

# First Results of the Anomalies Identification Method for PV systems

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**Abstract.** A simple quality check procedure for early detection of photovoltaic (PV) isolated system anomalies had been previously presented [1]. The proposed method was developed over a short set of monitored system parameters from the Pierre Auger Project data base. In this paper we summarize the main results we obtained by using that protocol as well as the matching between them and the actual failures recorded within the Pierre Auger's data log.

**Keywords:** solar energy, PV system's online diagnosis, batteries, system failures, stability.

## 1. Introduction

The stand-alone photovoltaic (PV) systems applications are typically characterized by a continuously energy requirement. Under these conditions, a quality check procedure for early detection of PV systems' anomalies is needed [1].

It is well known [2,3] that batteries play an important role in isolated PV systems' performance, since their average operating lifetime is lower than in the case of the other components of the system and they can present anomalies in their behavior that are temporary causes of systems' troubles. In this context, we had developed and proposed a quality test for early battery anomalies detection [1], in which we use the battery voltage distribution as a sensitive tool for finding the problem before the final lack of energy supply. In this paper we show the first results we obtained by using this protocol.

The experimental set-up is the photovoltaic power supply of the ground detectors at the Pierre Auger Observatory (PAO) [4,5], which consists of a macro-grid of isolated PV systems, forming an hexagonal network, composed of 1600 particle detector stations. Each 100 Wp station includes two 53 W panels, two series 105 Ah batteries and a MPW regulator which ensure a stable charge-discharge process.

This experiment has an expected lifetime of 20 years, during this period main PV system values are continually monitored each 10 minutes. The data analysis of this

experimental set-up constitutes a database of about  $10^5$  data in the first 2 years of normal operation.

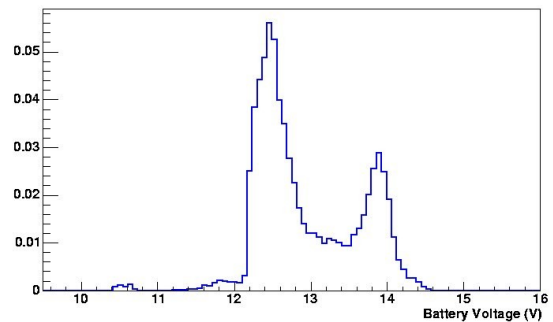


Fig. 1. Generic Voltage Distribution of a battery

## 2. Brief Reminder of the Method

The analysis of the battery voltage distribution,  $f(V)$ , was proposed as an indicator of the state of health for the PV system in general. In the  $f(V)$  distribution, we can define four operational regions (see Fig. 1 as an example):

- *Deep discharge region* where the voltage is lower than 11.8 V in the battery;
- *Discharge region* (voltage between 12 V and 13 V);
- *Regulation region* where the battery voltage is in the interval [14,15] V;
- *Over charge region* where the voltage is below 15.5 V in the battery.

The frequency in which each battery is working in each region is used as an indicator of anomalies related to different periods in the battery performance. Fig. 2 shows this probability along the year for each working region. Deep discharge and over voltage probabilities should constitute a few percent in normal working conditions. Dependence of  $f(V)$  with both irradiation and temperature is taken into account, since, for example, deep discharge increases in the months of winter (June, July and August in this case) whereas regulation decreases.

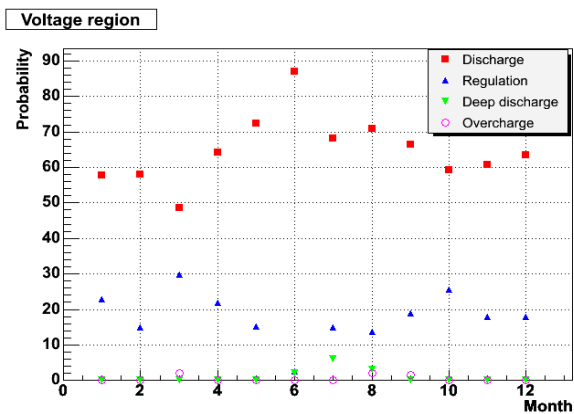


Fig. 2. Probability along the year for each working region. A sample of well working system has been used.

### 3. First New Results

It is clear that, once one has a method for the anomalies detection which produces different kinds of alarm, like that we had proposed, it is obligatory to match the method predictions with the actual results so that we can decide about how well the method is working and evaluate its utility. Depending on the time period in which the method is used, we can compare its predictions about the hypothetical failures that could appear to the real ones that happened in this period. At the same time, we can feedback the method by using the different cases we find, and achieve an iterative-improving procedure to the best develop of our method.

Taking into account the different kind of anomaly and the two batteries of the stations, we can also study the relationships between these different anomalies, because of the serial connection/regulation, and the way to solve the asymmetries that do exist there. This will mainly be treated in the next section, but we will do some necessary comments about the issue in this one.

#### A. Deep discharge

The voltage probabilities in deep discharge should constitute a few percent in normal working conditions, so the batteries with a high integral of the frequencies has an abnormal performance which can be an indicator of an anomaly. The most common causes are either connection or installation failures or a broken regulator.

An important point is we noticed (see Fig. 3.) that one of the stations' batteries (called battery 1) is twice as probable to be in deep discharge as the other one. At the same time, when we look into the station failures' log, in the corresponding months, we find out that the 80% of the serious deep discharge alarms that our method creates, corresponds to a station which broke down because of a battery failure.

In this moment we have established limits with respect to the probabilities of working under a deep discharge regimen (for example, a clear one is that a gap of three

sigmas with respect to the gaussian fit of all the batteries, or a deep discharge probability higher than 40%, is predictable to be translated into a battery damaged once and for all after five months of work), and it is being improved as the number of failures to be analysed is increasing and, thus, the statistics we need to the best tune of the method.

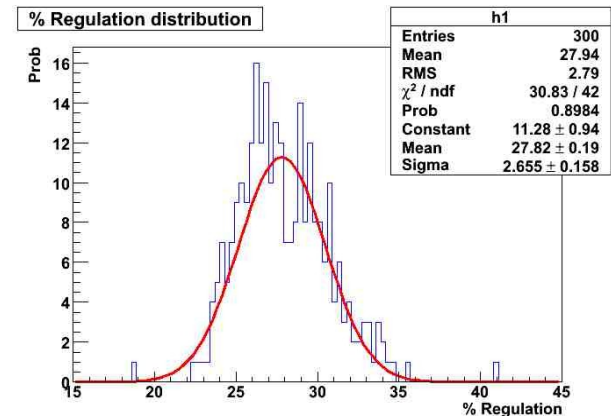


Fig. 3. Distribution of the regulation percentage from 300 stations in March 2005, fitting to Gauss function.

#### B. Regulation

As in the case before, the percentage of time in which the battery is in the regulation region is analyzed to find an abnormal performance.

As a general reminder, the distribution of the percentages (%) corresponding to an enough number of stations can give us parameters, by fitting to a Gauss function, with which obtain limit values (see Fig. 3. for example). Moreover, a battery can present this anomaly in two ways, because it has a % below the low normal limit (worse case) or because is higher than the high normal limit value. This last case is suspicious, since the other battery could be having a net insufficient supply and hence being damaged.

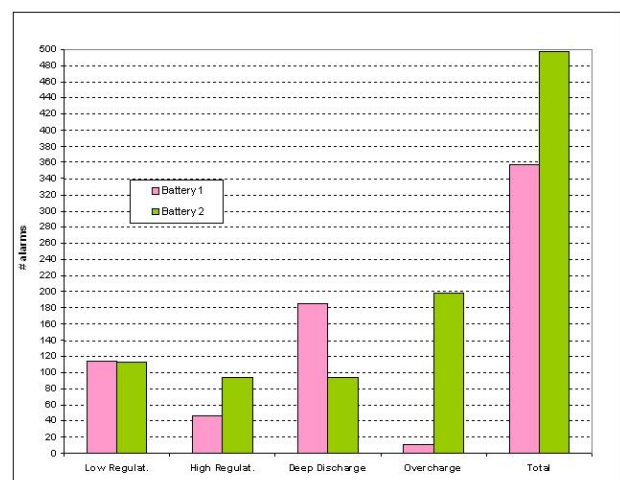


Fig. 4. Summary of several results obtained by applying the proposed method in the year 2005 to all batteries.

In Fig. 4, we can see that the batteries of the set-up which are less probable to have deep discharge are more likely to show a regulation time higher than the others. This is an example of how the different kinds of anomaly can be related each other, mainly because of the serial connection set-up. We will come back to this with more detail in the next section.

### C. Overcharge

As it is well known [2,3,5], a battery supporting voltages over 15.5 V for long periods of time, gasifies by electrolysis, losing liquid. The effect is a decrease on the battery capacity and thus on the lifetime.

In this case, when one run the anomalies identification protocol, the battery 1 of the stations turn out to be, in a similar sense we have just seen in the previous case, much less probable to be in overcharge than the other ones. Moreover, if we look into the register of the experiment, we find out that the substitutions are notably less frequent (25%) in these last cases than in the deep discharge's ones, so we can conclude that the most dangerous anomaly is clearly this last one. Furthermore, as we will see afterwards, it is worth mentioning in this point that we find that in the 20% percent of batteries 1's deep discharge alarms the other battery is in overcharge, so we can infer that a non-early detection of such an anomaly causes a stress in the other battery that can also be definitive (see Fig. 5.).

## 4. Matching between the different aspects

The serial connection of the two batteries of every station, together with the fact that the regulation is based on their total voltage, implies that a decompensation between the batteries is possible. At the same time, if one battery is damaged, its weakness can be translated into an excessive demand for the other battery's functioning, causing a damage which seriousness will depend on the time during which this situation had happened and its conditions. The most recommendable thing is that every battery has its own charge regulator, but an anomalies identification method like ours could be enough to prevent these eventualities.

### A) Deep discharge and overcharge

We have in short 186 alarms of deep discharge for the batteries 1 and 196 of overcharge for batteries 2. Among these cases, we found 40 coincidences with each other (see Fig. 5. as an example), so the relationship between them is of about 20% (the above mentioned number). This is a significative result with respect to the importance of a method for an early detection like we have proposed: if one does not quickly solve the anomaly that a battery presents, the other battery could be damaged.

### B) Deep discharge and low probability of regulation

Within the 186 alarms for deep discharge and the 114 for a low probability of regulation (in both cases for the battery 1), a 34% of coincidence rate with respect to the

low probability of regulation's rate is present. This could be expected, since the worse the battery's operation is the more difficult is to charge it. Furthermore, this certain correlation also agrees with an incidental lack of energy supply in the battery.

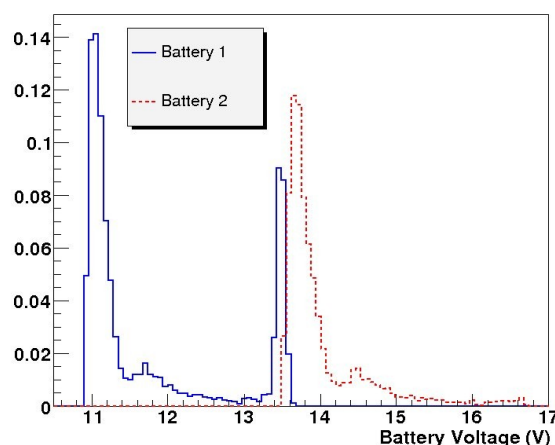


Fig. 5. Voltage distributions of a station which batteries present deep discharge and overcharge (red-dotted line)

### C) Overcharge and low/high probability of regulation

Among the 196 overcharge alarms that are present in batteries 2, and the 114 low regulation ones, there are 17 coincidences. If we consider the cases of high probability of regulation, the coincidences are 13 over 94 alarms. Both cases are understandable since a battery has problems to keep itself with high voltages and the behaviour can become "caotic", i. e., both cases, low and high regulation probabilities, are expected. Moreover, depending on how much time the battery has spent in overcharge, there could be cases in which they can support the overcharge and there could be cases in which the batteries are already damaged and thus present difficulties to be charged.

It is worth mentioning that in every case that we analysed in the previous sections, we only showed the data from the batteries that present enough number of alarms to do the analysis. For example, there are not almost any cases of overcharge in battery 1, so it is not possible to come to a minimally reliable conclusion with them, etc.

## 5. Conclusions

The normal expected lifetime of a PV system is at least twenty years of continuous working. The only way to prevent failures in such a system, once deployed, is an early detection of possible problems. Main typical ones appear related to the solar panel connections, the regulator's way of operation as well as to any intrinsic anomaly in the batteries (too much time of stock without any charge, manufacturing defect, corrosion...). The quality check for early anomalies detection that we had proposed is based on the battery voltage distribution and the ambiental temperature.

By using this protocol and comparing its results to the actual failures recorded in the Pierre Auger data log, we concluded that the most dangerous anomaly is the deep discharge of the batteries. There is also an asymmetry in the behaviour of the two series batteries of each station: the battery 1 is twice as probable to be in deep discharge as the battery 2 whereas this last is ten times more probable to be in overcharge. Such a decompensation should be because of the serial connection and the regulation based on their total voltage.

Although less harmful, the batteries' overcharge is also another way of becoming damaged. Moreover, this kind of anomaly and the deep discharge one are often related to each other (20%), as the bad functioning of one of the two series batteries, jeopardizes that of the other. The effect of a large delay in failures detection is thus experimentally proved.

Once seen the utility of the quality check method, the procedure will be implemented as standard on-line check in the data acquisition system of the PAO.

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