Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Power Sources 116 (2003) 243–247
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Installation and operation of a large scale RAPS system in Peru

J.F. Cole*

International Lead Zinc Research Organization Inc. (ILZRO), P.O. Box 12036, Research Triangle Park, NC 27709-2036, USA

Abstract

In 1997, International Lead Zinc Research Organization Inc. (ILZRO), Solar Energy Industries Association (SEIA), and the Ministry of Energy and Mines (MEM) of Peru signed a Memorandum of Understanding to facilitate the installation of hybrid remote area power supply (RAPS) systems in the Amazon region of Peru. Many remote villages in this vast region have either no or limited electricity supplied by diesel generators running a few hours per day. Subsequently, ILZRO sponsored the engineering design of the hybrid RAPS system and SEIA supported a socio-economic study to determine the sustainability of such systems and the locations for pilot installations. In mid-1998, the Peruvian government approved the design of the system. ILZRO then began efforts to obtain governmental and inter-governmental funding to supplement its own funds to underwrite the cost of manufacture and installation of the systems in two villages in the Amazon region. Additional major funding has been received from the Global Environmental Facility (GEF) administered by the United Nations Development Program (UNDP) and from the Common Fund for Commodities (CFC). Funds have also been received from the US Department of Energy, the International Greenhouse Partnership (Australia) and the Peruvian government.

The RAPS system consists of modules designed to provide 150 kW h per day of utility grade ac electricity over a 24 h period. Each module contains a diesel generator, battery bank using heavy-duty 2 V VRLA GEL batteries, a battery charger, a photovoltaic array and an ac/dc inverter. The batteries and electrical components are housed in modified shipping containers. The modules can be installed with a new generator or retrofitted to an existing generator. The charging and discharging regime of the batteries has been recommended by a study carried out by CSIRO, which has simulated the RAPS operation. The system will employ a partial-state-of-charge (PSOC) regime in order to optimize the life of the batteries, which have a projected life of 8–10 years. A remote monitoring system will consist of a satellite link between each of the remote area power systems and one or more central hosts. The system operator will be able to obtain actual operational status of the system and will be able to change set points and to force operation of certain functions in order to test the system.

Preliminary cost analyses indicate that such RAPS systems are more economically attractive to provide electricity to remote villages than other alternatives, including 24 h diesel generation and grid extension.

The past 5 years have provided a number of lessons learned, particularly related to dealing with government agencies in a developing country, overcoming logistical problems such as shipping long distances and dealing with difficult climate and terrain. Despite difficulties encountered, the promise of RAPS systems as a rapidly growing market for lead-acid batteries appears to be bright given the demand for sustainable remote electrification.

Keywords: RAPS; Hybrid system; 24-h power; Off-grid electricity

1. Introduction

According to the World Bank, over 2 billion of the world population has no access to electricity, and many billions more have only limited access. A composite satellite night-time photograph (Fig. 1) shows that vast areas of the planet are dark, indicating no electricity. This lack of electricity represents a simultaneous social and economic problem for governments of the world and a tremendous opportunity for battery producers and the lead-producing industry.

In many remote areas, the primary means of generating electricity is the diesel genset. While the gensets are relatively cheap to purchase and install, they use expensive diesel fuel and emit significant quantities of pollutants, including greenhouse gases.

On the other hand, remote area power supply (RAPS) systems provide 24 h electricity, while running the gensets only a few hours per day thereby reducing diesel fuel use and cutting pollution. Twenty-four hour power also allows the villagers to develop productive uses for their electricity, improving their economy, their lifestyle, reducing poverty, and urban migration.

In mid-1997, International Lead Zinc Research Organization Inc. (ILZRO), the Solar Energy Industries Association

* Tel.: +1-919-361-4647; fax: +1-919-361-1957.
E-mail address: jcole@ilzro.org (J.F. Cole).

0378-7753/03/$ – see front matter
doi:10.1016/S0378-7753(02)00697-3

Fig. 1. Composite satellite night-time photograph showing vast areas of the planet are dark, indicating no electricity.

(SEIA) and the Ministry of Energy and Mines (MEM) of Peru signed a Memorandum of Understanding to facilitate the installation of hybrid RAPS systems in the Amazon region of Peru. Following this the signatories embarked on a feasibility study, which was completed and accepted by all parties in January 1998. The group then sought funding from the Global Environmental Facility (GEF), the Common Fund for Commodities (CFC) and others. Funding from these bodies was assured by the end of 2000 and implementation of the project began. We expect to commission the system in the two villages in early 2003.

2. The project

Basically, the purpose of the project was to upgrade existing diesel gensets and village grid systems with RAPS systems consisting of solar photovoltaic panels, electronics and batteries to store the energy. These pilot systems were to be installed in two villages in the Amazon region of Peru. One of the villages, Indiana, requires approximately 600 kW h per day, while the other village, Padre Cocha, requires about half that, or 300 kW h per day. The RAPS modules are supplied as 150 kW h modules. Therefore, Indiana will use four modules, while Padre Cocha will use two modules. If the installations are successful, a further 150 villages with existing diesel gensets have already been identified as initial targets for replication. The total cost of the present project is approximately US$ 2.7 million.

The location of the villages is in the Peruvian region of Loreto, the far northeastern region of the country. The only way to get to the capital, Iquitos, is by air or by river as there are no roads. Iquitos is approximately a one and half hour flight from Lima on the Pacific coast. Loreto has over 3000 remote communities, but there are over 70,000 remote communities in all of Peru.

The villages of Padre Cocha and Indiana are relatively near Iquitos. Padre Cocha is on the Nanay River, which is a tributary of the Amazon. Indiana is on the Amazon River approximately 1 h down river from Iquitos by powerboat.

3. The installations

Indiana has approximately 500 households—about 2500 people—and will use approximately 600 kW h per day of

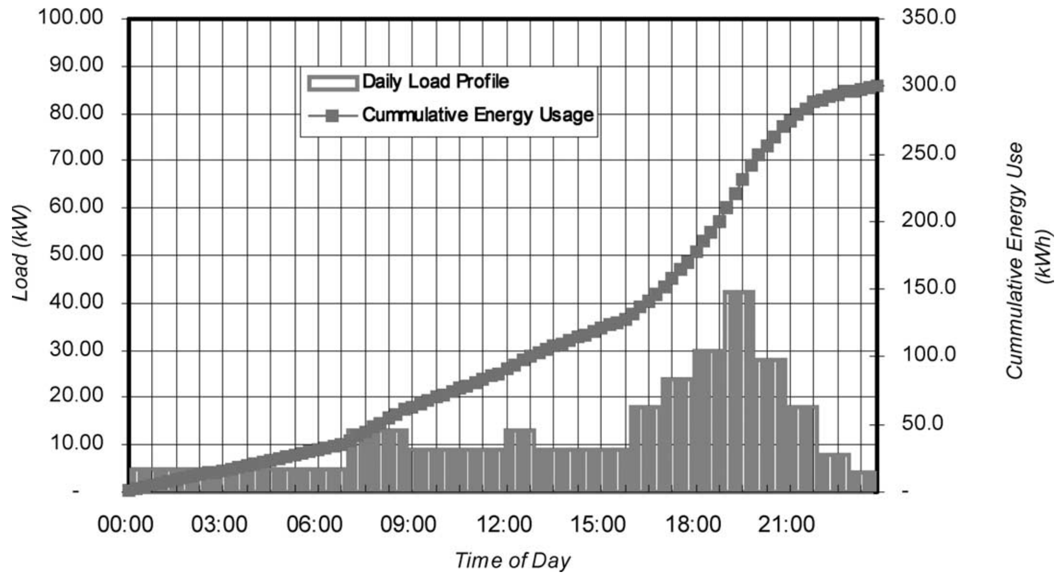

Fig. 2. Typical electrical load profile for Padre Cocha.

electricity. Indiana has an existing 200 kW diesel genset and an existing grid. The genset runs 4–5 h each evening.

Padre Cocha is roughly half the size of Indiana. When the project in Padre Cocha began, they had no electricity at all. Now they have a 100 kW genset and a new grid system. Padre Cocha has an extensive craft industry that will be enhanced by having electricity.

Fig. 2 represents a typical load profile, showing low demand in the early morning hours, with the load increasing at mealtimes, and then increasing further in the evening as people use lighting, TVs and radios. This curve shows a cumulative load of 300 kW h for Padre Cocha.

The state-of-charge of the battery declines during the early morning and night-time hours as electricity is used

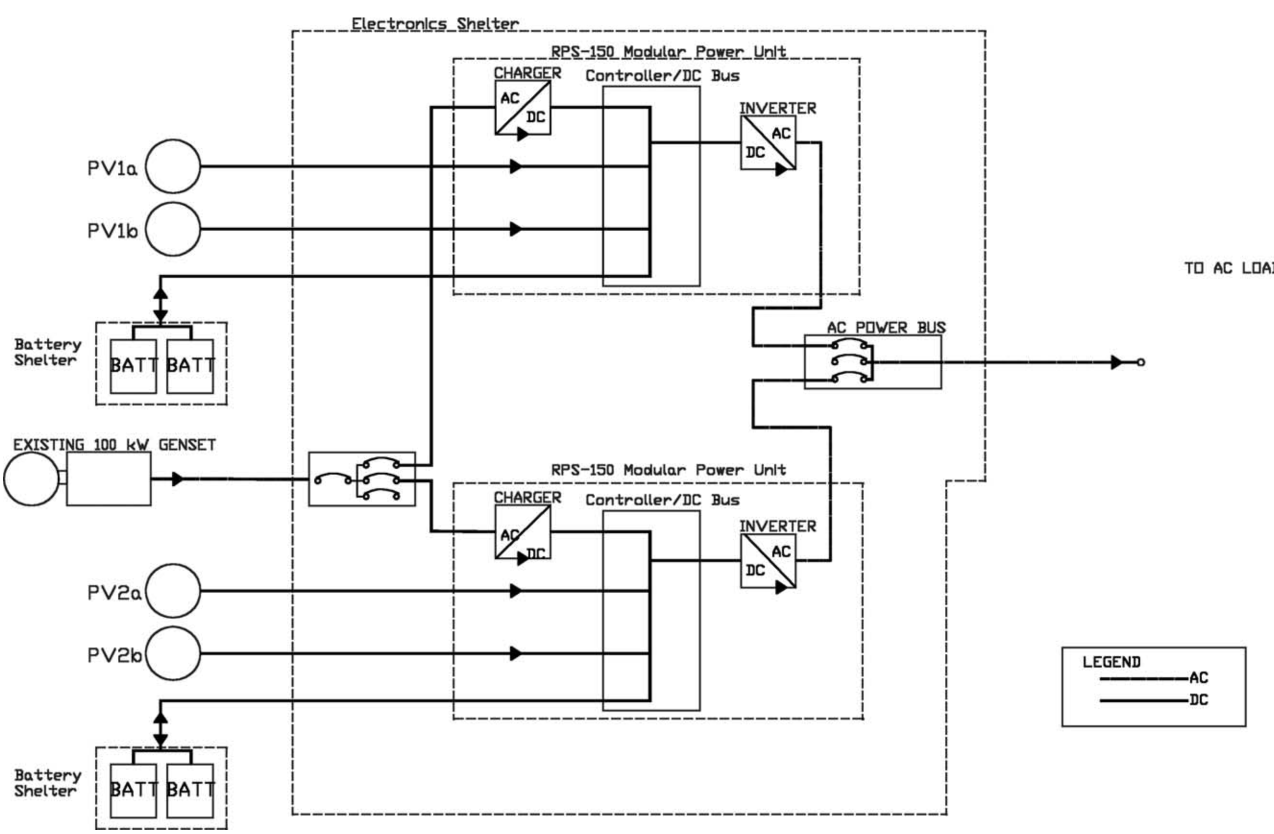

Fig. 3. Specific block diagram of the Padre Cocha installation.

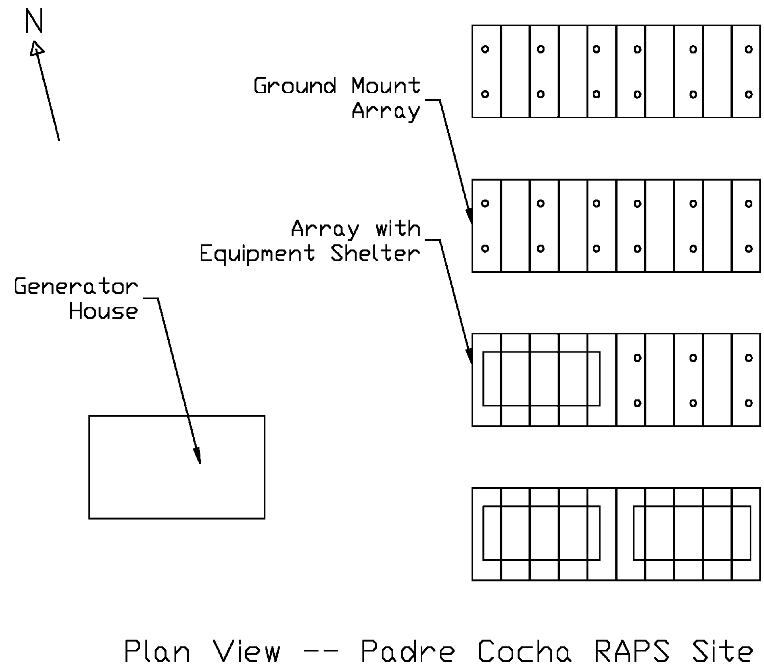

Fig. 4. System configuration for Padre Cocha.

primarily for street lighting. The state-of-charge increases as the sun rises, taking charge from the solar panels. Then the battery state-of-charge decreases as night falls, until the generator switches on and recharges the batteries over a 2–3 h period. Then, the cycle repeats itself daily.

In order to optimize the charge–discharge cycle for long battery life, CSIRO, with funding from the Australian International Greenhouse Partnership, undertook a laboratory simulation of cycling the gel VRLA batteries under RAPS conditions. Two 24 V banks of batteries were used. One bank was made up of "new" cells, while the other bank was put through an "aging" process in an attempt to determine the performance of the cells after a long period of use. Based on this work, CSIRO developed specific recommendations for charging and equalizing the cells with the diesel genset. Specifically the recommendations are:

- Cycle the battery banks for 14 days at partial-state-of-charge (PSOC) between equalizations.
- When determining state-of-charge, adjust regularly based on the open circuit voltage: state-of-charge relationship.
- When battery bank dips below 40% state-of-charge, charge the cells to an average of 2.45 V.
- Do a battery conditioning charge every 14 days consisting of:
  - equalizing at 2.45 V,
  - charge at 10 A to 102% overcharge.

Fig. 3 shows the specific block diagram of the Padre Cocha installation, with the two 150 kW h modules in parallel.

Fig. 4 shows the system configuration for Padre Cocha: the powerhouse, the solar arrays and the three-shelter-containers on concrete pads.

In the two villages, a total of 1440 2 V gel VRLA cells manufactured by the Australian company, Battery Energy Power Solutions, based on a design developed by CSIRO and TELSTRA in Australia will be installed. The total lead content of the two batteries for the two installations is in excess of 30 t.

BP Solar SX 80 solar panels providing a total of 90 kW will be used. The solar panels will provide approximately 35% of the energy with the remainder coming from the gensets.

Fig. 5 lists the power electronic components. While the components were designed and built specifically for the Peruvian RAPS systems, they are made up of standard electronic parts.

The systems will be equipped with satellite monitoring capabilities. The system will be monitored every 15 min for voltage, current, power and temperature. In addition, each 12 V block of batteries will be monitored for temperature and voltage. A number of controller functions will be able to be accessed and adjusted remotely. This monitoring and the ability to make adjustments will be a source of valuable operating information, and from a practical standpoint, will greatly aid maintenance scheduling.

✓ 40 kW 3-Ph inverters
✓ Hi Freq PWM IGBT
✓ 95% efficiency
✓ 40 kW Battery Charger
✓ 6 pulse SCR w/ filter
✓ Controlled setpoints for optimum charging

Fig. 5. The power electronic components used in the Peruviam RAPS systems.

Fig. 6. Villagers provide manual labor in the final placing of one of the equipment housings.

While the capital costs of RAPS systems are high—the estimated installed cost of each 150 kW h module is of the order of US$ 200,000–220,000—the operating costs are relatively low. Overall, it would appear that hybrid RAPS systems are the most cost-efficient means of bringing 24-h electricity to remote communities. Studies have estimated that energy costs for a family living in a remote community is approximately US$ 10 per month for candles, batteries, kerosene and the like. Basic 24 h electricity—on the order of 15 kW h per month—can certainly be supplied for US$ 10 per month. This would work out to about US$ 0.67 kW h. However, the operating costs for a RAPS system are really only on the order of US$ 0.15 kW h, so there is quite a bit of flexibility for setting tariff rates. By comparison, the operating cost of a 24 h diesel genset is approximately US$ 0.89 per month.

This project has been a sizeable and complex undertaking. The 18 different entities have had major roles in the project thus far. These include major funding sources, such as the Global Environmental Facility and the Common Fund for Commodities, but also engineers, equipment suppliers, and governmental entities. All this has been coordinated by ILZRO and ILZROs Peruvian subsidiary ILZRO RAPS Peru.

Delays have been substantial and the systems will not be fully operational until early 2003. The delay has been overwhelmingly due to government bureaucracy. Since this project began in 1997, there have been three political administrations, and four energy ministers. Multiple ministries and regional governmental entities have also been involved. All must conduct studies and evaluations, develop agreements and contracts, write reams of papers and wear out rubber stamps. Funding for the PV panels promised years ago has been budgeted but not yet released by the regional government. There have been major shipping problems. Two of the three shipping containers of batteries being shipped up the Amazon River through Brazil were seized by Brazilian customs because of improper paperwork by the shipping company. Even though the paperwork was quickly corrected, the batteries were permanently confiscated. This required the battery manufacturer to produce an additional 1000 cells, which are currently being shipped to Peru.

Obviously, these delays have been frustrating to all and they have caused considerable additional expense and cash flow problems.

Nonetheless, everyone involved has persevered and finally there is concrete progress (Fig. 6).

The picture in Fig. 6 conveys, at least to an extent, the spirit of determination and community pride in Padre Cocha. These people are poor, but they know that with 24-h electricity, their lives and their futures can be improved dramatically.

4. Conclusions

The RAPS systems that have been designed are state-of-the-art, cost-effective, and right for Peru.

Replication of systems like these can, in the spirit of sustainable development, make a major contribution to the quality of lives of remote people throughout the world. In doing so they also represent a major opportunity for the lead and lead-acid battery producers throughout the world.