ON-SITE TESTS FOR THE DETECTION OF POTENTIAL INDUCED DEGRADATION IN MODULES

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ABSTRACT: This paper presents different test alternatives which can be used on-site in a PV installation to detect potential induced degradation (PID) in modules. The testing procedures proposed are: thermal imaging; electroluminescence imaging; open circuit voltage measurements; operating voltage measurements; IV curve measurements; and dark IV curve measurements. Advantages and disadvantages of each test are reported.

Keywords: PID, PV module, evaluation, electroluminescence

1 INTRODUCTION

Potential induced degradation (PID) of modules in large grid-connected PV installations is an alarming phenomenon from 2006 [1]. Modules affected by PID have power losses due to leakage currents. Initially it was associated to special manufacturing procedures for modules, as SunPower modules (with high-efficiency back contact cells) and Evergreen modules (string ribbon cells) [1] [2] [3] [4]. Nevertheless, three years ago was reported that crystalline silicon modules are also susceptible to PID [5]. From that moment, PV manufacturers and researchers are investigating the origin of PID, the solutions to avoid it in the manufacturing process and the test to detect PID in a PV module [4] [5] [6] [7] [8] [9] [10].

PID has become a key issue last years because industry is worried about their effects: it can cause yield losses up to 80% [7]. The explanation why PID did not appear before is very simple: PID is related to high system voltages (some hundreds of volts), which are typical of systems installed after 2005. These high voltages joined with humidity and high temperatures facilitate PID come on the scene [1] [4] [5] [6] [7] [8] [9].

There is not a standard test procedure to detect PID yet, although there is a proposal of PID standard under discussion (draft stage [11]). It will be integrated into the design qualifications and type approval European standards for PV modules [12] [13]. This lack of reference is the reason why manufacturers and researchers have proposed different tests for the detection of PID in laboratories [4] [6] [7] [8].Another researchers have developed new and expensive tests for the detection on-site in full daylight of PID in modules [10].

This paper reports about different tests used by the Instituto de Energía Solar of the Universidad Politécnica de Madrid (IES-UPM) to detect PID on-site in a PV installation. The procedures here proposed can be carried out without the need of disassemble the modules from its supporting structure and some of them can be carried out every day at every hour of the day.

2 ON-SITE TESTS TO DETECT PID

2.1 Electroluminescence imaging.

A slow but detailed test to discover if a module presents PID is to get an electroluminescence image of the module. This is done with a CCD camera (an expensive device) while the module is biased with a current source and without sunlight. So, this test only can be done on-site at night.

A module free of PID has an electroluminescence image with all their cells with almost the same brightness, while a module affected by PID has dark cells: that is, shunted cells due to PID. Fig. 1 shows the electroluminescence images of 24 modules connected in series in a string affected by PID.

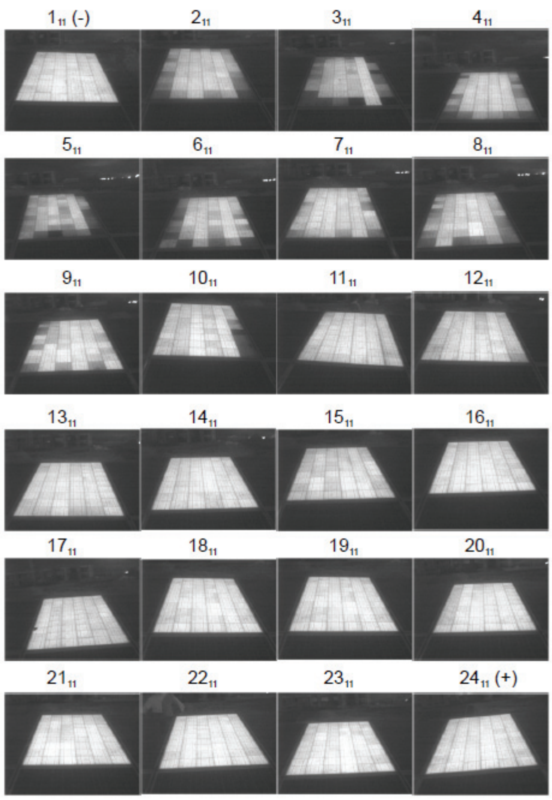

Figure 1: Electroluminescence images of 24 modules connected in series in a string affected by PID: the modules closer to the negative pole (module number 1) have dark cells (evidence of PID); the modules closer to the positive pole (module number 24) have their cells with almost the same brightness (free of PID). The module number 1 has not dark cells because the original one, severely affected by PID, was replaced.

The module number 1 is the module connected to the negative pole of the string; and the module number 24 is the module connected to the positive pole of the string. As can be noticed, the modules closer to the positive pole have almost the same brightness, while the modules closer to the negative pole have dark cells: they are affected by PID. It has to be pointed that the module number 1 has not dark cells even though it is close to the negative pole because the original module, severely affected by PID, was replaced.

The electroluminescence image reveals clearly if the module is affected by PID, but it does not report about how this degradation is affecting to the module efficiency.

2.2 Thermal imaging.

An IR inspection of the modules while they are in operation with an IR camera can be a useful method to estimate if a module is affected by PID or not [8]. A module with PID uses to have the affected cells with higher temperatures than the neighbour cells, while a module free of PID has all their cells almost at the same temperature. Besides, these hotter cells use to be together in the negative (or positive) pole of the string, as it can be seen in Fig. 2. This test can be easily done without interfering in the operation of the PV installation. Nevertheless, not always an IR analysis reveals the PID. Besides, this IR inspection has to be done in a sunny day to clearly detect the differences in temperature between the modules affected by PID and the healthy modules.

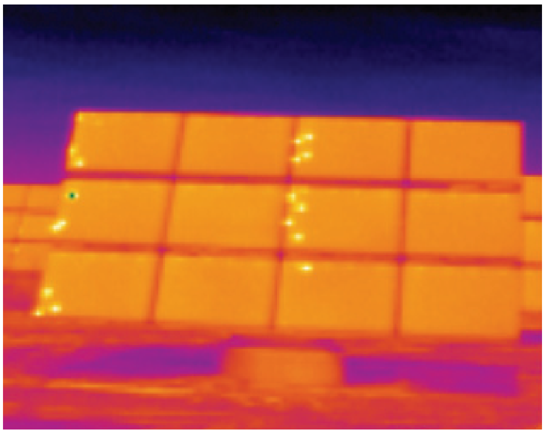

Figure 2: Thermal imaging of a tracker with modules affected by PID: the cells closer to the positive pole have higher temperatures (yellow) than the remaining cells (orange).

2.3 Open circuit voltage

Another possibility is to measure quickly with a voltmeter the open circuit voltage of the module. When a module is affected by PID its open circuit voltage can be lower than the expected one. This is because the reduction of shunt resistance can reduce the open circuit voltage [5] [9]. But this reduction is only noticed when the effect of PID is high.

Fig. 3 shows the normalized open circuit voltage measured in the previous 24 modules (the open circuit voltage of the module, Voc, divided by the nominal value from datasheet of the open circuit voltage, Voc nom). As can be seen, the difference between the Voc of the different modules is small. So, this time open circuit voltage does not reveal if a module is affected by PID because none is drastically affected. Besides, these measurements have to be done in a sunny day and in a short period of time to guarantee that all the measurements are done at the same irradiance and cell temperature conditions to compare the value of the different modules with the lowest uncertainty.

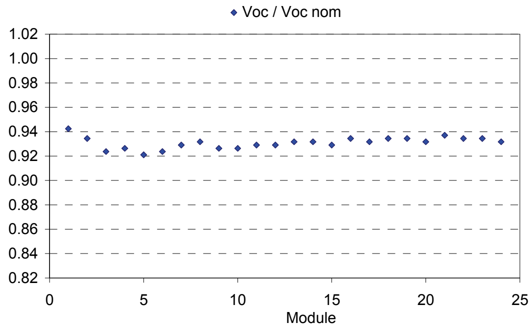

Figure 3: Normalized open circuit voltage of the 24 modules connected in series in a string affected by PID.

2.4 Operating voltage

The voltage of each module while they are operating can be also quickly measured also with a voltmeter. This value gives much more information than the Voc, as can be seen in Fig. 4. This figure shows the normalized operating voltage (the operating voltage of the module, Vop, divided by the nominal value from datasheet of the maximum power point voltage, Vm nom) of the previous 24 modules connected in series in a string. The modules more affected by PID have an operating voltage lower than the healthy modules. This is because the modules with PID have higher leakage currents and, consequently, to deliver the same current than the remaining modules in the string, they have to operate at a lower voltage. Besides, this decrease of operating voltage is proportional to the PID losses.

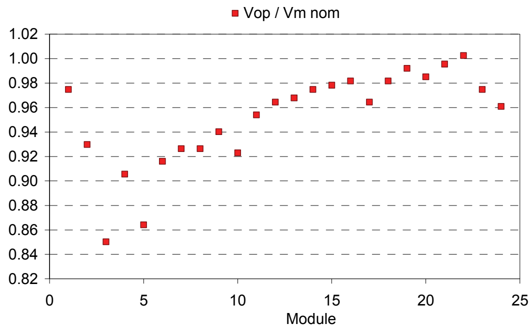

Figure 4: Normalized operating voltage of the 24 modules connected in series in a string affected by PID.

The easier method to measure Vop is to open the junction box to have access to the positive and negative poles of the module (besides the PV can go on in operation). Nevertheless, it is more and more usual that PV modules have a sealing label in the junction box (Fig. 5). If this label is broken, the module warranty is lost. So, another option is to prepare previously "T" connections in the poles of the suspect modules and in the poles of at least a healthy module in order to compare their Vop values (Fig. 6).

As in the previous test, the measurement of the Vop have to be done in a sunny day and in a short period of time to guarantee that all the measurements are done at the same irradiance and cell temperature conditions to compare the value of the different modules with the lowest uncertainty.

Figure 5: Sealing label of "warranty" in the junction box of a PV module.

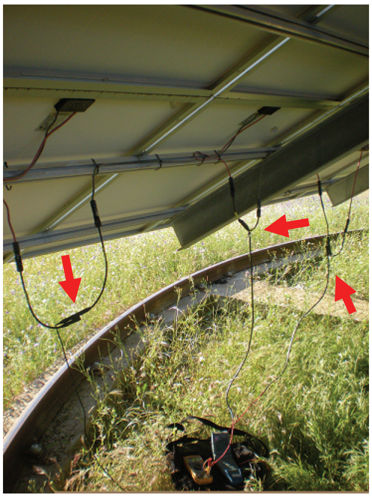

Figure 6: "T" connections in the pole of two modules to measure its operating voltage without open the junction box.

2.5 IV curve

The typical test to know if a module is free of PID is to measure its IV characteristic with an electronic tracer. Only the shape of the IV curve can report the presence of anomalies in the characteristic of the module, as can be seen in Fig. 7.

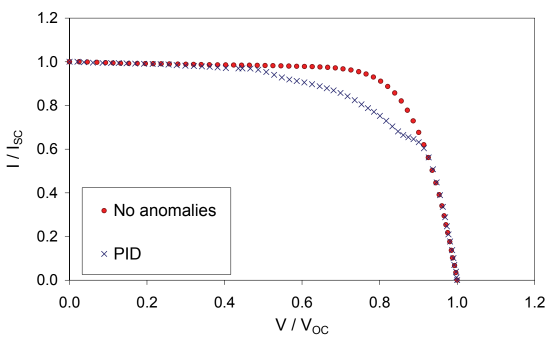

Figure 7: Normalized IV curve of a module with no anomalies (circles) and normalized IV curve of a module with PID (crosses).

But not always the differences on the shape are so evident. Then, it is needed to compare the power of different modules at STC, as is shown in Fig. 8. In this figure the normalized power of the 24 modules of the string analyzed (the maximum power of the module extrapolated to STC, Pm, divided by the nominal value from datasheet of the maximum power, Pm nom) is represented. These results are coherent with the measurements of the operating voltage.

Other authors report that the efficiency of modules at low irradiances is more affected by PID that the efficiency in standard test conditions (STC) [8]. So, another alternative is to measure the IV power module at low irradiances. This can be done by measuring the IV curve at very first hours or very late hours of the day.

Again, as in the previous tests, the measurement of IV curves has to be done in a sunny day and in a short period of time to guarantee that all the measurements are done at the same irradiance and cell temperature conditions to compare the value of the different modules with the lowest uncertainty.

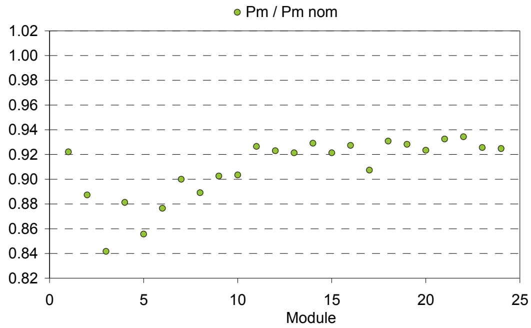

Figure 8: Normalized maximum power of the 24 modules connected in series in a string affected by PID.

2.6 Dark IV curve

Finally, another on-site test to detect PID is to measure the voltage of the module when it is biased with a current source and without illumination (dark conditions). It can be done with a blanket or a cardboard covering all the module area, as is shown in Fig. 9.

Figure 9: Cardboard covering the area of a module which is being biased with a current source (lower left corner).

Fig. 10 shows the results of measuring this dark Vbias in the previous 24 modules. The modules were biased with a current of -1.5 amps (about 20% of the datasheet short circuit current). In the graph the normalized Vbias (the biased voltage of the module, Vbias, divided by the nominal value from datasheet of the open circuit voltage, Voc nom) is represented. As can be noticed, the measurements are coherent with the tests of operating voltage and IV curve.

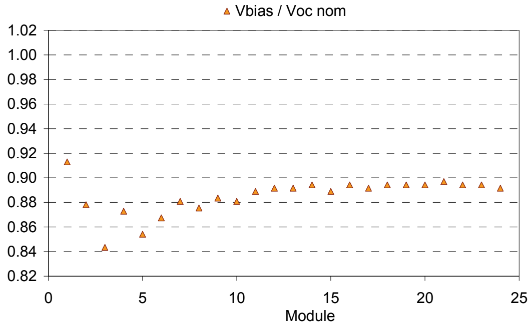

Figure 10: Normalized biased voltage (dark conditions) of the 24 modules connected in series in a string affected by PID.

These points represent one of the points of the dark IV characteristic of the modules, the point associated with Ibias = -1.5 amps. In fact, a value of this current closer to zero would be better to detect PID. Fig. 11 shows the dark IV curve from 6 of the 24 modules under analysis. As can be noticed, the more negative Ibias (higher absolute value, |Ibias|) the less difference between the Vbias of all the modules; and the less negative Ibias (lower |Ibias|) the more difference between the Vbias of the healthy modules (modules 1, 21 and 24, with almost the same Vbias value) and the Vbias of the modules affected by PID (modules 3, 4 and 8, with lower and different Vbias values, in function of their degradation).

So, the dark IV curve reports about the PID because it shows if the shunt resistance (related to the slope of the curve for low |Ibias|) is high or low and consequently the associated low or high leakage current, respectively.

As in the previous tests already presented, it is needed a "reference" module free of PID to compare its dark IV curve with the dark IV curve of the suspect module. But it would be enough to compare the Vbias value when the module is biased with a current close to 5% of the datasheet short circuit current. This last option is faster.

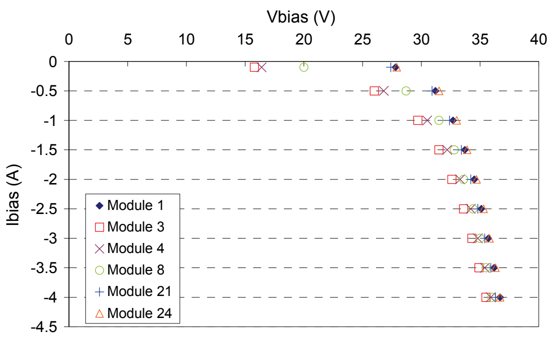

Figure 11: Dark IV curves from 6 of the 24 modules of the array under analysis. The modules affected by PID have lower Vbias values when biased at lower |Ibias|.

The main advantage of this method to detect PID in the PV installation is that these measurements can be done every day at every hour: there are not time restrictions because the voltage is measured in dark conditions. These conditions can be reproduced by covering the module with a blanket or a cardboard, as has been previously shown in Fig. 9. The only restriction is to do these measurements in the healthy module and in the suspect modules at the same cell temperature conditions to reduce uncertainty.

3 SUMMARY

This paper has reported about on-site tests to detect potential induced degradation (PID) in PV modules.

Electroluminescence imaging shows the shunted cells in a module due to PID; but an expensive device is needed (CCD camera) and the images have to be taken without light (at night). Besides, the electroluminescence does not quantify how much decreases the module efficiency.

Thermal imaging with an IR camera while the modules are in operation can be used to detect groups of cells with higher temperatures than their neighbour (these hot cells use to be together at one pole of the PV array) But an IR analysis does not quantify the degradation and not always reveals the presence of PID.

Open circuit voltage measurements with a voltmeter can be useful to detect modules drastically affected by PID. But the open circuit voltage does not reveal the presence of PID when this phenomenon has a light or even medium impact in the module efficiency.

Operating voltage measurements with a voltmeter are a better option: they report about the module efficiency losses when compared with a module free of PID, can be done faster if module junction boxes can be opened and does not require to stop the operation of the installation (unless the junction boxes have sealing labels of warranty; then, a "T" connection is needed).

The measurement of IV curve with an electronic tracer is also a good method to detect PID. Sometimes only the shape of the IV curve evidences the PID phenomenon. Other times it is needed to compare the power measured with the expected one to know if a module is affected by PID.

Another test to detect PID is to measure the dark IV curve of the module when it is biased with a current source (or only a point at low current level). This curve reports about shunt resistance, that is related to the leakage currents that origin the PID. Unlike the previous tests, this one has not time restrictions: the dark conditions required can be achieved with a blanket or a cardboard covering all the module area every day at every hour.

4 ACKNOWLEDMENTS

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