Estimating the estate of charge of lead-acid batteries.

G. G. Demetino¹, I. M. Pepe², V. L. Filardi¹, L. C. S. Soares Júnior², C. E. T. Silva¹, G. P. Guedes³, J. G. Lima
Brasílio³, D. Rey Rey⁴, A. L. Aguera⁴, J. C. Anjos⁵

¹ PPGM – Programa de pós-graduação em Mecatrônica
Laboratório de Propriedades Óticas
Instituto de Física, Universidade Federal da Bahia
Campus de Ondina – Salvador, 40210 340 – Salvador (Brasil)
Phone/Fax number: +0071 3283 6619, e-mail: jdemetino@gmail.com

² Laboratório de Propriedades Óticas
Instituto de Física, Universidade Federal da Bahia
Campus de Ondina – Salvador, 40210 340 – Salvador (Brasil)
Phone/Fax number: +0071 3283 6619, e-mail: lapo.if@gmail.com, mrfilardi@hotmail.com,
luiz_carlos_simoes@hotmail.com, eduardotanajura@gmail.com,

³ Laboratório de Instrumentação e Energia Solar
Departamento de Física, Universidade Estadual de Feira de Santana
Feira de Santana (Brasil)
Phone/Fax number: +0075 3161 8289, e-mail: germano.uefs@gmail.com, joseandro.brasilio@ig.com

⁴ Laboratorio de Aplicaciones Energetica Sostenibles
Departamento de Física de Partículas, Universidad de Santiago de Compostela
Campus Vida – Santiago de Compostela, 36310 Vigo (Spain)
Phone/Fax number: +0034 981563100 Ext:14000, e-mail: daniel.rey.rey@gmail.com, a.lopez.aguera@gmail.com

⁵ Centro Brasileiro de Pesquisas Físicas
Rio de Janeiro (Brasil)
e-mail: janjos@cbpf.br

Abstract. A new system approach for battery discharge to estimate the state of charge of lead-acid batteries has been developed and tested. This new system is based on an industrial network that runs the Modbus Protocol with RTU format. Each unit includes an ID for communication in this network, its own power supply, a stable current supply for battery discharge and its own calibration curve for each channel at the analogical-digital converter. All parameters can be configured by the software supervisor. This system is able to discharge up to 16 batteries simultaneously and save voltage and current values for each unit. All information can be saved into a file that can be read simultaneously to the data acquisition. Thus, it is easier to have it integrated to a database and distributed on to a computing network system. This system will bring more information to the battery ageing estimator, based on the observed voltage distributions over one month. The Pierre Auger Observatory works with different set-ups for the 1600 PV-stand-alone systems. Therefore, a larger scale system capacity to test each battery unit a time has become necessary.

Key words

State of charge, battery discharge, Modbus protocol.

1. Introduction

The Pierre Auger Cosmic Ray Observatory studies high energy particles that reach the Earth. These particles are detected in two different ways: a set of three fluorescence detector fly-eye type and 1600 surface Cherenkov detectors [1].

Each surface detector has a photovoltaic stand-alone system which is composed of two solar panels and two 105 Ah lead-acid batteries. The detectors performance is directly affected by the quality and quantity of the lead-acid battery stored charge.

The replacement of one or both batteries requires high maintenance costs, due to the fact that the detectors are distributed in a 3000 Km² area and the access is difficult. Moreover, bad batteries affect the whole detecting array performance.

For this reason it is necessary determine the state of charge of lead-acid batteries, since this parameter provides information about the quantity of charge stored and capability to retain charge. The state of charge must be known before the batteries are installed on the field. It

can bring more information to estimate the battery ageing and life-time.

The State of Charge (SoC) is estimated by means of the amount of charge obtained over the discharge curve and the time necessary to discharge the battery. The curve is built by the battery voltage as a function of time during the battery discharge [2]. To perform this process equipment has been developed and tested. It is capable of storing voltage and current values using the discharge at constant current method to determine state of charge. These values are used to plot the discharge curve, allowing the amount of charge and SoC calculation.

2. State of charge and method of discharge at constant current

State of charge is defined as the relation between the amount of charge in the battery, at a given moment, and the amount of charge when the battery is new (100% storing capability).

The state of charge can be calculated using the equation (1), where Q , the quantity of charge at a given moment and Q_0 is the quantity of charge when the battery is new, that also called battery capacity [2].

$$SoC = \frac{q}{q_0} \quad (1)$$

The SoC is an important information to guesstimate lead-acid batteries performance before its installation in photovoltaic systems as the Pierre Auger Observatory surface detector. On PAO the batteries are located 1.5 Km apart from each other and the access is very difficult (land road). This way, its mandatory send to the field just batteries passing the SOC quality test.

There are several methods to determine the SoC, one of them is discharge at constant current method. It consists in discharging the battery through a dynamic resistance capable of maintain the discharge current constant. The battery voltage is monitored during the discharge until a preset value (11.2 V). The figure 1 shows a diagram of the method.

Fig 1. Constant current discharge method diagram.

Therefore, to calculate the SoC it is necessary to use the equation (1). But first, the quantity of charge Q needs to be

obtained using the equation (2), where I is the current intensity and Δt is the time interval to discharge the battery.

$$Q = I\Delta t \quad (2)$$

Using the voltage values acquired during the discharge, the discharge curve can be plotted as a function of time. The graphic is important to analyse the voltage behaviour during the discharge. The figure 2 shows a typical discharge curve.

Fig 2. Typical discharge curve.

In the Pierre Auger Observatory, the SoC is estimated using a constant discharge current equal 5.25A, in less than 20 hours of a discharge regime. According to the manufacturer, under this condition, at 25° C, the battery furnishes 100 % its charge.

3. The system developed to determine the state-of-charge

The system comprises of electronic, mechanical and software components. To implement the discharge at constant current method, the battery is discharged through a constant current source. The constant current source electronics circuit comprises two metal wire power resistances, a power transistor and a constant current driver, responsible to the battery discharge control. Moreover, the current intensity can be adjusted aiming to perform testing on different capacities lead-acid batteries. The figure 3 shows the electronic diagram.

Fig 3. Electronic diagram

In this setup, the current flows through the power resistors and transistor which are heated. Therefore, the mechanical aluminium structure and three coolers are used to heat dissipation. The figure 4 shows the dissipation system.

Fig 4. Dissipation system

A microcontroller is used to manage the electronic set: perform an analogical to digital conversion of the battery voltage and current and implements the communication protocol type Modbus. Furthermore, each microcontroller is responsible to establish communication with the supervisory software and each one has its own ID on the RS - 485 network. The figure 5 shows the electronic board.

Fig 5. Electronic Board

The system was built to perform the state of charge tests safely and stably. The units can be connected as a daisy-chain network based on RS - 485. Due to this network standard and the supervisory software, the test may be performed in 16 batteries simultaneously, what is an advantage, since each battery takes 20 hours to be discharged. The figure 6 shows the unit prototype.

Fig 6. Constant current discharger prototype.

The supervisory software has been written in Visual basic programming language. It manages the equipment and provides communication. It stores voltage and current values into files, each file corresponding to one equipment unit, implements Modbus communication protocol and stores calibration parameters. Figure 7 shows the supervisory software interface.

Fig 7. Supervisory software interface

4. Results

As said before, to determine the state of charge, the battery needs to be discharged under 20 hours in constant current regime at 25° C of temperature. In the Pierre Auger, where 105 Ah stationary batteries are used, the SoC test is done at 5.25 Ampere [3].

Tests were performed on the laboratory using two equipment units and two batteries: a Moura© used battery with 60 Ah capacity and a new Zetta© battery with 45Ah capacity.

All the tests were performed in 5.25 A discharge regime as used in the Auger.

According to manufacturer, a battery is considered discharged when its output voltage reaches 10.5 Volts, but the batteries used in the test were discharged down to 11.2 Volts for safety reasons, a battery discharged down to 10.5 Volts can be irremediable damaged.

Both batteries were recharged before the test, the charge procedure adopted was to charge the battery over constant current using 10% of the battery capacity as charge current. Therefore, the 45Ah Zetta© battery was charged over 4.5A and the 60Ah Moura© over 6A.

In the first test, the 45Ah Zetta© battery was discharged using unit 255, the figure 8 shows the test result.

Fig 8. Zetta battery discharge curve.

This battery was discharged in 4 hours and 30 minutes, it represents 23.80 Ah of quantity of charge (Q), according to equation (2) and SoC of 52.89 %, using the equation (1). During this test the equipment was kept stable, with constant current, no overheating and no communication problems. The voltage and current values were stored into files on supervisory software without any problem. The second test was performed with unit 254, using the 60 Ah Moura© battery, the figure 9 shows the discharge curve.

Fig 9. Moura battery discharge curve

This battery was discharged in 2 hours and 56 minutes and, as in the first test, the system was kept stable. It presented 15.40 Ah of quantity of charge and 25.67 % of SoC.

A third test was carried out using the equipment units, 254 and 255, connected as a network to perform tests in both batteries simultaneously. The same batteries Zetta© and Moura© were used. This test aimed to validate the communication, the RS – 485 network and whether the supervisory software manages more than one unit. Figure 10 shows the discharge curves of each battery.

Fig 10. Discharge curves.

The Zetta battery was discharged in 3.5 hours whereas the Moura was discharged in approximately 0.27 hours (16 minutes). The Zetta battery capacity was 18.375 Ah and the SoC of 40.83 %. The Moura's capacity was 1.4 Ah and SoC of 2.33 %.

In all tests the batteries have presented low quantity of charge and SoC. There are several reasons that could explain this behaviour, such as temperature, discharge current values and battery age.

As said before, to obtain the state of charge of the 105 Ah batteries in the Auger, the discharge current needs to be 5.25 A. But since the batteries used in the laboratory tests needed to be performed at 2.25 A for Zetta© and 3 A for Moura©, this was not the case and 5.25 A was adopted in all tests, aiming to make sure the equipment maintained the current constant in this value. However, using this current value the Zetta© and Moura© cannot deliver 100%.

The Tests were performed mainly to validate the system, that is, check the electronics, mechanics, software and data acquisition. The calculations of quantity of charge and state of charge were carried out only to figure out the quantity of charge.

In all tests it could be clearly realized that the state of charge might be estimated over quantity of charge, acquired using the discharge curve obtained using the data stored.

5. Conclusion

The equipment was built and tested. During the tests it was clearly realized that it works, the electronics kept stable, no communication problems came up, data acquisition was well performed and the discharge curves could be plotted using it, since the curve is important for analyse the battery drop voltage

At the Auger tests will be performed in the batteries which were recently bought and are stored for a long time. This way, only good batteries will be installed on the surface detector, that is, batteries which present good quantity of charge and SoC. As a result, it presents less battery failures, less Photovoltaic system failures and thus, the surface detection performance is not affected.

There are today five equipments like that in the Auger Observatory acquiring data, interconnected and discharging batteries simultaneously. The results will be analysed as soon as the data are received.

Acknowledgement

The authors wish to thank all the team from Optical Properties Laboratory, Instrumentation and Solar Energy Laboratory, Sustainable Energetic Applications Laboratory, The Pierre Auger Observatory and CBPF.

References

- [1] ALLEKOTTE, I; BARBOSA, A. F ; BAULEO, P.; PEPE, I. M. (2008) The Surface Detector System of the Pierre Auger Observatory. *Nuclear Instruments & Methods in Physics Research A*. v. 586, p. 409-420.
- [2] Ademarlaudo França Barbosa, Iuri Muniz Pepe, Germano Pinto Guedes, Luis Carlos Simões Soares, A. López Agüera, I. Rodríguez Cabo, María de Fátima N. C. Rossolem. Batteries performance characterization – I. GAP2007022 (internal publication of the experiment).
- [3] BATERIAS Moura: Manual técnico acumuladores Moura S.A, Available in: http://manoel.pesqueira.ifpe.edu.br/fmn/anterior/2010.2/infra/CL_EAN.PDF. Accessed at: 02/10/2011.