FIELD EVALUATION OF A PV RURAL ELECTRIFICATION PROJECT IN A TITICACA LAKE ISLAND

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ABSTRACT: The Renewable Energies Centre of the National Engineering University in Lima (CER-UNI) is promoting a rural electrification programme with Solar Home Systems in the Titicaca Lake. The beneficiaries (end users) had to buy their SHS, paying most part of the costs, using a bank loan financing scheme. Today, there are 421 SHS in operation and many families are interested to buy their own SHS under similar conditions. In the frame of a PV project fund by the European Commission, TaQSolRE (Tackling the Quality in Solar Rural Electrification), a field evaluation of this programme have been made on August of 2003. A sample of 41 SHS was technically evaluated in situ, and 50 end users were interviewed.
Keywords: Rural electrification: evaluation: ecotourism.

1 INTRODUCTION

Since 1995, the Renewable Energies Centre of the National Engineering University in Lima (CER-UNI) is promoting a rural electrification programme with Solar Home Systems (SHS) in the Titicaca Lake region, on the Andean highland between Peru and Bolivia, at an altitude of 3810 m and 16º south latitude. The beneficiaries of the PV programme are the Quechua and Aymara communities living in islands or villages near to the lake, in the Department of Puno. Their incomes come from the agriculture, the fishery, the tourism and the textile handicrafts, clearly related with the previous. After the payment of a five year loan, the end user is the owner of the PV system.

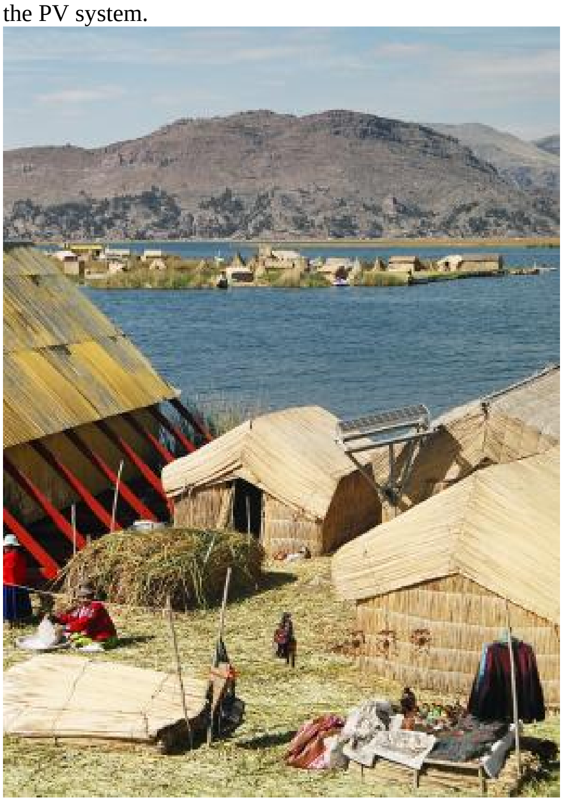

Fig. 1 A SHS in Uros, a group of floating islands in the Titicaca Lake. They are constructed with a plant which grown in the lake, named Totora (*Csirpus Totoral).*

The experience accumulated in eight years of operation allows to consider this project as a "good practice" in PV rural electrification, because it exhibits clear sustainability signs; by way of proof, the high interest of the population in to participate on the next phase of the electrification programme. For this reason, it was selected to evaluate their results in the frame of a project, fund by the European Commission in the FP5, which is focused in to improve the quality in the PV rural electrification [1].

In August of 2003, a team composed by two technicians –one of them, the O&M technician of the PV programme— and an expert in social studies have evaluated the technical performance of the PV systems and the human aspects which are linked with the management of this energy source in one of the location of the programme: Taquile, one of the biggest island of the Titicaca lake and the most visited by the tourists. The objective was to appraise the features of the SHS and how they are perceived by the end users.

2 DESCRIPTION OF THE RURAL ELECTRIFICATION PROGRAMME EVALUATED

2.1 Hardware characteristics

The PV systems installed are composed by a PV module, 35 Wp or 50 Wp, a lead acid battery, 100 Ah to 130 Ah, a charge regulator, three fluorescent lamps, a connection box with fuses and a DC/DC converter (3 - 9 V_{DC}, adjustable) to connect a radio or a B/W television; in fact, a typical solar home system like one of the more than three million which are distributed by the developing countries [2]. The figure 1 is a picture captured in one of the floating islands that compose the community of Uros. The raw material to manufacture the island, the builds, the boats, etc, is a plant which grown abundantly in the water, Totora. It is the worldwide famous image of the Titicaca Lake.

The table 1 shows the distribution of SHS among the communities included on the PV programme. As can be observed, Taquile is the village with more experience in the PV technology and were the share of population with access to electricity is biggest (Suasi Island have only five families). This fact is a consequence of their tourist value, because all the visitors that come to Puno

Department go to Taquile and some spend the night also. This was the motivation to start the programme there: one third of the SHS are linked with the tourist sectors (restaurants and room location), which produces an income level higher than other near villages. However, the demand of SHS is still considerable in those villages.

Table 1 Solar home systems installed by CER-UNI [3]

Installation Year	**Taquile**	**Uros**	**Soto**	**Amantaní**	**Suasi**	**Huancho**	**Total**
1996	100						100
1998	36	23	13				72
1999	88	86		52	5	18	249
SHS	224	109	13	52	5	18	421
Total Houses	350	300	25	700	5	100	1480
% with SHS	64	36	52	7	100	18	28

Since March 2001, ten houses have an ampere-hour meter to evaluate the electricity consumption per house and to analyze the utilization pattern [6]. The mean daily consumption is 9 Ah/day, but the range is wide: from 5 to 13 Ah/day. In this region, the theoretical mean daily production is about 15 Ah/day.

2.2 Financial scheme

The beneficiaries have to buy their SHS, paying most part of the costs, but with credit facilities. The financial scheme has evolved; in the last phase, the systems could be sold, without a direct subsidy, with five annual payments of US$ 150, totalling US$ 750. In the initial phase, 1996, the best bid of a private company resulted in a cost of US$ 850 per SHS (all components imported, paid cash, including about 40% taxes) [4]. At the present, 141 SHS are already paid completely, 34 % of the 421 SHS in operation.

As can be see in the table 1, the programme has been developed in three phases, matching the installation year. The funds for the first 100 SHS were granted by the Peruvian Ministry of Energy and Mines. With the annual instalments collected, the CER-UNI created a revolving fund and additional 72 SHS were installed in 1998.

Based on these achievements, in 1999 the CER-UNI went a step further, trying to reduce the subsidies nearly to cero, taking a bank loan (US$ 100 000 at 10% yearly interest rate). At the present, the fulfilment on the payments by the end users is allowing the regular reimbursement of the loan.

2.3 Previous evaluations

A team of technicians and sociologists were displaced to Taquile during the month of December 2000 to evaluate the results of the electrification project [5]. The study group was composed by 110 users and comprises SHS with 35 and 50 Wp PV modules. The analysis was planned to identify technical, socioeconomic and cultural parameters related with the sustainability of the project.

As can be observed in the fig. 2, the majority of the SHS were in operation (242 in Taquile); only 2 % of the systems of 50 Wp were stopped. An important rate of PV modules, 26 % of 35 Wp and 17 % of 50 Wp were deficiently oriented for the solar radiation. Over 60 % of batteries have decreased his charging capability and the 15 % were replaced. At the moment of this evaluation, all charge regulators and lamps used in the 35 Wp SHS had been replaced by the poor quality of them. This is a good indicator about the quality of the solar market; with the exception of PV module, highly standardized the balance of systems components show a very heterogeneous quality. Probably this experience increased the interest among the end users in a maintenance service; the 90 % of end users surveyed would be willing to pay this service.

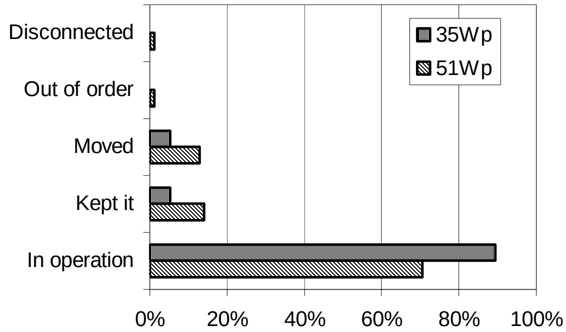

Fig. 2 Status of the PV programme at the end of 2000.

3 METHODOLOGY

3.1 Objectives for the evaluation

The evaluation was undertaken in the frame of a research project fund by the Directorate-General for Energy and Transport (EC), named *Tackling the Quality in Solar Rural Electrification*, which has the objective to improve the technical quality of PV rural electrification. The strategy started with a literature survey and some field evaluations in order to analyze the present reliability of SHS, and what are the technical and social parameters which have influence on it. For that, in August 2003 was accomplished a technical evaluation on a sample of 50 installations at Taquile. The study intends to analyze the functioning of the solar systems from a double perspective: the purely technique and the relation with the end users' training. With those results that can be expressed in terms of reliability, such as B.O.S. components or the PV system as a whole, are fill in a reliability data base that is being developed in the European project referred (it can be freely accessed in http://www.TaQSolRE.net).

3.2 Technical parameters analysed

The main tests were:

- a visual inspection, which include a functional test, the PV module orientation and position (preventing shadows), and appliances directly wired to the battery;
- in the charge regulator: the voltage set-points and self-consumption current;
- in the electrical installation: the wire voltage drops

and

— voltage current characteristic of PV modules.

All the instrumentation used is quite simple: ammeter, voltmeter, a variable resistor to test the charge regulator set points and the IV characteristic of PV modules, a reference PV module to measure the cell temperature, and a reference solar cell to measure the solar irradiance; both data are required to model the IV characteristic, in Standard Test Conditions, of the PV module under test [7].

Fig. 3 Reference PV module and solar cell used for testing PV modules performance at Standard Test Conditions.

As charge and discharge battery tests are time consuming and require a controlled current source, their measurement in a place without electricity is not easy. Then, three selected batteries in operation, representing different phases of the solar program, were sent to Lima in order to be tested on the CER-UNI laboratory. Three equivalent batteries were bought in Puno, before to travel, for replace them.

The advantage of the test procedures methodology used is, in one side that can be reproduced easily in developing countries, which are the main actors on PV rural electrification; in the other side, the technical quality of the PV system can be accuracy evaluated.

The field data were complemented with the historical operation and maintenance data base, which is being filled on, since the beginning, by the technician in charge (figure 4). Here is collected all the replacement made and the causes for them. It should be highlighted the low reliability of batteries and lamps in comparison with the PV modules. Breakdown of the fuses are related with the use of SHS by the end user. The parts replacement only can be made by the technician, in consequence during the maintenance visits. This figure only can be considered as an estimation of the mean time between failures.

3.3 Socio-economic survey

A factor sharply related with the PV system reliability is the knowledge of the end user about the management of their energetic system. Important efforts were made on this topic in the history of the electrification programme: the users were trained individually by the technician when the SHS was installed and each SHS was provided with a short manual especially designed for this community, plenty of draws and sketches.

In order to analyze the training level a survey was made over fifty end users, which contain questions about this subject and other issues to evaluate the benefits of the solar programme.

As long as the technicians were more than welcome in their evaluation visits, the social researcher has not the same luck. The villagers are a bit tired; the novelty of this project on the region is attracting a lot of foreign and national visitors, students and experts in solar electricity, which, almost out of control, inquiry to the PV users about their experience.

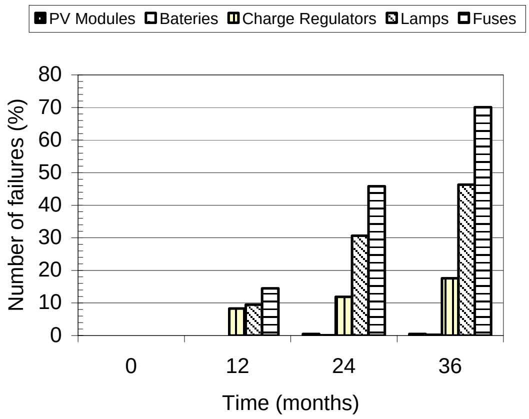

Fig. 4 Number of accumulated failures recorded by the O&M technician during last three years operation.

4 RESULTS

On the tests and the data collection some problems have been detected. A significant number of PV modules are badly oriented to the annual sun path. In some cases, it is a consequence of a seasonal home transfer, in other cases, the pole used to support the PV module is not well fixed and the wind turns the structure. These facts are combined with the ignorance about the topic by the end users.

The low voltage disconnection set point in most of the charge regulators is excessively low. The batteries are managed by two different charge regulators –same manufacturer but different models—, one calibrated in 10.5 V, the other in 11 V: the first one give not any protection to the battery and the second one allows discharge the battery until 90-95%. In both cases the battery life is dramatically reduced.

The figure 4 shows the discharge curve for one of the three batteries replaced, that was tested in the laboratory of the CER-UNI. The real capacity after two years and half in operation is 20 Ah±10%, i.e. a 20% of the nominal capacity. Taking into account that below the 75%, the life of the battery is finished according to the general battery catalogue specifications, it can be deduced the evident damage of the battery and, as secondary conclusion, that in PV rural electrification the batteries are used beyond their limits.

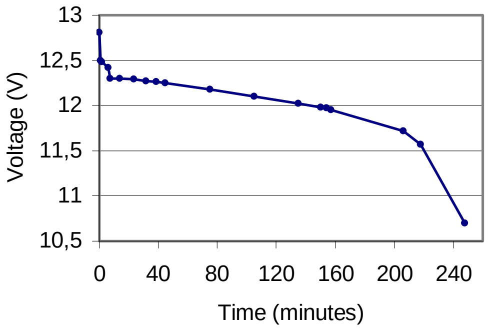

Fig. 5 Discharge curve of one of the local batteries (110 Ah) tested, with a discharge current of 5 A. The real capacity measured was 23 Ah.

One of the major problems detected is the voltage drops between the loads and the charge controller as can be observed in the figure 6. More than 20% of SHS have voltage drops greater than 1.2 V, which is equivalent to 10% of the nominal voltage (the recommended value is less than 5 % of the nominal voltage, 600 mV with 12 V batteries [8]). This voltage losses can damage the fluorescent lights (when the ballast is powered with low voltage values, the tubes are prematurely blackened) and is also a gratuitously power loss. The voltage drops in the wire between charge regulator and battery are very low in all installations tested

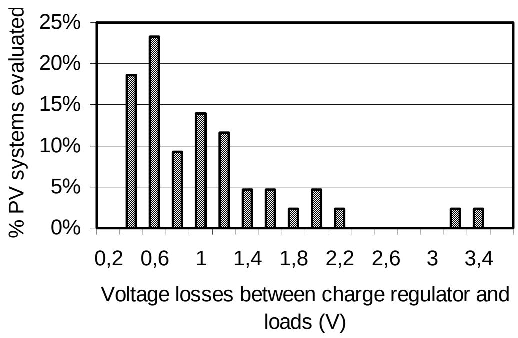

Fig. 6. Frequency of voltage drop between charge regulator and lamps measured.

A 15 % of the SHS tested have charge regulators short circuited or have some load directly connected to the battery, which have a double explanation: the lack of end user training or the bad management of the charge regulator battery set.

From a general point of view, only 25% end users have not shutdowns, the others state electricity supply problems, and more than 80% have had to replace the battery, some of them twice. At the same time, some batteries of 1996 are still working, seven later.

The present survey was coincident with the social evaluation made in December 2000: the users need and request more training [9]. It shows that 38% of the interviewed have not been trained and 14% even unknown such as training. The short manual distributed among the user has not achieve its objective: only the 26% consider it useful, 22% of the people surveyed do not understand it, 14 % have loss the manual and 40% do not answer this question.

Despite all the problems presented, the success of the electrification programme is undeniable. The people stopped us in the streets asking when the next phase will be started; unfortunately, there is not still date, because the lack of funds and bank credits. For example, the 38% of surveyed people declares that solar lighting has increased the daily time to textile works, with the subsequent income improvement.

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