The Pierre Auger Project as a Challenging Tool for Studying PV Systems

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Abstract The Pierre Auger Observatory, PAO, has been created to detect highly energetic cosmic rays, with a macro-grid of stand-alone photovoltaic systems (PS) as a power source system. The Observatory's grid offers the largest source of statistics for stand-alone PS, 3.10^8 of each principal magnitude per year, creating the possibility of performing unprecedented research in this field. In this article we will describe the experimental set-up and analyze the main capabilities of the PS as a source of research.

Keywords: Power system, solar energy, isolated photovoltaic device, online diagnosis, scientific applications.

1. Introduction

The Pierre Auger Observatory [1] may be considered one of the most ambitious high-energy cosmic ray detection projects, hoping to describe the energy spectrum around and beyond the cut-off of Greisen-Zatsepin-Kuzmin (GZK) [2]. The experimental setup required the construction of two giant detector grids, one located in the northern hemisphere and another in the southern hemisphere, in order to reach a large part of the celestial space. The grids in the southern hemisphere, in an advanced stage of construction, are located in the Argentinean region of Mendoza, and will be completely operational by the end of 2006. They will cover a total area of 3000 Km^2 with a hexagonal matrix of 1600 Čerenkov water placed at intervals of about 1.5 Km (surface detectors). The detection is performed by means of the characterization of the energy and the arrival time of the secondary particles of the atmospheric cascades, with these parameters one can reconstruct the primary cosmic ray. The detection is also performed with four fluorescence detectors that examine the atmosphere over the tanks, collecting the fluorescence light produced by the cascade while passing through the atmosphere and using it to reconstruct the primary. The combination of both, Čerenkov and fluorescence techniques, improves the precision of the final measurements. The lifespan for data taking is 20 years.

View 1: A Pierre Auger Čerenkov tank. In detail the PV modules

Each Čerenkov tank uses 12 tons of water bacteria-free as its sensitive material. With the aim of eliminating redundancy, the produced signal is received by three photomultipliers placed symmetrically on the upper part of the tank. Due to its "isolated" geographical location, each of the 1600 tank surface detectors are on a stand-alone system with its associate reading and acquisition electronics applications, and thus, its own photovoltaic power systems.

The photovoltaic system (PS) is fundamental for the proper performance of the Pierre Auger Observatory, since the failures in this system translate into data acquisition losses, which may be serious while capturing interesting events. Therefore, it is of the utmost importance to maintain a precise control of the PS. In this article we glance at some of the first research results on the PS of the Pierre Auger Project, specifically at those regarding the preliminary proposals for the Quality and Ageing Control of the system.

Finally, while scientific aims of the Pierre Auger detector go much beyond the mere technical aspects, a study of its power system constitutes a unique experimental setup in the realm of Solar Energy because of the number of monitored stations, being the largest ever projected source of statistics referring to the stand-alone photovoltaic systems.

2. Experimental Set-up. Performance Conditions

Each of the photovoltaic systems in the network is required to supply power to the electrical readings of each PAO ground based detector. This includes 3 PMTs, a motherboard, a trigger and a radio transmission. The electronic parts [3] have been designed for low consumption. In its final version it consumes less than 240 W a day, despite the high voltages imvolved in PMT's.

The usual sizing measurements taken indicate that a stand-alone system of 100 Wp of power will properly provide the energy needs for the experiment. In the case that the system functions autonomously for 6 days in complete darkness, we would need batteries with a minimum storage capacity of 100Ah. To limit the sulphation effects, the battery accepts a maximum deep discharge of 40%. With these guidelines, the photovoltaic system have been designed as a grid of 1600 stand-alone PS's of 100 Wp each. Each of the systems includes two photovoltaic modules (Isofotón W53) in series, two six celled lead-acid batteries connected in series (Clean Moura) with a 105 Ah capacity and a MPW regulator (Mode Pulse Width, Morning Star Sunsaver 10) which ensures the stable charging and discharging process of the battery.
Once the system is installed, the most relevant characteristics are monitored: voltage and panel current, voltage and battery current, current consumed, temperatures, solar radiation and other meteorological parameters. An average of 2.4×10^5 data readings per day of each magnitude are performed of the complete grid, 144 per system, analyzed on-line.

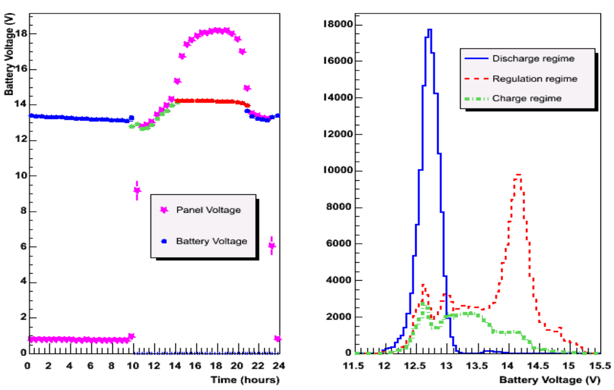

Fig. 1. Left: voltage values throughout a day for photovoltaic modules (empty and pink) and batteries (rest). Right: the corresponding voltage distribution functions. Each performing regime is in a different colour.

As an example, in Fig. 1 it can be seen the system's behavior throughout 1 day. The plotline shows one month of data from a total of 100 PS's. On the right, the function of the battery voltage distribution is displayed for the different working modes. In the discharge mode (dark blue in the graph), the battery is powering the system. This is when we can independently study the battery's behavior. The regulation regime (in dark red in the graph) shows the regulator's behavior. In the charging regime we can study the systems structural characteristics.
As it will be briefly seen later, we usually use this kind of figures to perform our studies and algorithms.

While the system is completely operational once installed, the optimal operating conditions are achieved after 3 to 4 months of use [4,5]. This process is mostrated in Fig. 2. by means of the batteries' behavior. At first, the width of the voltage distribution in the discharge rapidly decreases in the first two months (Fig. 2. right). After this, a slight increase occurs due to the natural aging of the battery. On the left we can see in detail the voltage distribution functioning in the discharge regime of a recently installed battery (top part) and after 4 months of usage (lower part).

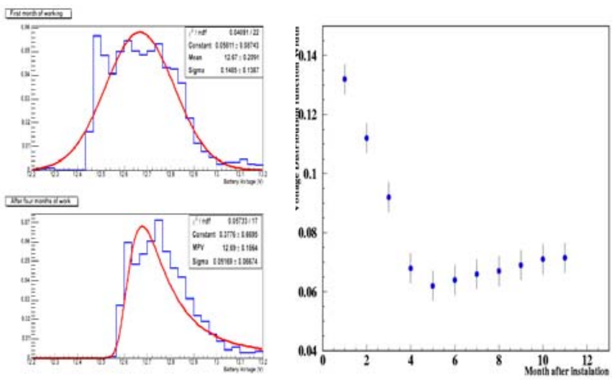

Fig. 2. Left: discharge distribution of a sample of batteries recently installed (adjusted with a Gaussian) and after 4 months of use (adjusted to a Landau distribution). Right: width of the voltage distribution in discharge regime throughout the first year of life in a sample of 100 batteries.

Once systems normal performance has been established, the way a photovoltaic works is characterized by its structural conditions as well as the meteorological ones, both of which we will analyze in the following sections. Within the structural conditions we highlight the performance regime, the circuit losses, the correct sizing, etc. Moreover, due to its location, the system suffers from adverse meteorological condition, in particular from extreme temperatures and the region's strong winds.

A. Structural conditions. Sizing

A correct assembly ensures the optimal performance of the system. Particularly, it can reduce the losses in the connections and falls in the associated voltage. The losses in the connection can be estimated through the quotient of the panel's voltage factor and the voltage of the charge regime. In this performance regime, the total available charge is used to charge the battery. In Fig. 1 left, the adjustment shows that the losses due to the connection are less than 2%.

The sizing conditions the system's performance. The Charge Factor (RF) is a good parameter for corroborating the correction of the sizing. It is defined as the relation between the total available charge in the accumulation system and the total charged consumed. In Fig. 1, we can see the annual distribution of the RF in our system (left). If the system has a deficit less than 1% of the time, it is understood that a well sized system has RF values between 1.08 and 1.20 [6]. Our system is below comfort levels 23% of the times on days with the lowest radiation levels. In spite of the fact that these periods coincide with the harshest winter months, we could think of using batteries with more capacity.

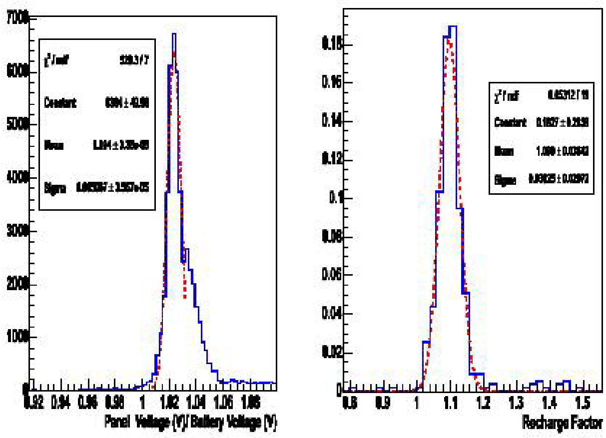

Fig. 2. In the left, the rate between the panel voltage and the batteries ones. The right figure shows the Charge Factor distribution throughout a year.

A third parameter influencing the system's functioning is the way in which the batteries are charged or discharged. The panel's available charge must be limited so as to prevent a surcharge, yet sufficient to prevent a deep discharge from deteriorating the system.

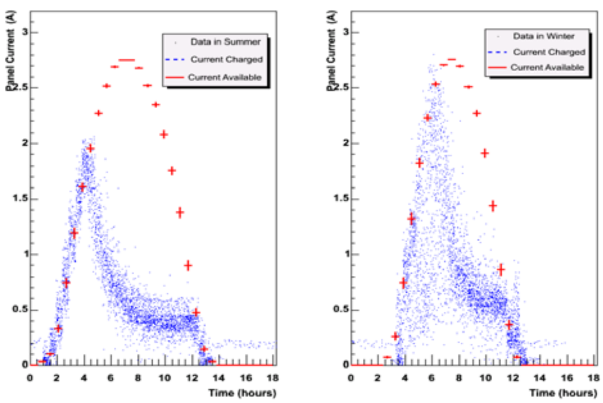

Fig. 3. In the left, photovoltaic module's current and batteries input's one (blue) versus time in summer. The right figure shows the same in winter.

A direct way of observing this is the comparison between the panel's available charge and that used to charge the battery. In Fig. 2 we show the available current and charge distributions throughout one day in the summer (left) and winter (right) for a sample of batteries. Even in winter the available charge exceeds the amount used. This ensures us that there are no deep discharges. In a similar fashion, we can see how the charging current in the regulation regime is under control. Comparing the panel's capability to produce charge (in red in the plot) with the charge used to recharge the batteries (in blue in the plot), we can see that in summer only 50% of the available charge is used. In winter around 80% of the available charge is used. This demonstrates that the charge provided by the panel is underused.

As a final remark, the installation of higher capacity batteries would optimize the use of the charged produced by the panel by increasing the battery's available charge. With this we would increase the RF values and decrease the depth of the batteries´ discharge. The battery's performance would increase in comfort thus increasing its life expectancy.

B. Meteorological conditions.

The outside temperature is what most affects the batteries. Any electrochemical process is accelerated with a rise in temperature. As a general rule, the life expectancy of a battery decreases by 50% with the increase of 10 degrees centigrade [7] in its performance temperature. Furthermore, sudden changes encourage disconnections from a failure in the battery charging process. Moreover, in low temperatures the electrolytes may freeze.

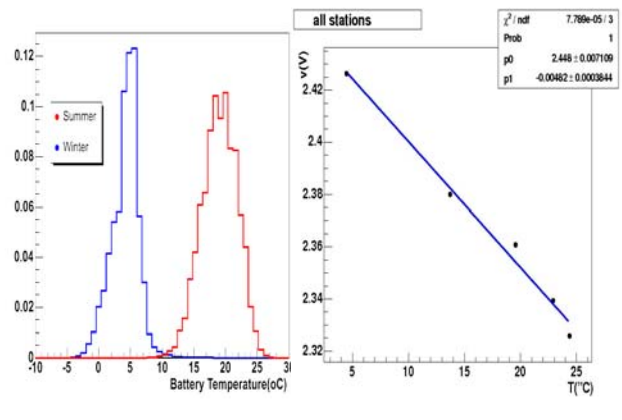

Fig. 4. In the left, temperature distribution in extremes (winter: blue, summer: red) Right, each cell's voltage dependence in discharge mode by temperature.

In Fig. 3 left we can see the system's temperature distribution throughout the year. The battery could be said to work 10% of the time in extreme conditions. The voltage variations due to the temperature are around 5mV/ºC. This effect is kept in mind in the regulating process.

The region's strong winds (gusts of 160 Km/hour) mainly affect the photovoltaic modules. In the shortterm, connection failures have been observed. In the long-term, we can expect a degradation process due to the wear and tear of the material. It will be the first time that experimental research can be performed on the ageing of these modules.

3. Capacities: Quality Checking

One of the largest advantages of the Pierre Auger PS is its monitored high amount of statistics, (3.10^8 of each relevant magnitude per year). This allows for the improving of a so-called Quality Checking control.
As it is already well known, a Quality Test consists of a series of procedures that ensure the proper performance, or quality, of each of the components, in this case the photovoltaic system. This allows for the defining of performance standards criteria without the need for modeled simulations of the PS.
At first, we have to know the performance conditions of the system.

In this situation, we can define an accurate control of the system performance in several stages: previous to installation (the quality of the components); once installed (uniformity and stability); and for the detection and identification of the possible anomalies during normal performance and the system ageing:

A. Check-up Procedure and Uniformity

The first step consists in a check-up procedure of the different basic parts that make up the system [8]: photovoltaic modules [9], batteries and charge regulators. The next one checks the preliminary uniformity of the performance of these parts, once installed. With this two stages and since there are two serial connected PV modules, each one with its particular features, we can study from an experimental point of view the effect of this serial connectivity concerning the efficiency of the solar panels[10].

B) Identifying anomalies and ageing studies

The last stage consists in establishing the systematic method of detecting and identifying the anomalies that may appear in the PS (and its ageing process), mainly with its batteries, since they are the weakest part of the system. In particular, this last stage is of utmost importance from the experimental point of view, due to the singular characteristics of the Pierre Auger Observatory (large extension, difficult access, etc.), with 20 years of expected performance during which the batteries must be changed at least 4 times. Our aim is to detect and understand the different types of anomalies that may appear and decide the necessary measures to adopt in order to ensure the proper performance of the system.

The proposed method for detecting and identifying the anomalies consist in the use of the Voltage Function of the batteries (see Fig. 1.), specifically with its probability distribution. This variable seems to be sensitive not only to the presence of the most common anomalies in the system's accumulation, but also to any other in the PV system. The method is based on the study of the probability of working in the different regions of interest (commented in section 2.) for every battery [11], establishing the different types of anomaly in terms of this probabilities.

The battery ageing process is much faster than that of the other components of the PV system [4, 5]. Moreover, its degradation may remain unperceived for a long period of time, therefore foreseeing its remaining lifespan is very important for all PS's. In the particular case of the Pierre Auger Observatory, this importance is even higher because of it's huge dimensions and the difficult access to the different detector tanks; if we are able to predict the evolution of every system's ageing, the technicians could organize themselves to solve the different problems without stopping a big part of the array. We proposed a preliminary method for surveying the state of batteries ageing based in the voltage distribution function. There is further information about the algorithms used in paper [5] sent to ICREPQ'07.
In the present paper we only show, as an illustrative example of the timing evolution, the way a PAO's battery modifies its discharging performance with time (increasing the slope and the nonlinearity), that is our next step in studying batteries ageing.

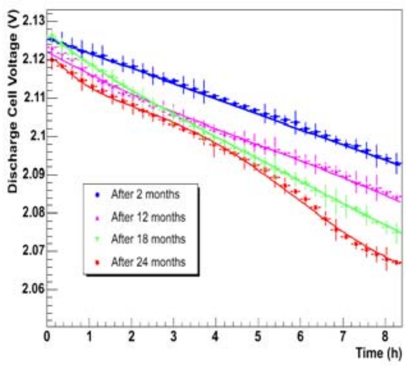

Fig. 5. Temporal dependence of the discharge tension of a PAO's battery: dark blue: after 2 months, pink: 12 months, light blue: 18 months, red: 24 months of performance.

4. Conclusions

The ground detector’s power system at the Pierre Auger Project with its 1600 stand-alone PV systems, its high number of statistics and the extreme meteorological conditions at the geographical locations is an unprecedented experimental setup for the study of stand-alone PV systems.
The near future entails the systemization of the proposed procedures verifying the sensitivity of the method for controlling the system. Moreover, we hope to develop new estimation methods to evaluate the state of ageing of the batteries (for example, from viewing the mode of discharge of the batteries [12]). The comparison a posteriori of the different methods of treatment will allow us to optimize the quality control procedures of the PV

systems. We also plan to study the effects of the meteorological conditions on the PV systems. We do not disregard the use of neuronal networks to extract data analysis conclusions.

At the same time, we will use the Pierre Auger PS as experimental setup for new system components characterization. At this moment, different types of regulators have been installed and we are also studying the possibility of installing gel batteries.

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