ELSEVIER

Journal of Power Sources 64 (1997) 193–196

JOURNAL OF POWER SOURCES

Monitoring the battery status for photovoltaic systems

Myungsoo Kim, Euijin Hwang

Korea Research Institute of Standards and Science, PO Box 102, Yusong, Taejon 305-600, South Korea

Abstract

Photovoltaic power systems in Korea have been installed in remote islands where it is difficult to connect the utilities. Lead/acid batteries are used as an energy storage device for the stand-alone photovoltaic system. Hence, monitoring the battery status of photovoltaic systems is quite important to extend the total system service life. To monitor the state-of-charge of batteries, we adopted a current interrupt technique to measure the internal resistance of the battery. The internal resistance increases at the end of charge/discharge steps and also with cycles. The specific gravity of the electrolyte was measured in relation to the state-of-charge. A home-made optical hydrometer was utilized for automatic monitoring of the specific gravity. It is shown that the specific gravity and stratification increase with cycle number. One of the photovoltaic systems in a remote island, Ho-do, which has 90 kW peak power was checked for actual operational conditions such as solar generation, load, and battery status.

Keywords: Photovoltaic systems; Lead/acid batteries; State-of-charge; Internal resistance; Specific gravity

1. Introduction

The solar energy utilization project in Korea started in 1988 as a part of Renewable Energy Technology Development Program. The objective of this program is to raise the ratio of renewable energy to the total energy consumption up to 3% in 2001, which, today, is less than 1% [1].

In Korea, there are about 530 islands around the peninsula where more than 200 islands are not grid-connected. Their major power sources are diesel generators and during the 1980s photovoltaic (PV) power systems have been installed in remote islands for household power supply. We have three large residential PV systems on three islands such as Hahwa-do (60 kWp), Mara-do (30 kWp), and Ho-do (90 kWp). Major components of the PV power systems are PV modules, diesel backup generators, power controllers, batteries, and d.c./a.c. inverters.

The shelf life of PV systems is expected to be twenty years, but for batteries it is less than ten years. Even this life could be shortened when the system is operated under poorly maintained conditions. Hence, monitoring the battery status of PV systems to prevent overdischarge or overcharge is quite important to extend the total system service life.

Since 1989, the battery performance evaluation program has been carried out by the Korea Research Institute of Standards and Science (KRISS) for deep-discharge PV application. There are several ways to monitor the battery state-of-charge (SOC) indirectly, such as measurement of internal resistance (*IR*) of the battery [2–5] and the specific gravity (SG) of the electrolyte [6,7]. *IR* can be measured by an a.c. impedance technique [8,9], but it is not adequate for large batteries. To monitor the SOC of batteries, we adopted a current interrupt technique to measure the *IR* of battery.

2. Experimental

2.1. Laboratory tests

Flooded lead/acid batteries (SPS-680, Global and Yuasa Battery, South Korea) were used to test the methods for indirect monitoring of the SOC during cycle service. The capacity at 10-h rate was 550 Ah, both charging and discharging currents being set at 55 A. The charging voltage was limited to 2.4 V to protect batteries from overcharging. The depth-of-discharge (DOD) was 80% and the cycle test was performed using cycle-life testers (LCN-300, Bitrode).

To measure the *IR* of lead/acid batteries, the current interrupt technique was adopted. During the cycle-life test, charge or discharge current was halted for 1 or 2 s, every 30 min. The *IR* was calculated from Ohm's law, $IR = \Delta V/\Delta I$, where ΔV and ΔI denote the voltage and the current differences between those of normal operation and current-interrupted period, respectively.

The SG of electrolyte was measured at every tenth cycles with regard to battery SOC during charge and discharge.

0378-7753/97/$17.00 © 1997 Elsevier Science S.A. All rights reserved
PII S0378-7753(96)02521-9

Direct measurement of SG was performed using a digital hydrometer (DMA 35, Anton Paar). An optical hydrometer made in our laboratory was also used for automatic monitoring of the SG. This optical hydrometer was specially designed to reduce the effect of stray lights by using d.c. nulling and phase-sensitive detection techniques [10]. The optical hydrometer was calibrated with solutions of sulfuric acid of known SG in the 1.12–1.33 range. The linear relationship between the SG and the response was in good agreement within 0.002 of SG in the 25–35 °C temperature range. One drawback for this hydrometer is that it needs periodic cleaning of the U-shaped glass rod which is used as a light path, because of the impurity adsorbed on the surface.

2.2. Field tests

The battery storage system of the PV site on an isolated island, named Ho-do, located in the Yellow Sea, midwest of South Korea, was examined for checking the actual operational conditions, such as solar generation, load and battery status. There were 60 households reside on the island and the PV system consists of 90 kWp solar cells, 100 kW diesel generator for backup power supply, power controller and d.c./a.c. inverters. The battery bank had 270 cells (2 parallel and 135 series, SPS-2700, Global and Yuasa Battery) of 1800 Ah nominal capacity at $C/10$ rate.

The major items to be checked were daily solar power generation, load power consumption, backup power by diesel generation if needed, battery voltages for unit cells and whole system, current passed through batteries, SG of the electrolyte, and the conductance of each cell.

The voltage of each selected cell was monitored using a portable data acquisition system. For this system a 20 channel scanner (Model 7001 switch system, Keithley), a digital multimeter (Model 2001, Keithley), and a notebook computer (486DX) equipped with GPIB interface were used. This system was controlled by lab-made software that was operated under Windows' operating system.

The SG of the electrolyte was measured using a digital hydrometer and Celltron Plus (Midtronics) was used to measure the cell conductance.

3. Results and discussion

3.1. Internal resistance

When the lead/acid battery is discharged, the positive (PbO_2) and negative (Pb) electrode materials become lead sulfate ($PbSO_4$) which is a nonconducting material. Therefore, *IR* increases as battery discharges. Furthermore, the electrolytic conductivity decreases during discharge due to the sulfuric acid consumed in the electrolyte. These two factors can be assigned as electronic and ionic resistance, respectively, which are fully ohmic components. The other factor affecting the *IR* is charge-transfer resistance that is associated with the electrochemical reaction rate. As the charge/discharge process goes to the end of each step or the battery is aged after a long cycle service, the active sites should be decreased. Therefore, the overall reaction rate decreases and the charge-transfer resistance increases. *IR* is the sum of these three contributions.

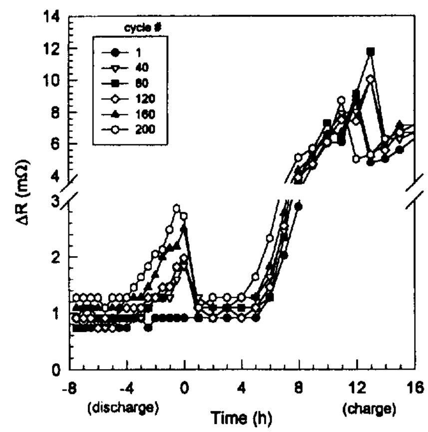

Fig. 1. Internal resistance change during charge/discharge cycles for 80% DOD.

Fig. 1 shows the change in *IR* during charge/discharge steps versus cycle number. As shown in this figure, *IR* increases at the end of discharge or charge. It seems mainly due to the charge-transfer resistance. But in the case of fresh cell, there was not a serious change in *IR* at the end of discharge. This can be described as there were still many active sites available in the fresh cell even at the end of 80% discharge. It also explains that the contribution of electronic and ionic conductivity to *IR* was not so great. As cycling proceeds, the *IR* change was quite high at the end of discharge due to the lack of active sites.

One thing to note is the change in *IR* versus cycle number at the early stages of both charge and discharge steps. The slow increase in *IR* with cycle number indicates some other factors not being mentioned above, e.g. an ageing effect. The possible reasons may come from the structural change in active materials and corrosion of the grid. They should decrease the electronic conductivity. Continuous checking of the *IR* change at the early stage of charge/discharge step is strongly recommended to monitor the battery ageing.

3.2. Specific gravity

The SG of the electrolyte was measured in two positions, top and middle, inside the battery during cycling. Fig. 2 shows the measured results of the SG change for discharge/charge steps with cycle number. The difference in SG between two positions was about 0.1 to 0.2 and this stratification was great with cycle number. The SG change showed a general trend of increasing with cycle number. It was due to the loss of water by overcharging even though there was a recombination catalysis cap at the top of battery. The SG

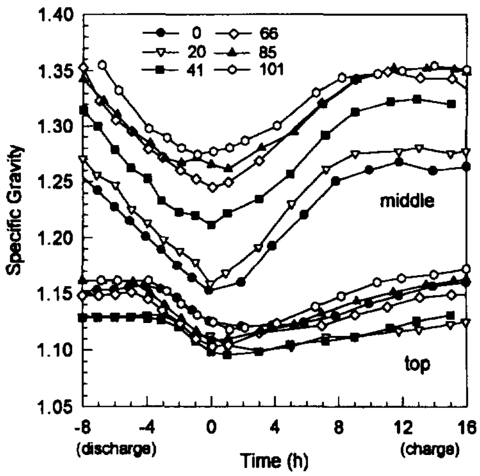

Fig. 2. Specific gravity change during charge/discharge cycles for 80% DOD.

change at the middle position during cycling was about 0.1 while about 0.03 at the top position. This means that the utilization of the active material at the top of the plate was less than that of the middle position. For large capacity batteries, this can cause severe cycle-life shortening, so periodic circulation of the electrolyte is necesary [11].

During the discharge, the SG decreased with SOC almost linearly. Although the SG could be a good index of SOC for a given cycle, it might be quite difficult to be used as an indicator for battery ageing during the whole service life due to the large change with cycle number.

3.3. PV system site check

Fig. 3 shows the daily profile of the PV system at Ho-do on a sunny day. The total voltage of battery storage system

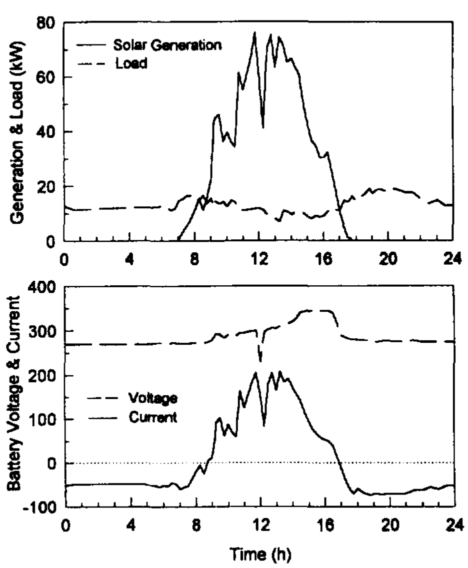

Fig. 3. Daily generation, load and battery status profile at Ho-do's PV system.

Table 1
Daily generation and load profile

	Solar generation (kWh)	Diesel generation (kWh)	Load (kWh)	Battery charge (kWh)
Sunny day (fall)	421		315	106
Cloudy day (summer)	163	325	373	115

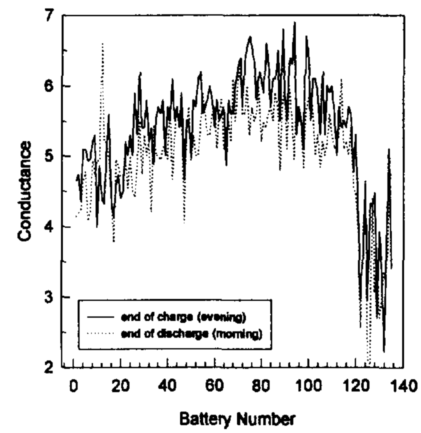

Fig. 4. Cell conductance comparison for each battery in the morning and evening at Ho-do's PV system.

was in the 270–344 V range (2.0–2.55 V for unit cell) and the SG of each battery was between 1.20 and 1.25, which indicates the batteries were in good status without deep-discharge. Daily solar generation depends on the weather conditions and in the case that solar generation is not sufficient to charge batteries completely, a diesel generator was used to back up the charging. Typical daily generation and load profile for a sunny day in fall and a cloudy day in summer are summarized in Table 1, showing the batteries were always in a fully charged state.

The charging voltage was limited at 344 V (2.55 V for unit cell) and it could make the batteries being overcharged. It is necessary to supply water frequently in order to maintain the electrolyte level constant. The cell voltages of arbitrarily selected 40 batteries were checked at every 5 min for one day, and the results are almost similar. Simple monitoring of battery voltages, however, could not give any exact indication of battery ageing in the case of shallow discharge.

Cell conductance was measured for each battery to compare the state-of-health. Fig. 4 shows some batteries, numbered 122 to 135, having relatively low conductance values. Measured results may suggest these batteries being relatively aged to have higher internal resistance. This technique could give information on the relative comparison of each cell, but it is difficult to set up the instrumentation for automated continuous monitoring.

4. Conclusions

We have tested some techniques for checking battery status and ageing. The concluions drawn from this work are:

1. Continuous monitoring of internal resistance can be a good indicator of monitoring battery ageing. The current interrupt method, however, has some problems in application.

2. Periodical checking of the SG of the battery is only required to maintain the batteries in good condition. It cannot be an index of battery ageing.

3. Simple monitoring of the cell voltage can only be an indicator whether battery failed or not.

4. Manually measured values of cell conductance may suggest which batteries are more aged.

5. The best way to check battery ageing seems to be continuous monitoring of the internal resistance from the relationship between cell voltage and current. This work is currently under progress.

Acknowledgements

The author gratefully acknowledge the Global and Yuasa Battery Co. for the research grant.

References

[1] *Renewable Energy Technology Development Program*, R&D Management Center for Energy and Resources, 1993.
[2] J.B. Copetti and F. Chenlo, *J. Power Sources, 47* (1994) 109.
[3] S.A. Ilagovan, *J. Power Sources, 50* (1994) 33.
[4] M.P. Vinod and K. Vijayamohana, *J. Power Sources, 52* (1994) 135.
[5] J.L. Weininger and J.L. Briant, *J. Electrochem. Soc., 129* (1982) 2409.
[6] G.P. Hancke, *IEEE Trans. Instrum. Meas., 39* (1990) 247.
[7] C. Armenta, J. Doria, M.C. De Andres, J. Urrutia, J. Fullea and F. Grana, *J. Power Sources, 27* (1989) 189.
[8] Ph. Blanchard, *J. Appl. Electrochem., 22* (1992) 1121.
[9] R.T. Barton and P.J. Mitchell, *J. Power Sources, 27* (1989) 287.
[10] E. Hwang, J. Lee and M. Kim, *J. Korean Chem. Soc., 36* (1992) 442.
[11] M. Tsubota, *J. Power Sources, 35* (1991) 355.