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Short communication

Energy storage in remote area power supply (RAPS) systems

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Abstract

Preliminary cost analyses indicate that hybrid RAPS systems are more economically attractive as a means to provide electricity to remote villages than are alternatives such as 24 h diesel generation. A hybrid remote area power supply (RAPS) system is being deployed to provide 24 h electricity to villages in the Amazon region of Peru. The RAPS system consists of modules designed to provide 150 kWh 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 gelled electrolyte batteries, a battery charger, a photovoltaic array and an inverter. Despite early difficulties, the system in the first village has now commenced operation and the promise of RAPS schemes as a means for providing sustainable remote electrification appears to be bright.

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

1. Introduction

The standard of living of a large proportion of the world's population is limited by lack of an adequate supply of energy. The final report of the G8 renewable Energy Task Force concluded that 'Modern energy services are fundamental to economic, social, and political development and are essential in sustaining human life and improving human welfare' [1]. The World Bank estimates, however, that some two billion people live without access to electricity and many more millions have limited, inadequate electricity. Populations living beyond the reach of the distribution systems from large power stations can only be supplied by so-called remote area power supply (RAPS) systems.

Efforts to bring electricity to hitherto deprived communities should be sustainable in global terms. In this context, sustainability has been defined [2] as follows: 'sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. Thus technical development such as the expansion of the availability of electricity should preserve the earth's resources (minerals, etc.) and protect the environment, while raising the standard of living in an affordable manner.

In many remote areas, the primary means of generating electricity at present is the diesel generator. While the generators are relatively cheap to purchase and install, they use expensive diesel fuel and emit significant quantities of pollutants, including greenhouse gases. The logical approach to provide new electrical capacity in a sustainable fashion is to take some advantage of the fact that, on average, 235 W of solar radiation reach the surface of the earth [3], representing a 'renewable' source of energy.

2. Hybrid RAPS systems

Although a system drawing all of its primary energy from a renewable source such as solar radiation offers the most environmentally friendly configuration for a RAPS system, the capital costs of photo-voltaic panels are very high and, in fact, the lowest life-time cost is achievable through a 'hybrid' system. This takes some of its primary energy from solar photo-voltaic panels and the balance from a diesel generator, and has a battery bank storing energy to balance out-of-phase

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Table 1
RAPS life cycle cost comparison ($) for a 300 kWh system

Item	System 1 (0% PV)	System 2 (35% PV)	System 3 (100% PV)
Capital	165000	553800	1200000
Fuel	1338771	326285	0
Recurring non-fuel	217962	33275	30000
Non-recurring	193087	111508	185000
Total	1914820	1024868	1415000

Data for systems 1 and 2 from reference [4]. Data for system 3 derived by extrapolation from systems 1 and 2.

supply and demand. In such a system the diesel generator can be run for just a few hours per day, but at its optimum efficiency, which minimizes fuel consumption and exhaust emissions. Table 1 illustrates how a hybrid system can have lower lifetime costs than either a system using diesel alone (a ‘prime diesel’ system) or a system with no diesel generating capacity at all.

3. The choice between batteries and fuel cells for energy storage

In principle the energy storage system in RAPS could be provided either by a fuel cell or by a battery. Since the supply of fuel to remote locations represents a significant cost it would be preferable for there to be no addition to the transport cost involved in the supply of diesel. Any fuel cell system would therefore need to be coupled to an electrolysis unit operated with system power which is surplus to the instantaneous requirement of the system load, and provision would then need to be made for storing the fuel produced. Storage of hydrogen remains an expensive option. An alternative might be to operate a system producing metallic zinc particles which could be supplied to a zinc/air fuel cell. Energy stored in this form could be stored for months if necessary, at quite low cost.

To date, however, energy storage in RAPS has been provided exclusively in the form of banks of batteries, despite the fact that battery life has represented a challenge.

4. The choice of battery type

In the past, lifetimes of batteries in photo-voltaic (PV) systems have sometimes been shorter than would have been expected based on the experience with other applications and this has been, at least partly, attributable to the development of stratification of the acid concentration within the electrolyte (greater concentration towards the bottom of the cell [5]). In flooded batteries acid stratification can be overcome by the use of a device for stirring the electrolyte or by employing a regime which causes gassing from time to time. In remote situations there is a preference for batteries characterized by the least complexity and with minimal servicing requirements. In general valve-regulated lead-acid (VRLA) batteries would fit this profile but the subgroup which incorporates absorptive glass mat separators is still prone to acid stratification and cannot be subjected to a routine gassing operation to overcome the problem. Gel batteries, however, do not suffer from acid stratification and are well suited to RAPS operation involving cycling (Fig. 1) [6]. An ideal regime is one in which the battery spends much of its time below a full state-of-charge, where its charge efficiency is high, and is treated to a conditioning charge at infrequent intervals. It is very difficult to hold VRLA batteries near a full state-of-charge without losing charge efficiency due to the operation of the internal oxygen cycle. VRLA batteries perform less well than flooded batteries when on float duty for a long period (Fig. 2) [6]. It is thus recommended that a RAPS energy storage system should make use of gel batteries operated at a partial-state-of-charge [7].

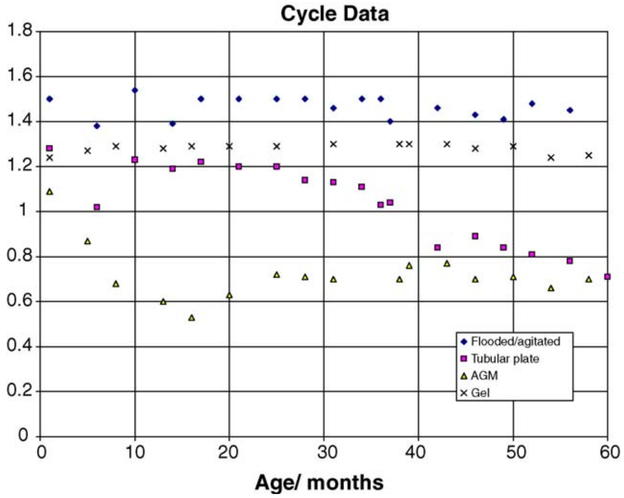

Fig. 1. Evolution of capacity of batteries of different types under a cycling regime [6]. A battery with a flooded electrolyte and a forced-air electrolyte agitation system performs best but is somewhat complex and costly. A gel battery also exhibits a good performance sustained over a long life. The capacities of batteries with a tubular positive plate (and an undisturbed electrolyte) and those with an AGM separator fall away due to acid stratification.

An important factor in designs aimed at limiting the extent of the oxygen recombination is that the level of saturation of the negative plate should be high [8]. This is because the diffusion of oxygen through the electrolyte film on the negative plate is the step which limits the rate of the oxygen recombination process.

5. RAPS systems in the Amazon region of Peru

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 RAPS systems in Peru. Subsequently, ILZRO sponsored the engineering design of the hybrid RAPS sys-

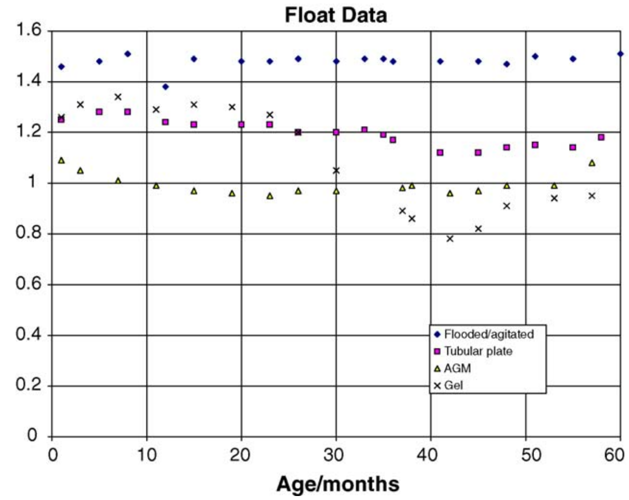

Fig. 2. Evolution of capacity of batteries of different types under a float charge regime [6]. The capacities of both flooded-electrolyte batteries hold up better than those of VRLA batteries in this regime because the latter suffer an irretrievable loss of water from the electrolyte when operated for long periods at or above top-of-charge.

tem 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 was received from the Global Environmental Facility (GEF) administered by the United Nations Development Program (UNDP) and from the Common Fund for Commodities (CFC). Funds were also received from the US Department of Energy, the International Greenhouse Partnership (Australia) and the Peruvian government.

A hybrid remote area power supply (RAPS) system in which photovoltaic panels are used to minimize diesel genset run time as well as to reduce overall cost is being deployed. Over the life of the system (at least 20 years) the reduction in CO_2 emissions will amount to over 1 million metric tons. There will also be huge reductions in the lifetime emissions of nitrogen oxides, hydrocarbons, sulfur oxides, carbon monoxide and particulates. 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.

6. The installations

The two villages where the RAPS systems are being supplied are Padre Cocha, where there is a requirement for approximately 300 kWh day^{-1}, and Indiana, where the need is for 600 kWh day^{-1}. The RAPS modules are supplied as 150 kWh modules. Therefore, Padre Cocha will use two modules, while Indiana will use four modules. Each module includes 30 kW (peak) of photovoltaic (PV) panels which provide 35% of the energy input, the balance coming from the diesel operating at maximum efficiency for 2–3 h each evening. Energy is stored in a battery bank which comprises two groups each of 120 lead-acid cells, in parallel, contributing a stored capacity of 180 kWh (240 V dc, 750 A h). Fig. 3 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, TV's and radios. This curve shows the cumulative load of 300 kWh for Padre Cocha.

The state-of-charge of the battery declines during the early morning and nighttime hours as electricity is used primarily for street lighting. The state-of-charge increases as the sun rises, taking charge from the solar panels. Then the battery

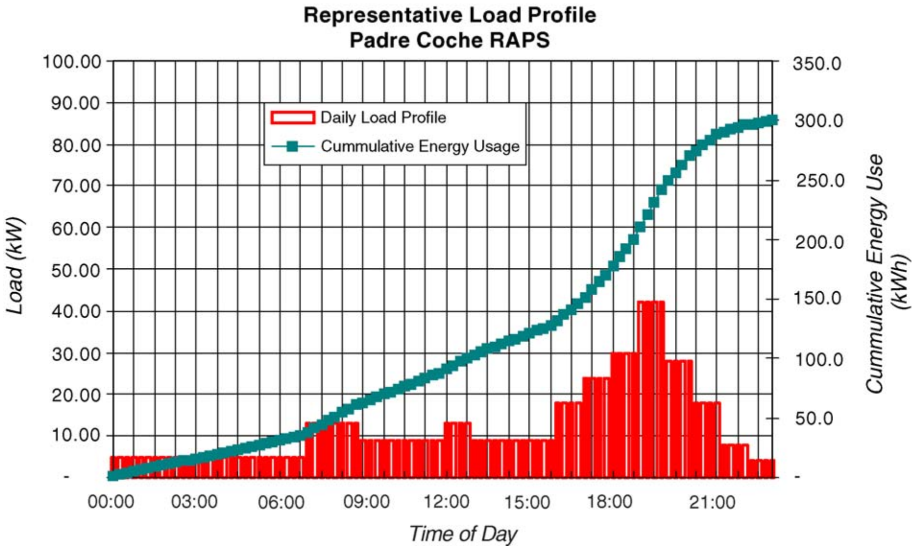

Fig. 3. Typical electrical load profile for Padre Cocha.

state-of-charge decreases as night falls, until the generator switches on and recharges the batteries over a 2–3 h period. The cycle repeats itself daily. 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 $ 2.7 million, but this includes all the initial design work, prototyping, legal arrangements, etc. The cost for replication will be very much lower. Indeed it is anticipated that future installations can be provided for $ 200k per 150 kW unit.

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 1.5 h flight from Lima on the Pacific coast.

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.

7. The batteries

Many earlier efforts to provide continuous electrical power from PV systems have been defeated by an inappropriate choice of battery and a lack of attention to system management, leading to battery failure after 2 or 3 years. In the present project batteries which have been expressly designed for RAPS duty have been used and are expected to provide an operational life of 8–10 years. The batteries, which were manufactured by Battery Energy Power Solutions in Australia, have robust plates and are of a gelled electrolyte valve-regulated design. The thick plate gel design allows the batteries to operate in the favorable partial-state-of-charge region (see Fig. 3), where charge efficiency is very high, without the danger of stratification or of charging in conditions which aggravate corrosion. Laboratory tests of batteries of this general type have yielded over 5000 cycles compared with less than 2000 cycles for a flooded design in the same test [3]. The valve-regulated design recombines the low levels of gas that are produced and, since no water is added during life, the danger of self-discharge arising from the use of impure top-up water (common in developing countries) is also avoided. The total lead content of the two batteries in 10 years for the two installations is in excess of 30 tons.

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 between equalizations.
- When determining state-of-charge, adjust calibration regularly based on the open-circuit-voltage/state-of-charge relationship.

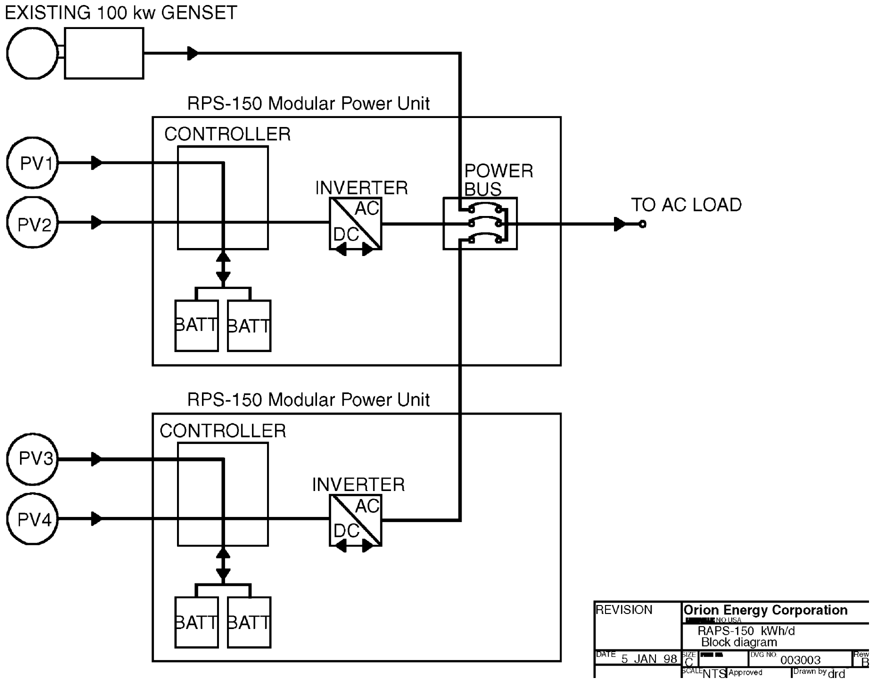

Fig. 4. Specific block diagram of the Padre Cocha installation.

- 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. 4 shows the specific block diagram of the Padre Cocha installation, with the two 150 kWh modules in parallel.

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.

8. Costs

While the capital costs of RAPS systems are high, the operating costs are relatively low (see, for example, Table 1). 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 the cost of energy for a family living in a remote community is approximately $ 10 per month for candles, batteries, kerosene and the like. Basic 24 h electricity – on the order of 15 kWh per month – can certainly be supplied for $ 10 per month. This would work out to about $ 0.67 kWh^{-1}. However, the operating costs for a RAPS system are really only on the order of $ 0.2 kWh^{-1}, so there is a good deal of flexibility for setting tariff rates. By comparison, the operating cost of a 24 h diesel genset is approximately $ 0.9 kWh^{-1}.

9. Conclusions

Delays in the installation of the first of the RAPS systems in Peru have been substantial. Since the project began in 1997, there have been three political administrations, and five energy ministers. Multiple ministries and regional governmental entities, all contributing their own bureaucracy, have also been involved. There have been major shipping problems. Two of 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 and to ship them 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. The system at Padre Cocha went on power for the first time in the summer of 2003 and, despite some teething problems with the conventional plant (the diesel generator and the distribution grid), the system is now operating close to its design specification.

The RAPS systems that have been designed are state-of-the-art, are cost-effective, and right for Peru. In the Loreto region there are 3000 remote communities and only 150 of these even have small diesel gensets (providing part-time electricity). In Peru as a whole there 70,000 remote communities, all crying out for access to electric power. Replication of systems like these can, in the spirit of sustainable development, make a major contribution to the quality of lives of remote people in Peru and throughout the world. In doing so they also represent a major opportunity for RAPS system component suppliers and lead-acid battery producers throughout the world.

The key that has unlocked the route to the introduction of these systems has been the development of a battery technology with sufficient operating life to render the economics of the scheme acceptable. The work of Professor Garche and his colleagues has contributed an important part of this progress.

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