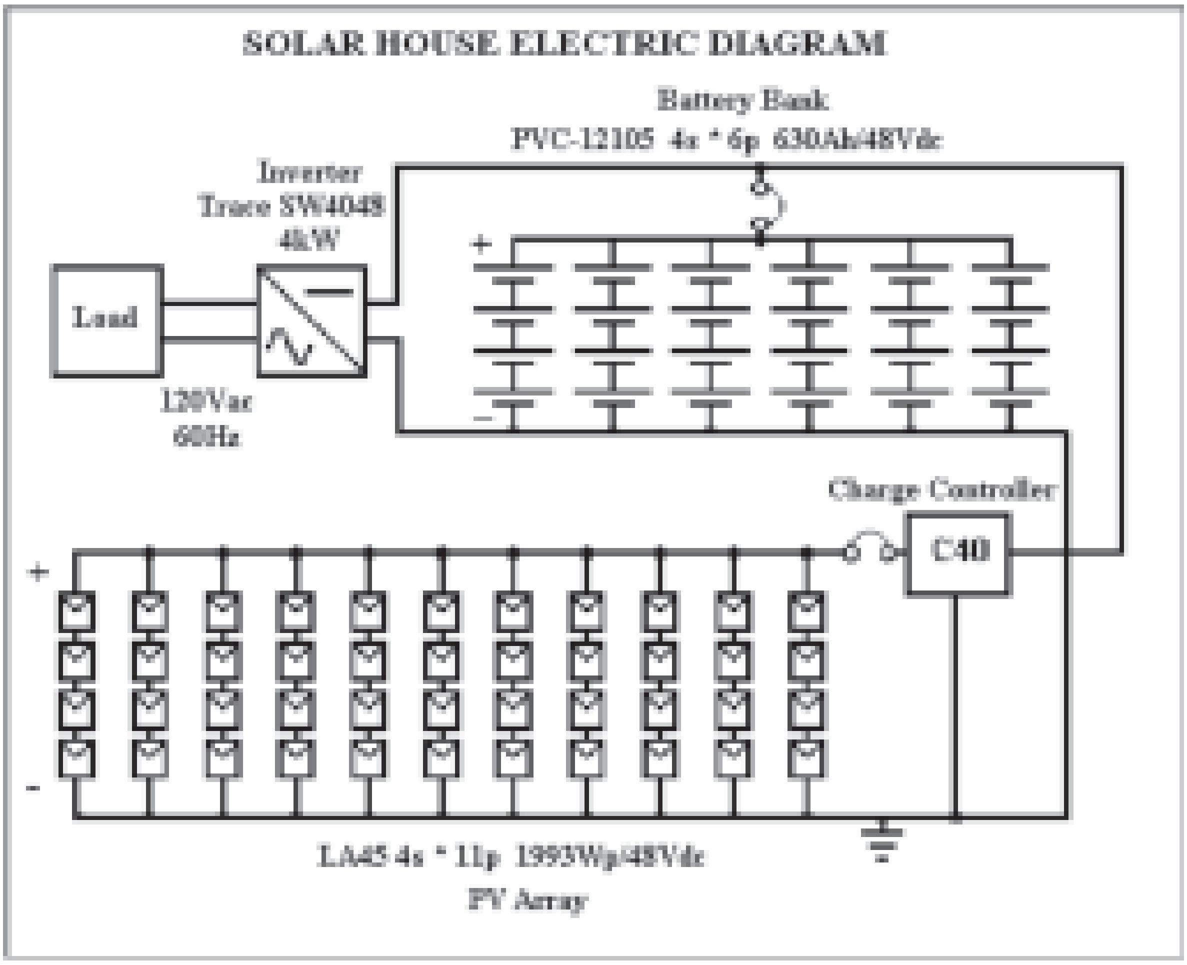

Figure 2 - Electric diagram.

Part of the PV panel (32 modules) was installed on the roof in a fixed structure, and another part (12 modules) on the ground in a passive tracking structure.

The PV array was installed facing true North and tilted 25° (latitude of Rio de Janeiro). In order to allow the right installation, the House was built with a facade facing True North. However, the roofs in Brazil are normally tilted in the range between 15°-20° and an increase in this angle would represent a major modification in the house and add a significant cost to the project. Therefore, a support structure was used, in order to correct the tilt to 25°. This solution, however, had a negative aesthetic impact.

The one-axis passive solar tracker (Zomeworks Corporation, model Track Rack) uses solar thermal energy to accomplish the tracking (Figure 3). The mechanism is based on the distillation (evaporation/condensation) of R22 ($CHClF_2$) refrigerant. According to manufacturers' data it operates with ±10% accuracy.

The battery bank was installed in an external compartment (Figure 4), located in the South facade, avoiding direct solar radiation, what would reduce significantly the lifetime of the batteries due to the high temperature. This compartment also provides adequate ventilation (venetian blinds), not to allow accumulation of gasses produced by the batteries (H_2 and O_2) which would pose a risk of fire or explosion.

The inverter and the charge controller are installed on an electric board inside the house, what meets demonstrations purposes. Of course, in a real installation, this solution would not be acceptable, since it allows free access of unauthorised persons to the electric equipment and also wastes living space. In a real house, this equipment should be installed externally in the South facade, in a separate closed compartment, next to the batteries' compartment.

Only a charge controller is used, since the load control is done by the inverter and is totally configurable (set-points).

The PV system was sized considering a solar radiation of 4.2kWh/m^2.day (yearly average for Rio de Janeiro on the horizontal plane) and a consumption of 6kW/day, based on a simplified sizing method (Sandia 1991). The expected monthly consumption is180kWh, what would correspond to middle class family of 4 persons (without air conditioner or electric shower) in Rio de Janeiro.

Figure 3 - Battery compartment.

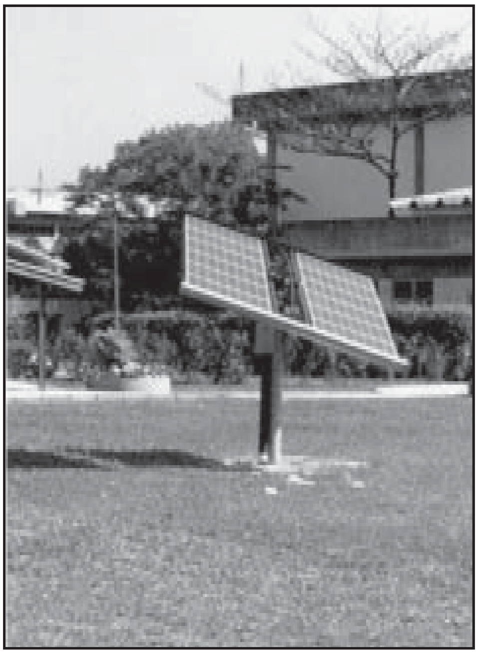

Figure 4 - Passive tracker.

2.2- PV water pumping system

The PV water pumping system includes the following equipment:

- PV array [3] comprising 2 Kyocera KC60 modules (60Wp, Voc=21.5V, Isc=3.73A), associated 2s (nominal voltage of 24Vdc);
- Solarjack SDS-Q-128 dc water pump;
- a water tank simulating a borehole.

This pumping system is completely independent from the electric energy generation system.

According to the brazilian standards [4], a minimum volume of 120L/person.day is to be considered for water supply of rural households, so the water consumption for the House should be at least 480L/day (4 persons). Sizing charts (Solarjack) presented by the manufacturer indicate that this small PV water pumping system is able to produce more than 4000L/day, considering a total dynamic head of up to 20m. This represents a significant excess of water, which in a rural area could be used for small livestock breeding or small irrigation.

2.3- PV public lighting systems

Two PV public lighting systems [5] are also installed (one of them is visible in Figure 1), according to the following configurations:

System I

- module Siemens M75 (48Wp, Voc=19.0V, Isc=3.35A);
- charge controller Mornigstar Sunsaver 6 (12V/6A);
- battery Concorde PVX1285 (12Vdc – 85Ah @ C_{20});
- 11W compact fluorescent lamp.

System II

- 2 modules Solarex MSX53 connected in parallel (53Wp, Voc=V, Isc=A);
- charge controller Mornigstar Sunsaver 10 (12V/10A);
- battery Concorde PVX1285 (12Vdc – 85Ah @ C_{20});
- two 11W compact fluorescent lamps.

2.4- Solar water heating system

It is common in Brazil the use of electric showers with power ratings up to 7kW. Of course this kind of equipment is not a load suitable for the PV system of the Solar House. The alternative is a low-cost solar water heating system of the type commonly used in Brazil:

- 1m^2 flat plate collector, consisting of a front glazing, a metallic black absorber, back insulation and a enclosure box (installed directly on the roof, no support structure);
- insulated hot water storage tank of 150L;

This kind of system normally operates based on direct heating and water circulation trough a thermosiphon. However, as the distances/heights required by the thermosiphon are not met in the Solar House, a small water circulation pump is also needed.

At the time of the project, the brazilian flat plate collectors and storage tanks were not yet labelled, since the INMETRO [6] programme for labelling begun only in 1998. So, the efficiency and quality of the equipment used is not actually known.

---

[3] The PV water pumping system was also donated by MME, within PRODEEM.
[4] NB-92/ABNT.
[5] The PV public lighting systems were also donated by MME, within PRODEEM.
[6] INMETRO – Instituto Brasileiro de Normalização Metrologia e Qualidade Industrial (Brazilian Institute for Normalisation, Metrology and Industrial Quality).

Of course, this water heating system was installed for demonstration purposes only, as it is not able to produce the hot water required for a family of 4 persons, considering the common practices (Agência Energia, 2000) adopted for such projects in Rio de Janeiro (middle class families).

Such a real installation would require a minimum of 300L/day of hot water (although this number is probably oversized for a rural household), which would require a system with a thermal reservoir of 300L and a collector of 4m^2 (installed directly on the roof, no support structure).

2.5- Efficient appliances

As the PV energy is extremely expensive, there is a strong effort to use in the Solar House the most efficient appliances available in the brazilian market:

- The refrigerator is the Continental Elegance RC36GS, which received the label of most efficient of Brazil for the year of 1999 in the category “one door refrigerator”, granted by INMETRO/PROCEL. The consumption presented in the label is 33kWh/month.
- The lighting fixtures are equipped with high efficiency electronic ballasts, 32W tubular fluorescent lamps and reflectors of high reflectivity. Circular fluorescent lamps are also used.
- Other appliances are also available, to be used for demonstrations concerning power requirements, energy efficiency and conservation measures: microwave oven, mixer, table fan, iron, board with different illumination types, etc.

2.6- Data acquisition system

The PV electric energy generation system is monitored by a real-time Data Acquisition System, which measures the environmental and electrical quantities relevant for the continuous analysis of the operational conditions.

The monitoring system is based on a PC-compatible microcomputer equipped with an analog input board, sensors, transducers and auxiliary boards. It allows the visualisation of the monitored data in real-time.

The quantities monitored are the following:

- global solar radiation (W/m^2);on the plane of the PV array (Eppley black & white pyranometer);
- dc current (A) generated by the fixed PV array and by the tracking array;
- dc voltage (V), dc current (A) at the battery bank;
- ac current (A) and ac voltage (V) at the inverter output;
- ambient temperature (°C), internal temperature in the House (°C), temperature of water in the thermal reservoir (°C), temperature of the water entering and leaving the solar thermal collector (°C).

2.7- Other considerations

Wind Generator: A Bergey BWC1500 (1500W/220Vac) wind generator is installed for demonstration purposes only (not connected to the electric system, visible in Figure 1), since the yearly average wind speed at the Fundão Island does nor allow its operation (2.0m/s at 15m height).

Cooking: The ideal Solar House should be self-sufficient not only concerning water and electric energy, but also concerning combustible for cooking. So, it should be equipped with a efficient lumber stove/oven or preferably with a bio-digestor (sewage, organic residues) for producing CH_4 (methane) gas for cooking. This was not part of the project, since the House is not inhabited.

Solar Heating: Since the solar water heating system installed on the roof is not accessible for teaching, a second one was installed on the ground (200L, 2m^2). It is visible in Figure 1.

3- PERFORMANCE EVALUATION

3.1- Failures and maintenance

The Solar House allowed CEPEL to gain experience in operation and maintenance of a stand-alone PV system for a long period of time. During this 7-year operating period, several failures in the electric energy generation system were recorded:

- charge controller: two failures, the charge controller was repaired in the first failure and replaced after the second one;
- battery bank: the original battery bank had a lifetime of more than 6 years, and was replaced in March, 2004;
- inverter: is was replaced by an identical equipment in March 2004;
- connection boxes (diode boxes of the PV array): were replaced due to corrosion.

The water pumping system has been operating perfectly since the installation and presented no failures. It must be considered, however, that the real water consumption is very small.

The PV public lighting systems presented several failures. Its batteries were already replaced 2 times, what means a lifetime of approximately only 2 years. The charge controllers were also already replaced. These systems were used in the beginning of PRODEEM, but were abandoned precisely due to its high failure rate (Galdino, 2002).

3.2- Performance

The data acquisition system allows the real time visualisation of the data, in order to evaluate the instantaneous operational conditions of the PV system, but does not record the data for further system evaluation. Therefore, another data acquisition system was installed, to complement the existing measurements and allow a more detailed analysis.

This work was done at the Solar House as part of a diploma thesis sponsored by CRESESB/CEPEL (Herold, 2001).

The available data allows the preparation of the graph presented in Figure 5, which shows the mean daily energy consumption during of the years 2001 and 2002.

According to these data, the daily consumption lies in the range of 2-4kWh, which is much less than the value of 6kWh considered in the original project. Since the House is not inhabited, this fact was expected.

The basic consumption is due to the refrigerator and the computer (24h/day). Additional consumption occurs during the visitation, which normally happens several times a week during the school year. The maximum consumption occurs during the courses (subsection 3.3) and can reach 9kWh/day.

The average monthly consumption lies in the range of 80-90kWh.

3.3- Training and Visitation

The Solar House, more than a demonstration object, is a centre for visitation and training.

It is estimated that during seven years of operation it received circa 9.000 visitors. This number includes professionals, teachers, university students, high school and technical school students and public in general. It represents a new activity in CEPEL, so CRESESB has trained people specially for it. The visitation of secondary students was specially prepared and intends mainly to stimulate their interest in technical/scientific careers, using the topic of renewable energies (Hortencio Borges et all., 1998).

Up to 2004, 8 courses for training technical people in PV systems happened in the Solar House. The courses had a duration of 2 to 4 days and were tailored for the targeted public, which included teachers of technical schools, technical staff of electric energy utilities, technicians of PRODEEM, public in general, etc. Many of the courses involved practical exercises of assembling different PV systems. According to declarations of the trainees, the use of the Solar House as a classroom for these courses is highly appreciated.

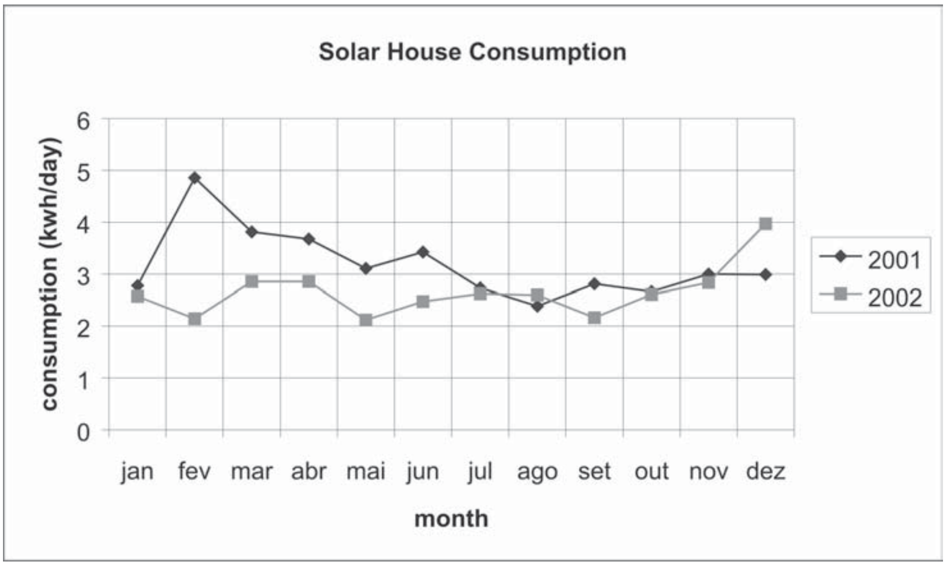

Figure 5 - Daily consumption in years 2001 and 2002.

The courses that are open to the public must have a limited number of participants, and normally receive participants from several states of Brazil. There is a steady demand for new courses, what shows that the interest in this subject is significant. The House also attracted mass media attention (TV, radio, newspapers and magazines), resulting in several reports in Brazil's main communication vehicles, contributing to spread out renewable energies and energy efficiency concepts for a varied public estimated in millions of people.

4- CONCLUSION

The Solar House is an object of research in CEPEL, concerning the operation and maintenance of A PV system for a long period of time. It has also been an important and efficient medium for divulgation of the PV energy in Brazil. The results are encouraging and this work shall be continued for the next years.

As objectives for the future, several items can be listed:

- the data acquisition system shall be updated, preferably making the real time data accessible to everyone via internet;
- appliances and lighting shall be also updated, using the best available at the brazilian market nowadays;
- interactive activities (experiments) shall be prepared for the students, so that they become more active during the visits;
- incentives to the replication of the Solar House in organisations (utilities, universities, etc.) of other states of Brazil must be pursued.

5- REFERENCES

[1] Agência Energia; Aquecimento Solar – Curso de Capacitação; Edição Rio de Janeiro; março de 2000.
[2] Helmut Herold; A Method for Monitoring and Evaluating Photovoltaic Systems in Brazil; Diploma Thesis in Electrical and Control Engineering; University of Applied Sciences Giessen-Friedberg; Faculty of Energy Technology and Thermodynamics; April 2001.
[3] Hortencio A. Borges; Hamilton M. de Souza; Maurício Moszkowicz; Marco .A. Galdino; João C. Aguiar; Antonio L. de Sá; Pedro Bezerra; A Strategy to Stimulate Technical Education in Renewable Energies and Energy Efficiency-CEPEL/PUC Cooperation; ICEE98 - International Conference on Engineering Education, Rio de Janeiro, August 17-20, 1998.
[4] Marco A. Galdino; Jorge H. Lima; PRODEEM – The Brazilian Programme for Rural Electrification using Photovoltaics; RIO 02 – World Climate and Energy Event; Book of Proceedings; 6th-10th of January of 2002; Rio de Janeiro; Brazil.
[5] Sandia National Laboratories; Stand-Alone Photovoltaic Systems – A Handbook of Recommended Design Practices; November 1991.
[6] Solarjack – Solar Pumping Products; SDS Series DC Submersible Pumps; (sizing chart).