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Lead-acid battery capacity in solar home systems—Field tests and experiences in Lundazi, Zambia

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Abstract

Batteries in solar home systems can cause problems and costs for the users and/or operators of the systems. In Zambia the Lundazi Energy Service Company (LESCO) operates 150 solar home systems on a fee for service basis. The aim of the study was to investigate how the capacity of lead-acid flat plate batteries had changed after one year of operation under real conditions. The results indicate that the batteries capacity has been significantly reduced in comparison to new unused batteries of the same type. Changes in battery management and maintenance, along with additional education of customers on correct use of SHS is advised in order to improve the life span of batteries in practical use.

Keywords: Lead-acid battery performance; Field test; Photovoltaics; Africa

1. Introduction

Solar home systems (SHS) have been promoted as an alternative to grid extension for rural electrification in many developing countries. During the 90s the cost per installed kW decreased significantly (Green, 2000), and ambitious projects for solar home system diffusion have been running in countries such as Zimbabwe (Mulugetta et al., 2000), South Africa (Afrane-Okese and Mapakao, 2003; DME, 2002) and Ghana (Abavana, 2000). Kenya is one example where a more spontaneous diffusion of solar systems is taking place (cf. Acker and Kammen, 1996; Duke et al., 2002).

Systems in donor-funded projects are normally designed using a step-by-step sizing process (cf. Komp, 1995; PVPS, 1999; Stapleton et al., 2002) and a typical setup in Africa is a 50 W_p panel with a battery capacity ranging between 60 and 100 A h. These systems will serve a household, shop or small institution with light for a couple of hours. It can also give provision for a radio cassette player and a black and white TV set.

Even though the solar PV panel is the largest post in the system cost initially, the lifetime cost of the batteries will usually be higher (Banks, 1998; Díaz and Lorenzo, 2001). In addition to this, the panels work relatively well in the practical application (Nieuwenhout et al., 2001). The battery can theoretically work nicely for many years, but same battery can be damaged with a reduction

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of capacity as a result in a short period of time. Batteries in a solar home system (SHS) are affected both by the discharge patterns of the users, and by the uneven and often low charge current given from the panel.

The aim of this article is to present results from measurement of battery performance after one year of operation in SHS in a local energy service company in Zambia, and to discuss battery management and maintenance practices. Studies on the performance of solar batteries are mostly done in a lab setting (cf. Armenta-Deu, 2003; Potteau et al., 2003; Spiers and Rasinkoski, 1995), where the aim is to see how the battery will function during its lifetime. The present study looks at how the battery is performing after one year of real life use in a rural setting in a solar home system. Most knowledge on this issue is anecdotal, with some exceptions (cf. Huacuz et al., 1995; Reinders et al., 1999).

One of the problems is to examine the battery capacity. Normal field procedure is to collect specific gravity readings of the battery cells, but these will only serve as a rough estimate of the level of charge of the battery, but not give information on the storage capacity of the battery. As batteries deteriorate through practical use, the capacity goes down. To the operator (owner) it is crucial to slow down this process as much as possible in order to keep the lifetime of the batteries as long as possible and thus cut costs.

In 1996 a solar PV project was initiated in Zambia. This project was implemented by the Department of Energy, Government of Zambia. The aim of the project was to support the creation of three local energy service companies in the Eastern Province and learn from these experiences in order to see if, and how, solar technology could fit in the National Energy Policy (Ellegård et al., 2004; Ellegård and Nordström, 2001a,b). One of the three companies operates 150 solar home systems spread around the town Lundazi (Fig. 1).

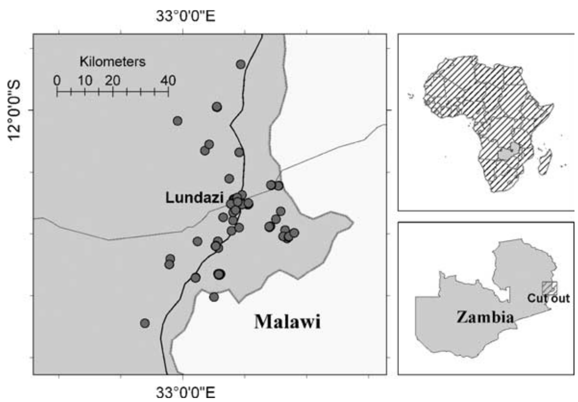

Fig. 1. Location of solar home systems operated by LESCO. Customers are represented by dots.

Clients pay a fee for the use of the SHS. At the time of the study, the fee was Zambian Kwacha (ZMK) 35,000 (8.6 USD, September 2003). While most customers do not have access to any grid extensions, there are some customers in the town that could opt for a grid alternative. The technicians perform monthly inspections of the systems and service them if necessary. If any problems occur, the clients are required to report to the office. The technicians have participated in training courses offered through the Zambia PV-ESCO project. [1]

2. Methods

Battery tests were performed on a random sample of 13 batteries found among the LESCO (Lundazi Energy Service Company) customers. Two new batteries (purchased in Lundazi) of the same brand were also tested as reference objects.

In the design of test procedures two important factors were considered. First the test should not affect the battery negatively in any way, i.e. deep discharge was not in question. Secondly, it had to be a simple and rigid test design. A solar regulator (BP solar GCR 1200) was used in order to solve the problem of not discharging the batteries below an acceptable level, and the regulator would also make the testing less dependant on attention during the test cycle. Data loggers in combination with software (Intab Easy view pro) that enabled simple download of data made the documentation of the test cycle as accurate as possible. A low cost test rig that could be used in the day-to-day operation of the ESCO was desired for the purpose (Fig. 2).

The test readings were logged with two separate 8 bit loggers (Tinytag Plus, IP68). The first logger measured the voltage over the battery, and the second logged the voltage over the shunt giving the load current. Logging was made in intervals of 30 s. The measurements of the voltage over the battery have an accuracy of 0.06 V and the load measurements have an accuracy of 0.08 A. A car lamp of 55 W was placed outside the test room and functioned as a load.

The regulator used in the tests is the same model and brand as those found in the customer's systems. The test-runs made to test and calibrate the test rig gave the 'low voltage load disconnection' to 11.7 V and the 'load reconnect point' to 12.2 V. The set points for 'low voltage load disconnection' and 'load reconnect point' were kept to those made by the manufacturer.

[1] Information on the Zambia PV-ESCO project can be found at http://www.sei.se/energy/pvesco.

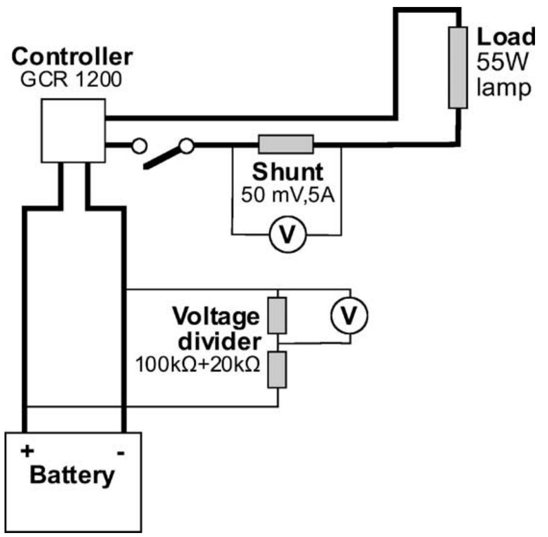

Fig. 2. Battery test rig.

A conventional grid connected battery charger was used to charge the batteries brought from customer's homes before the test-runs began. Customers were equipped with a replacement battery during the time tests were performed. It was decided that the batteries should be charged to a level where gassing commenced, and then the charging should continue one or two hours. Even though we could not assess exactly the charge of the battery through this, it was a practical approach in the field setting. The open-circuit voltage was measured in each test before the load was connected. In the analysis of the data we found that in all except one case open-circuit voltage above 12.8 V was reached. This level indicates a fully charged battery.

After the battery had been charged it was placed in the test rig and loggers were turned on. Thereafter the load was switched on. The test run went on until the power had been cut at least once, and then loggers were turned off and information downloaded to a laptop computer. The battery was then recharged to full again and then a second test run was performed in the same way as the first one. The battery was thereafter recharged and brought back to customer.

The batteries tested had been part of SHS that had been in operation for about 1 year. Batteries had not been shifted during this time. Customers were anxious to get their own battery back once the tests had been performed. They argued that they had taken care of their battery and did not want a faulty or less efficient one back.

The test design used does not follow standard routines for controlled discharge (cf. PVPS, 2002), thus making comparison to other tests difficult. Through the inclusion of two reference batteries a level comparison was achieved and hence an assessment of the reduction of capacity within the sample was possible.

2.1. The SHS in Lundazi

The systems used in Lundazi consist of a 50 W_p solar panel (BP250/1) mounted on the roof of customers' houses. Battery and regulators are found inside a lockable metal box placed inside the house. There are four lamps included in the system, two 8 W and two 13 W incandescent lamps. In most cases the people living in the house have decided the location of these lamps. Wiring is done in conduit pipes. In addition to this, one double 12 V socket is provided including two plugs. Installations follows the Zambian standards for solar installations (ZBS, 2000). The households that are customers to LESCO normally belong to what could be referred to as a higher or middle-income group in the rural setting. The majority of the households have at least one formal income (Gustavsson, 2004).

Lamps are used in the mornings, and in the evening the system is used for lamps and appliances for entertainment. Typically 10–15 A h (12 V) are used per day, and the load is in the range of 2–4 A. Most households have electric appliances other than the lamps provided with the systems. Radio cassette players are the most common, followed by TV (12 V, black and white). The design of the systems was made according to general design parameters, and an assessment of the need for electricity for entertainment appliances.

The systems were procured by the Government of Zambia, and were subsequently installed at the customers' houses in Lundazi. The cost (including panel, battery, plugs, cables, lamps, and installation) was about 900 USD each. The cost of the batteries found in the systems are about 460,000 ZMK (2003, 90 USD). If assuming that batteries have a life expectancy of 3 years and that the systems were supposed to be operated for 15 years, it would mean that each system would use five batteries during the lifespan.

2.2. Batteries tested—First National RR2 battery

The batteries used in Lundazi are of the brand First National RR2 battery, which is a typical leisure, or (medium cost) solar type. These batteries have been extensively used in solar home applications in a number of Southern African countries. The DOD (depth of discharge) 80% rating is 250 cycles with a nominal capacity of 96 A h.

The open circuit voltage after the load was disconnected gives an indication of the charge of the battery. This voltage was in the range of 12.12–12.17 V, which indicates that the batteries were discharged to a level of about 60% DOD. According to a C_{20} discharge curve

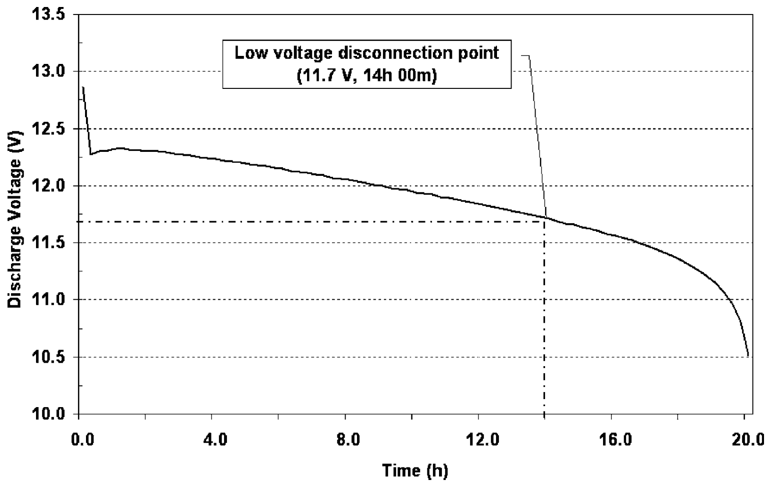

Fig. 3. RR2 Battery, 20 h discharge, 5.25 A.

supplied from First National the available energy should be about 70 A h (Fig. 3).

2.3. Temperature

Temperature is a factor that will affect the life of the battery. Temperatures were collected from one battery box and from this it should be possible to deduct a value that can be used as a rough value for all the batteries (Fig. 4). The temperature inside the battery box varies, but ranges from 30 °C to below 20 °C. During the period of measurements the average temperature was 24 °C. This temperature range suggests that flat plate open lead-acid type batteries, such as solar batteries, truck starter batteries or leisure batteries, can be used as a low cost option (Spiers and Royer, 1998).

3. Test results

3.1. Discharge tests

All batteries tested, except the reference batteries, had been operated for about one year. The technicians do a monthly visual inspection of acid levels and topping up with distilled water. Specific gravity readings are collected and records are kept in each battery box, and in the office. The information on specific gravity for all LESCO's batteries suggests that batteries are seldom fully charged, but rather DOD is in the range of 40–60%. An analysis of the records for July 2002 shows that according to specific gravity readings 45% of the batteries had a DOD of 50%, about 75% of the batteries were below 40% DOD. Only about 5% of the batteries were

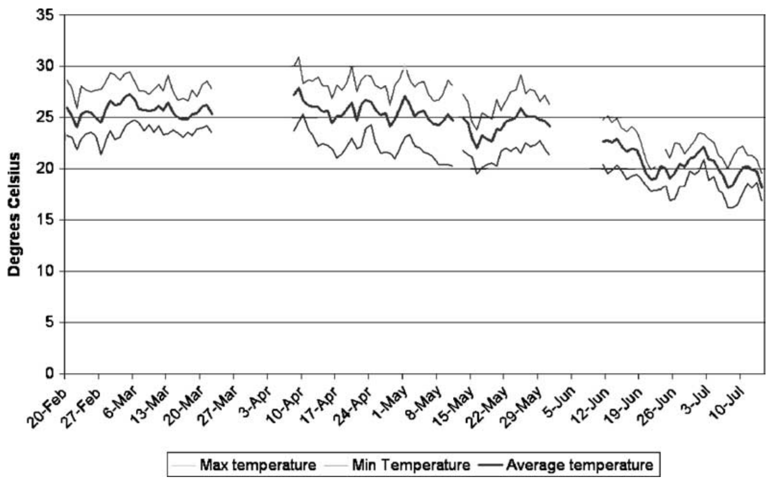

Fig. 4. Temperature inside battery box, 20 February–14 July 2003.

found with DOD less than 20%. Specific gravity metering of battery cells is, however, only a very rough estimate on the state of charge. Stratification of battery acid for example may make the readings show too low levels of charge (Spiers and Royer, 1998; Spiers and Rasinkoski, 1995).

3.2. Available energy

The results from the controlled discharge tests shows that available energy in a fully charged battery has decreased from average level of 61 A h in the new batteries (second test run) to 34 A h in the used batteries (second test run). This is 55% of the capacity in the new batteries (Fig. 5).

Almost all the batteries indicated a higher storage capacity in the second test run, which was expected. By letting the batteries experience a re-charge including gassing stirs the acid and this helps removing stratification as well as making some of the sulphate crystals to re-dissolve (cf. Lorenzo, 2000; Sauer, 2003; Spiers and Rasinkoski, 1995). Operating a solar system with shallow cycles in combination with a low state of charge is harmful to the battery.

According to the C_{20} discharge curve (Fig. 3) the storage capacity should be in the range of 70 A h. The two reference batteries did not reach this level, which is the result of among other things storage of the batteries. A number of charge cycles should recover the battery to some extent, which was also experienced. The same process as with the used batteries will be experienced as the battery is charged and gassing takes place.

Designing a solar system is done taking into account the expected daily usage patterns, climate conditions and economic limitations. The result is a system that has a slightly larger average charging capacity, than daily average use. This system would be able to recharge the battery and keep a high level of charge, even in cases where the state of charge drops. The problem is, however, that once the system has been installed, the charge capacity cannot be changed unless the charge capacity is increased, i.e. more panels are added. The load, on the other hand, will typically increase, as the customers are able to invest in electric appliances. Many of the LESCO customers have for example acquired TV-sets since they received solar service, and a number of clients express interest in connecting larger appliances, such as fridges, to their systems.

3.3. Load cut and reconnection

The discharge curves for used batteries and the reference batteries are different. While reference batteries were discharged in one go, the used batteries normally went on and off a couple of times. After reaching the 'low voltage load disconnection' point the battery would typically gain voltage in 1–2 h and then reach the 'load reconnect point' without being charged from outside (Fig. 6).

One explanation for this is that one cell of the battery is being discharged more quickly than the others and thus a more rapid decrease of voltage takes place. The voltage drop between a fully charged battery (about 12.8 V) and the 'low voltage load disconnection' point (at 11.7 V) is only 1.1 V and even one only slightly

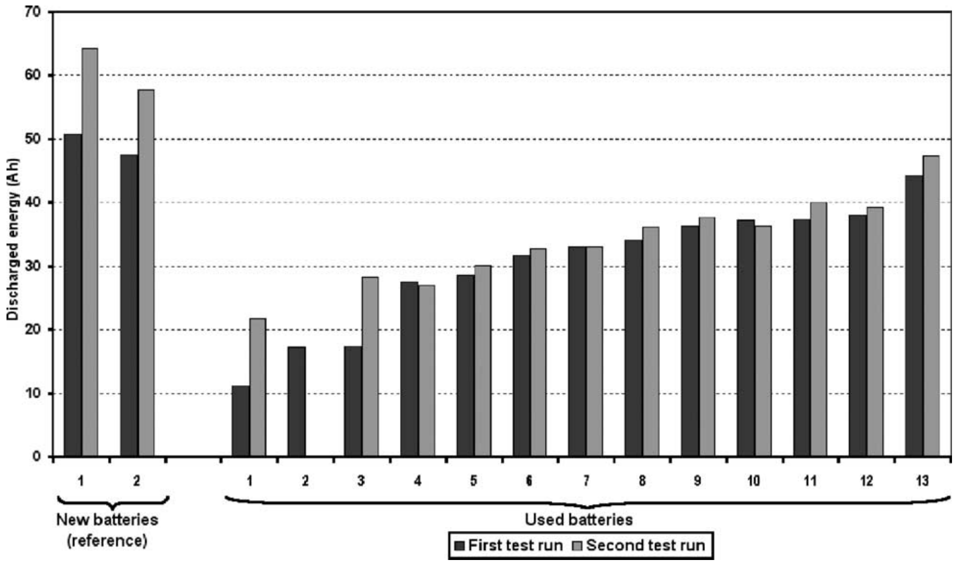

Fig. 5. Available energy in new and used batteries (discharge current 4.5 A). Two test runs per battery.

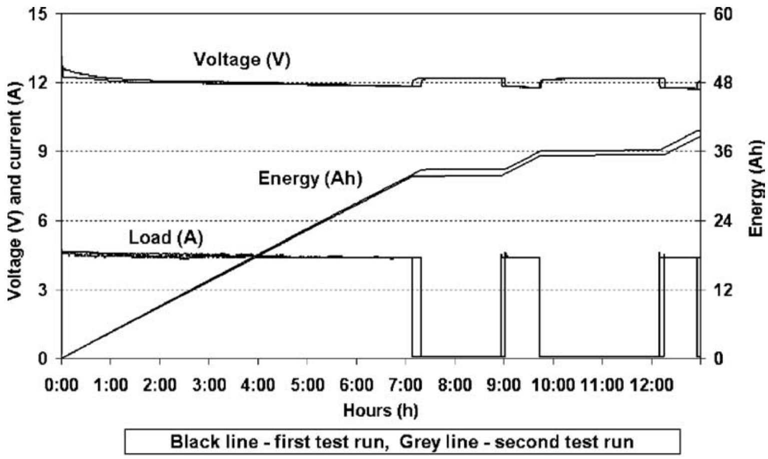

Fig. 6. Discharge curve (battery 7 in Fig. 5).

damaged cell can cause an unbalanced cell-potential that results in a reduction of the time it takes to reach the disconnection point.

The difference between the 'low voltage load disconnection' and 'load reconnect point' is 0.5 V. When load is cut, the potentials between the cells are balanced and the 'load reconnect point' can be reached without external charge of the battery. Then the load was switched on again. Díaz and Egido (2003) argue that the difference in set points should be in the range of 0.9–1.2 V in a 12 V system.

On average the batteries had 50 min of power (4.5 A) available between the first reconnection and second cut. This extra power might be one of the reasons why complaints are not very common. If the systems are overused during the night, in the morning the battery has reached above the reconnection point and thus making the results of over usage less visible to the customer. The load during morning is mainly for lamps and during the day the system gets re-charged.

Regulators have not been adjusted in terms of set points. We did not collect information on the set points in the field, but as these are also pre set values, it can be assumed that the levels are similar. To adjust set points in the field requires both training and equipment, which LESCO does not have at present. Adjusting the set points will also change the way the system behaves. The user will, for example, experience prolonged periods where the system recovers its state of charge after load is cut by the regulator. This may impose problems as users may try to bypass the regulator, leaving it without any protection (Lorenzo, 2000; Nieuwenhout et al., 2001; Reinders et al., 1999)

Sometimes the lifetime of a battery is described as the time until the battery capacity has reached 80% of the rated nominal capacity (PVPS, 1999; Spiers and Rasinkoski, 1996). Even though we cannot say anything on the actual percentage of decrease compared to the rated nominal capacity, due to the test setup, it is possible to state that compared to new batteries the reduction in capacity is substantial. To LESCO this reduction in capacity is of major concern as battery costs is a large post in their budget, and prolonged battery life would result in improved results, and service to the customers.

4. Conclusions

Most of the batteries tested in Lundazi are working satisfactory in the practical application, even though the results indicate a reduction of their capacity. At some level the SHS will not give the customer satisfactory performance as a consequence of the battery, but to judge the level is difficult. The creation of a battery test rig in the LESCO office, gives new opportunities to test battery performance. Once customers report reduced performance of the system, technicians can make inspections of the battery on site and judge if more thorough tests are required. If so, battery can be brought to the office and the capacity can be assessed. The test rig used has proved appropriate, but will still require some sort of charging station (grid connected or solar power) in order to recharge batteries before and after tests.

The test rig included a regulator of the same type found in customers' homes. The 'low voltage disconnect point' and 'load reconnect point' used were those pre-set from the factory and the gap was only 0.5 V. The discharge of used batteries showed repeated cut of load and reconnections, without any recharge of the batteries, while this was not the case of the reference batteries. A widening of the gap seems appropriate, but adjusting the set points requires procedures and equipment not usually available in the field.

The storage capacity of the batteries tested has reduced significantly during the period of operation. This has taken place even though the systems operated by LESCO are relatively advanced. It seems that the technical solution to manage the systems in order to secure a safe and long life must be seen together with additional measures.

The clients to LESCO explain that during the year that the systems have been installed they have learned how to use the systems in order to avoid cut of power (Gustavsson, 2004). But it seems from the results of the battery tests that avoiding cut of power is not enough. One of the challenges is to make the customers avoid over-usage of the systems. Adjusting set points would improve the technical protection against over-usage. An indicator showing the battery state of charge, the closed circuit voltage at the battery poles, could be an option. One such indicator is found on the regulator, but as the regulator is located inside a locked box in order to avoid direct connections to the battery, this cannot be used. This indicator should be a central part of the information package given to the users, it should be designed so that the information displayed is clearly understood by the receivers.

As a result of the discussions on battery performance and the experiences accumulated in LESCO and the PV-ESCO project in Zambia new routines were introduced when batteries were found with low 'specific battery acid gravity'. These systems got their load disconnected, leaving the systems for charge for four to five days. This brings the battery to a higher charge level and it is hoped that it will prolong the life of the battery. Customers have in general accepted this, and have understood the reasons given by LESCO for the actions taken.

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