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Solar Panels for Auger Southern Observatory: "SPIDERSHADOWS"

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Abstract. During the winter of 2009, technicians inform about how during a visual inspection they detect failures in the surface of different solar panels. The inspection was not casual, but due to problems with the level of charge of the batteries. Because of the aspect on the failure we will name it "spiders" *(arañitas*). But other anomalies, associated to the expected ageing, have been observed, like panels with blued cells, browed surface and others. In the present note, we will describe each of the observed failures, their possible causes and their effect on the solar panel operation. The full data sample we used has been obtained either on dedicated laboratory test (PAO, USC, CIEMAT) or by direct measurement in the field.

Key words

Photovoltaic modules, anomalies, quality check.

1. Introduction

The aim of this technical note is to evaluate the effects of the different alterations in a solar module. In principle, we could consider the huge number of data collected from the monitoring as a more than enough data sample. Unfortunately this sample it is not clear. In fact, the solar panel behaviour is mostly moderated by the battery state of charge and hence, in the monitoring data, the real performance of the panel appears 'shadowed' and cannot be used for absolute analysis. Moreover, monitoring data will allow us to identify the relative performance tendencies as well as to perform an off-line quality check (la otra GAP).

To have absolute evaluations, dedicated laboratory tests are mandatory. In the following, we will describe the exhaustive set of data taking performed to quantify, the influence of the different observed anomalies on our solar module performance, the corresponding data analysis and the evidences obtained.

We perform two scenarios of data taking: Measurements at laboratory (in Malargüe, Santiago of Compostela and CIEMAT) and direct measurements in the field. Data were taken both in open-circuit, short-circuit and charge. These measurements were supported by thermometric analyses (USC) and luminescence analysis. The full measurements have been cross-checked in the official certification laboratory at the CIEMAT [1].

There are several questions to answer: The effect of the different failures in the panel performance and, probably more relevant, the causes of them, in order to predict the future evolution of the most common damages. Moreover, in order to perform a simple protocol to test the panels' health in the field and, if possible, perform algorithms that are able to detect the appearance of new failures by means of a non visual inspection from the analysis of indirect measurements in monitoring data.

2. Problem definition

Standard technical details of photovoltaic modules are recorded in [2]. In the process of buying, the uniformity of behaviour was stressed. Even though, in the last months a power loss in several solar modules has been detected and, in some of them, the replacement of the PV system's batteries was even unavoidable. By September 2009, we were informed about some anomalies that technical staff did at least three stations of the PAO, concerning their solar modules, all of them related to the technical check of the station, which consisted mainly on a rough inspection of the panel. Each station is visited about 2 times per year. At the moment, 172 of them present spiders even if in different number and size (see annexe I for details). The common of this anomaly suggest the possibility of a manufacturer default. But spiders are not the only alteration reported by technicians, they remark the presence of browed cell, blue spot and others (see photos on fig. 1).

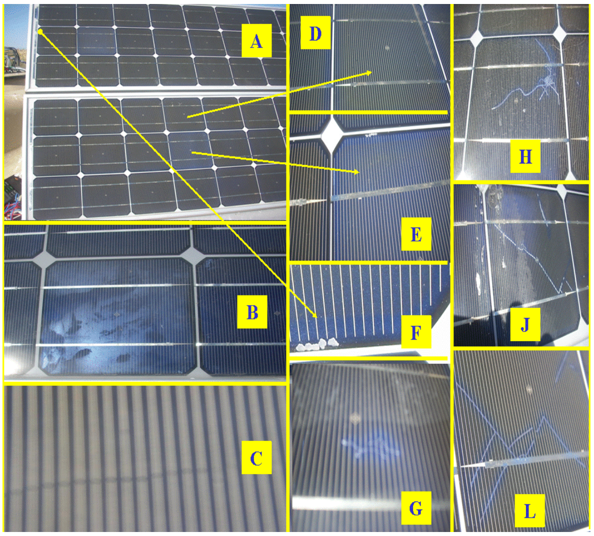


Fig. 1. Various photographs of a PAO's with the most common defects observed.

Let's describe the most common observed:

A. Laviform cells (figure 1-B).

Comprise anomalies in which the solar cell surface seems to be melted (in blue) like lava does. Never reported in the bibliography

B. Brown cells (figure 1-D)

Photovoltaic module's cells presenting a brown shade in its surface. It is associated to deterioration of the epoxy resins with the irradiation and take part of the standard expected ageing of the solar panel.

C. Blue cells (figure 1-E).

Photovoltaic module's cells presenting a blue shade in its surface. Normally it affects the cells with less production which induces an increase of the cell temperature. .

D. Metal excess on the shields (figure 1-F).

Normally without any consequence.

E. Spiders.

Presence of some evident lines, material or fissures in solar cells that we will name "spider effect" or "spider" in the following. We can distinguish at least two types of spider:

1) *Spider or type 1:* one cross-like that in general has two arms which subtends an angle of around 45º with respect to the main contacts and has a lead-like structure (figure 1-J, 1-L).
2) *Spider type 2:* A more complicated spider with a more transparent structure and bubbles (figure 1-H).

Moreover, normally the affected panels present several spiders. It is worth mentioning that in one of these cases, the number of spiders detected in the same panel was thirty two. This anomaly has never been reported in the bibliography.

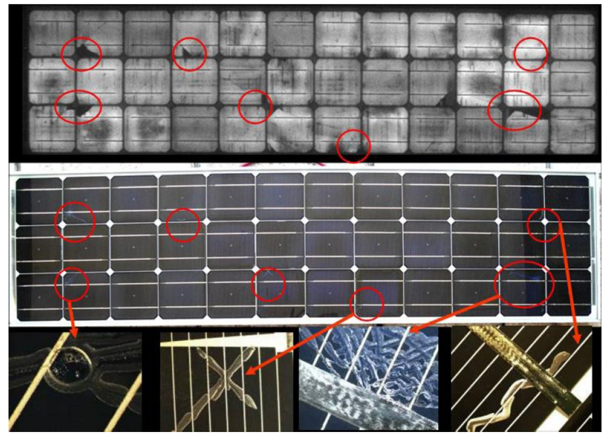


Fig. 2. From up to the bottom: electroluminescence images from, spider panel and this last detailed visual inspection.

Even if possible causes are still unknown and further investigations are under way, some remarks as well some work hypothesis can be advanced:

- Fig. 2 shows a detailed correspondence between regions with spiders in visual inspection and dark spots in electroluminescence images.
- Spider Type I, shows privileged directions compatibles with the symmetry axis of the silicon crystals. A possible cause is related to failures on the silicon wafes.
- From the big resolution images in visual inspection, we could see how spiders type II seem to be composed of something like different melted fluids and even bubbles of it.

In the figure, the normative (UNE-EN 61215) visual inspection photographs and the electroluminescence ones are shown. Among the possible causes, different hypothesis can be established:

- A problem during the manufacturing processes, in which invisible fissures or inhomogeneities in silicon slides could be translated into a macroscopic effect like spiders.
- The effect of a mixture between hard temperature oscillations and strong winds which can induce fractures in material in time.
- Accumulations of charge (polarisation) in some specific regions of the solar panels caused by some kind of bad connection in system installation.
- Storms or solar storms which very high electromagnetic fields involved could cause such degradation in modules.
- Damages correlated with the extreme

metrological conditions.

- A mixture between some of the previous ones or all.

From electroluminescence image and the strange appearance of spiders, the first hypothesis appears is the most probable one since the anomalies in that images are present even in the calibrated solar module and we expect they end up being normal spiders if the panel was installed in the field. More detailed studies including invasive tests are under way.

3. Data Taking

A dedicated series of measurements have been performed. In all cases, the analysis has been referenced to the response of a panel with well known behaviour. Data, both on open circuit and in charge, has been collected. Open-circuit and short-circuit measurements allows us to recuperate the characteristic parameters of the panel and then evaluate the status of deterioration. From the data obtained in charge, the solar panel behaviour in working regime can be extracted.

A. Measurements in the field (Pierre Auger Observatory).

In 2010 May, helped by the Auger technicians, a series of panels that were suspected of having failures have been measured directly on the field. One of the analysed tanks is shown in fig. 3. As it can be seen, the solar module presented blue cells, a slightly brown shade and some spiders. Our visits were focused in two different zones:

- The north-eastern area of the array where most of the stations were installed more or less recently. In that checks, we did almost not detected any spiders in their solar panels but, nevertheless, we had seen some blued and browned cases.

- An array spot in where there are several of the oldest stations in the observatory and it was just in them where we have seen spiders in every module. This suggests a possible correlation between the formation of spiders and the time of operation or/and exposure to sun/meteorological conditions, as well as maybe with the corresponding manufacture set. We come back to this point later on.

As it was a quick check, we have done some rapid and easy measurements which consisted on short-circuit current and open-circuit voltage ones for each solar module (in general once disconnected one to each other) and for the reference module. One of the advantages of doing so is the possible extrapolation to future and systematic measurements in the field once observed anomalies in the solar modules or even not**.**

Fig.3. Sample of solar modules with several anomalies.

Table I collects the technical information of the solar panels installed at the measured stations with spiders: Moulin, Federico and Gladis. In every case, independent data from each solar panel of each tank have been taken.

Table I - Measured station panels information. First Column gives reference panel information.

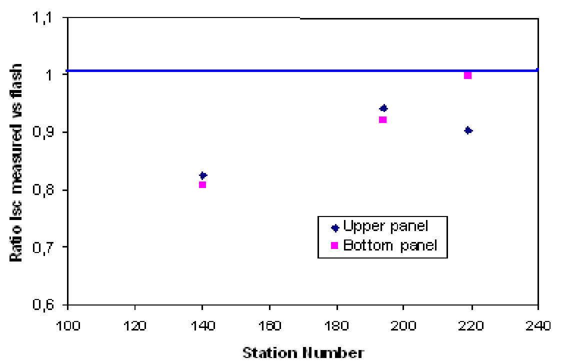
Stat.	**Reference Panel**	**Station: Moulin ID: 140**	**Station: Gladis ID: 194**	**Station: Federico ID: 219**
ID	020103510 63	upper: SN 02010351063 bottom: SN 02010351119	upper: SN 010098937 bottom: SN 020103510 48	upper: SN 020700880 31 bottom: SN 020700880 32
Obs.	No failures	Upper panel. Spiders. Bottom panel: Spiders. Oxyde at cell's rims	Upper panels. No failures. Bottom panel: Spiders in its three cell lines, some crossing the whole cell.	Upper panel :oxide and small lines. Problem of the EVA or Silicon. No spiders observed. Bottom Panel. No failures
Date	Never	2003-07-09	:2003-07-01	2003-08-13

In order to evaluate the actual degree of degradation on the different panels tested, we study the ratio between the measured short-circuit current, normalised to 1000 W/m^2, for these solar modules and the corresponding own values given by the manufacturer in their monitoring flash. Remember that these monitoring flash values and their reliability have been checked before installation. Fig. 4 shows the observed results.

Three observations could be extracted from the short-current plot:

- Solar modules of ***station Moulin, 140***, with spiders, shows the highest short-circuit current losses, equivalent to around 19%. One of the observed spider is the one higher in size.

- The ***station Gladis 194***, with several spiders, shows losses close to 10%. As main remark, visual inspection tells that the bottom panel of this station is the one with more number of spiders (17), even if smaller. The lower loss of current observed, suggests that is the size of the highest spider in one module, and not the number of them, the dominant effect. It is plausible since the cell with less current determines that of the others and thus the solar panel performance.
- ***Station Federico 219***: Upper module, with some observed failures, even if no spiders, presents losses close to smaller and compatibles with the calibration uncertainties, temperature dependence and others.



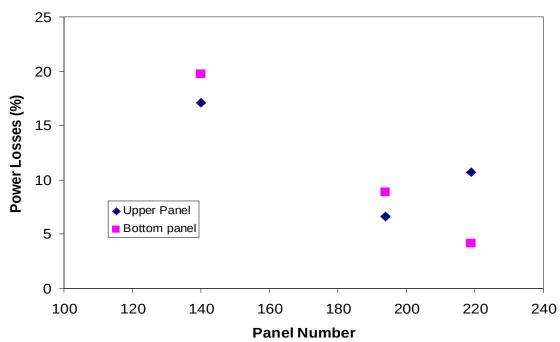


Fig. 4: On the top, the ratio between short-circuit currents corresponding to the solar modules of three Auger visited stations vs station number (Moulin 140, Gladis 194 and Federico 219).). In blue the upper panel and in pink the bottom one. On the bottom, the percentage of observed losses

The power loss plot ratifies, as in some way expected, the previous results. Power is calculated as the product of the short-circuit current and the panel voltage in open-circuit, weighted with flash measurements shape factor

As an initial assumption, we consider that open-circuit voltage is not dependent on irradiation. The obtained values show how the panels with spiders present associated power losses between 10% (Gladis 194) and 20% (Moulin 140). The observed 2.5% power losses correspond to the expected panel ageing.

A. Measurements at laboratory in working conditions..

The used experimental set-up is rather simple (see fig. 5): An automatic data taking using 'Fluke 189 true RMS' multimeters, connected to a portable PC: The full samples are taking using natural irradiation and, To avoid irradiation dependence, a Testo 545 photometer was used. The reference panel, calibrated in radiation, ensures redundancy. In the following, obtained results are presented.

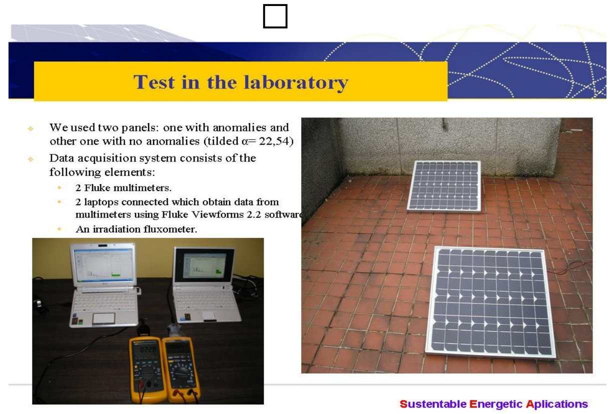


Fig. 5. Photographs of experimental set-up in the laboratory test.

As mentioned above, several samples of data taken both at PAO's hall, in Malargüe, and at Santiago of Compostela laboratory will be analysed

1) *Measurements at experimental hall, in PAO:* Panels representing the bulk of all detected anomalies, blue cells, surfaces with brown deterioration, and spiders in its different versions, were selected and tested as a whole in the own hall of the PAO. In photograph 6, this simple experimental setup is shown. From left to the right, a solar module with blued cells, a browned and spider one, a spiders one and a panel without apparent failures used as a reference. In this case, the reference module has been used for radiometer calibration (see on the left).

Table 2: manufacture flash measurements for the solar modules used in the check.

Solar Module	Reference code	Isc (A)	Voc (V)
Reference	10303001685	3.38	20.96
Browned	03030135009	3.47	21.88
Blued	05080068043	3.33	21.84
Spiders	02010350056	3.41	21.06

Data taking in open-circuit and short-circuit.

Fig. 7 shows the characteristic values throughout a complete day both in short-circuit current and open-circuit voltage of the reference panel. Unfortunately, temperature was not controlled during the test, but its influence both in short-circuits current and open-circuit voltage could be considered as negligible. Open-circuit voltage dependence with irradiation is not present -see Fig. 7-, so only short-circuit current will be analysed in the following.

Fig. 6. The four solar modules studied at PAO's assembly building

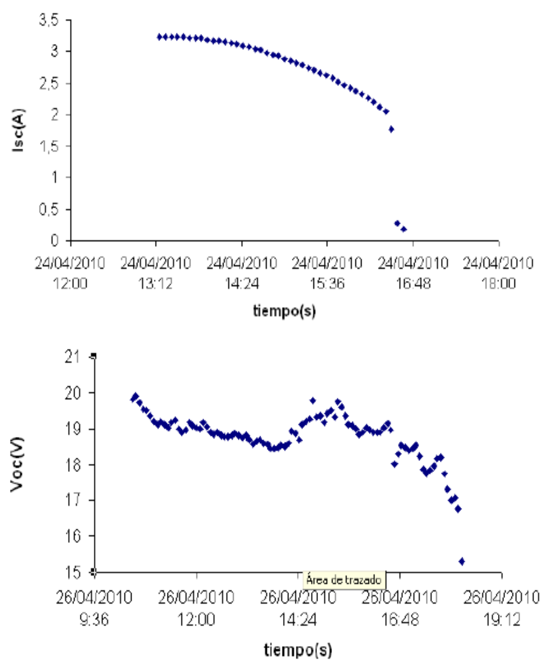


Fig. 7. up: short-circuit current in time for spider case. Bottom: the same for open-circuit voltage.

Fig. 8 resumes the main obtained results: On the left, a blued and a pure spider panel are compared. The first remarks is how the differences increases with the short-circuit current. To clarify the point, on the left, the variable is plotted versus the measured irradiation. Under 960W/m^2, blued solar module present lower values of short-circuit current than the module with spiders does whereas, above this region, the situation is inverted, so spider case seems to work worse as irradiation grows.

When we compare data with manufacturer flash measurements, it happens that, around 1000 W/m^2, the losses suffered by spider panel are in the order of 10%, whereas the blued and browned cases has losses comprised between 5 and 6% that could be assumed as a small factor within the normal ageing behaviour.

Concluding, spider effect it is dominant and increases with irradiation.

Meassurements in charge.

Until now, all our measurements have been done on the panel alone, that it outside the PV circuit because it is the simplest way. But it is not clear if the characteristic values (Isc, Voc) are efficient to detect any failure or dedicated measurements in charge regime (connected to the working system) are mandatory. To answer this question, we also checked the previous modules connected to a charge. Taken into account the high current values involved in the solar modules, it is necessary to use a resistor that is able to dissipate the considerable heat excess produced by the current. In this way, we used a wire of a heater which resistance was under control (we have taken the necessary number of spires to reach around 10 ohms, but this value is easily selectable).

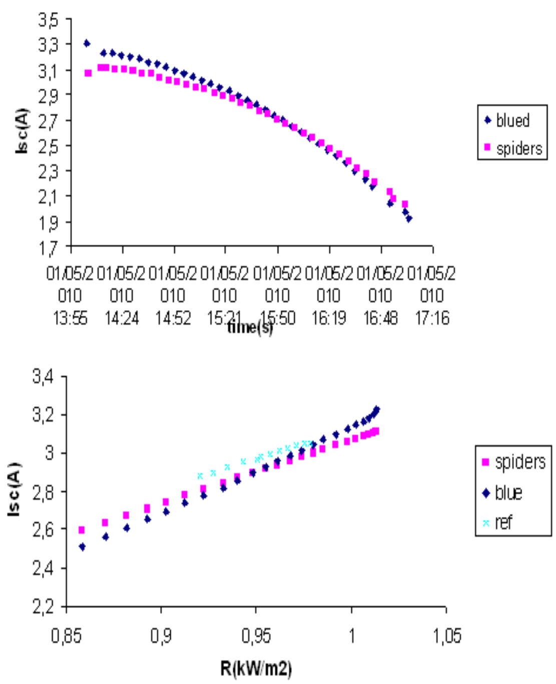


Fig. 8. Up: short-circuit current in time for blued (blue dots) and spider modules. Right: short circuit current with respect to irradiation for blued (blue dots), spider one day (pink) and reference one.

In Fig. 9, we show a comparison between the tendencies measured for the panels currents and voltages both in, respectively, short-circuit and open-circuit voltages as well as with the described charge connected. In spite o the fact that the irradiance and temperature could not be absolutely controlled, the tendencies look considerately similar. The corresponding set of power values that can be obtained from the data are as well expectable and compatible with short-circuit current and open-circuit voltage measurements. In this way, we could state from the carried out measurements that for this kinds of anomaly short-circuit current and open-circuit voltages are in general representative, sensitive and useful magnitudes which values could be easily extracted in the field by technicians during the normal station checks.

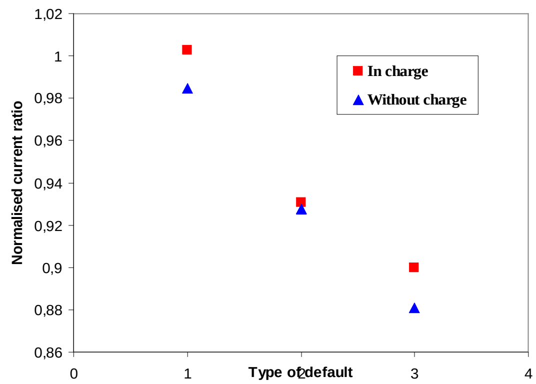


Fig. 9: Normalised short-circuit current with respect to reference's versus the type of anomaly: 1 blue, 2 brown, 3 spider for the solar module with a charge (red) and without it.

1) *Measurements at the lab of Santiago of Compostela*: The same outdoor protocol, but in a more exhaustive way, was implemented at the laboratory of Santiago de Compostela. Unfortunately, because of our meteorological conditions, only low irradiation level can be studied. In this case, we focused our study on the first panel in which the spiders were detected: The upper panel installed on the station Ezequiel, 102, with seven spiders (see fig. 2). A reference module ("patron") calibrated both in behaviour and irradiation [2], has been used for comparison. In this case, a parallel measurement of irradiation becomes unnecessary. Fig. 10. shows the open-circuit voltage during a day. On the left we show the scatter plot of open-circuit voltage for both panels during the central hours of the day, in order to avoid temporary problems related to low irradiation. Notice that spider case presents, systematically losses in voltage. Fig. 11 shows the short-circuit current behaviour through the course of a day. Results are compatible with the obtained in the test carried out at PAO : Under low levels of irradiation, both panels show a similar behaviour, whereas at the highest values of irradiation, spider module shows values up to 10 % smaller on the peak. Integrating along the full day we can assume that losses varied between 5 % and 8%, unfortunately depending on the irradiation level.

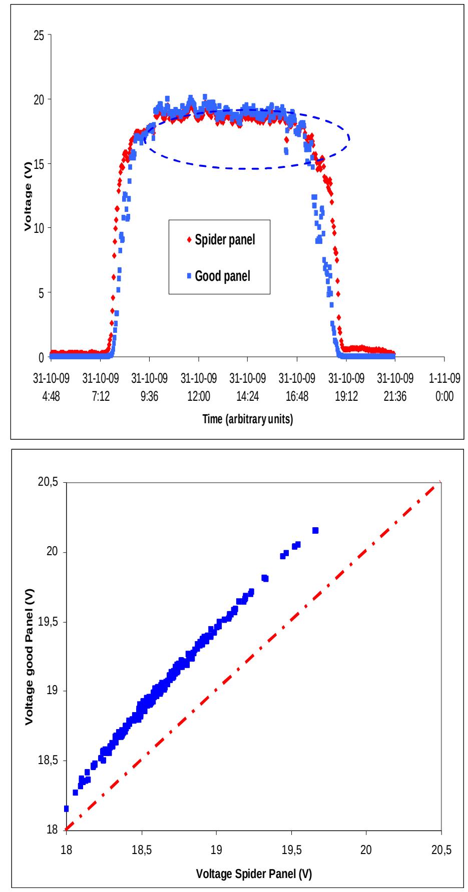


Fig. 10. Voltages of spider panel and calibrated one vs time. In the upper part, open-circuit voltage in spider case versus the same in calibrated panel.

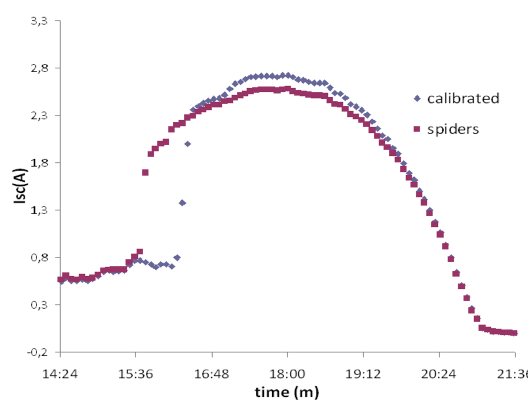


Fig. 11: short-circuit current vs time for spider panel (red) and calibrated one. It is worth noting that the differences in behaviour between 15:30 and 16:30 should not be taken into account since they are caused by an unavoidable, but controlled, shadow.

Size correlation measurements

The results obtained in our measurements in the Malargüe experimental hall suggest as a hypothesis that the effect of the spiders on the panel performance is dominated by the size of biggest spider on it and not by the number of them in the solar panel. In other words, it looks like if the surface occupied by the spider "shadow" the cell, producing the corresponding decrease on efficiency. To evaluate this possibility we perform a simple set of measurement on the USC lab:

- I-V curves for both spider and reference panels.
- I-V curves as before but covering about 80% of one panel cell. In the spider panel we cover the cell fired with the higher surface fissured. An 8x8 cm^2 opaque plastic surface was used for this purpose.

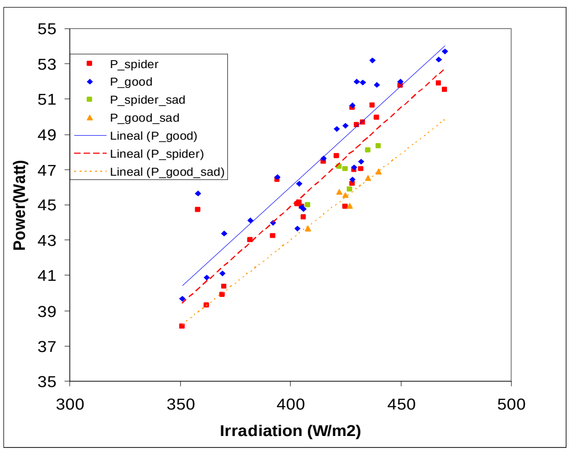


Fig. 12: Power of the solar panel vs irradiation. Reference panel with (orange) and without (blue)cover. Spider panel with (green) and without (red) cover.

Fig. 12 shows the obtained results. When one of the cells of the reference panel is partially covered, the power decreases about 10% at 450 $W/m^{2.}$ .At the same irradiation level, power decreases less than 3% when the fissured cell is covered on the spider panel. That is, if the surface of the cell with fissures is blocked up, there is only a small effect with respect to the same action effectuated over the normal panel. This suggests that the spider cell is less sensible and the losses in power are proportional to the spider surface.

Thermographic measurements

The apparition of a 'hot spot" could also explain the effect observed before. To determine a possible correlation between spider and hot-spots, a series of thermographic measurements were carried out in our lab. In fig. 13, photographs both infrared and visible of some representative spiders are presented: In the upper, the higher size spider in the panel, in the bottom one, a typical 2 arms spider.

From the photos, we could state that, although a habitual correlation between spiders and small inhomogenities concerning temperature of photovoltaic module is present, this effect does not exceed 2-3 extra degrees with respect to its surrounding area; neither is always placed in an accurate way over the structure of the spider itself. The temperature values are obtained over the glass surface and thus they are lower than the real cell-temperature in, at least, 10 degrees, but always, without reaching in any case alarming levels. Concluding, even if the spider's zone presents a slightly higher temperature, we can not conclude any evident relation between spiders and hot spots.

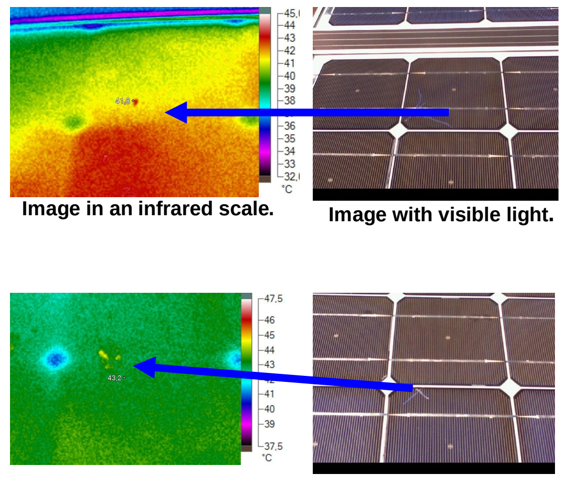


Fig. 13: infrared (left) and normal photographs of a spider solar module under the direct sun-light**.**

B. *Measurements at laboratories in CONTROLLED conditions.*

With the aim of reaching an as high as possible variety of checking and level of accuracy, we contacted the CIEMAT (Energetic, Environmental and Technologic Centre of Research), where there is one of the most complete and leading homologated certification centre for photovoltaic modules in Spain. We sent them the spider panel and the calibrated one to a high-accuracy and comparative description of their operation performance

The measurements they have carried out are the characteristic curve obtained from each solar panel under standard conditions of measurement (irradiance of 1000W/m2 -spectral distribution AM1.5G (IEC 60904-3)- and cell temperature of 25 ºC). In addition to these measurements, they have added a detailed visual inspection and electroluminescence images of both modules.

In Fig. 14, the characteristic curves of both solar panels are shown. There is a noticeably different shape between them, since spider case has a slightly more irregular shape than that of the calibrated one, as well as lower current values. The corresponding main parameters for each case are shown in Table 2, where spider solar module has a current with respect to that of the calibrated panel of around -3.27% whereas -5.11% at maximum power regime.

If we consider the flash data from the manufacturer, we could extract the corresponding losses with respect to its initial state. These results are shown in Table 3. As we can see, CIEMAT measured losses are somewhat smaller but clearly compatible, within intrinsic errors of such measurements and both irradiation and temperature dependence, with the ones we had done in other spider solar panels at the field and in laboratory.

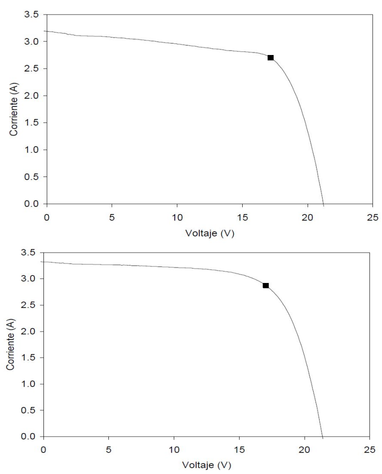


Fig. 14. Characteristic curves for spider case (up) and calibrated one.

Table III - Losses suffered by spider module since it was manufactured.

	Isc loss (%)	Voc loss (%)	Pmax loss (%)	Imax loss (%)	Vmax loss (%)
Spider	6.7	within error	8.3	10.3	-2.14

The obtained results in controlled laboratory can be easily compared because the same samples of panels where tested in or lab in working conditions. Results are compatible within the temperature conditions.

4. Conclusion

Different solar panel failures have been evidenced and tested: blued, browned and spider panels. Only spiders are unexpected. Tests have been carried out both in lab and field. The main conclusions we can extract are:

1.-The influence of the spiders as source of losses in the panel efficiency is evident, but assumable in a well dimensioned photovoltaic power system. Going in details spiders :

1.1.- Cause losses both in current and voltage evaluated in:

1.1.a- In controlled laboratory conditions (25^o C, 1000 W/m^2) the corresponding losses are around 7% (CIEMAT).

1.1.b- In working conditions, at the irradiation daily peak, observed losses vary between 10 and 15%.

1.1.c- Integrated daily losses vary between 5 and 8 % depending on the meteorological conditions.

1.2.- Moreover the observed losses:

1.2.a- Are dependent on the size of the higher spider in the module

1.2.b.-Are independent of the number of spiders in the module.

1.2-c- Depend on irradiation. Higher irradiation is losses increases.

1.3.- Are related to a small increase of cell temperature. No associated "hot-spot" have been detected.

2.- Blued and browned effect are smaller and can be considered as a factor in the expected ageing process.

3.- The present ageing of a panel without special failures is compatible with expected. The observed losses on short-circuit current is less that 2.5 % after seven years.

4.- Quick measurements of both the short-circuit current value and the irradiation level, (which could be easily extracted in the field by technicians during the normal station checks) constitute a sensible enough method for damage detection in the solar panels .

Waiting for more data and analysis, during July 2010, an incidence was opened with the manufacturer company to clarify the possibility of production problems as causes of the failures. If it is the case, guaranty covertures must take care of the full cost of panel repositions.

In parallel, we are working on methods, based on monitoring data analysis, for early detection of future anomalies [4].

Acknowledgement

To Prof F. Chenlo from the CIEMAT, M Salvadores and all the people of the Auger technical team.

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