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On-site Inspection of PV Panels, Aided by Infrared Thermography

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Abstract: Greece ranks 5th worldwide in per capita installed PV capacity and Photovoltaics covered about 7% of the country's electricity demand in 2014. Since the majority of installed Photovoltaic parks in Greece are 3 to 5 years old, their inspection and maintenance needs are increasing fast. Thus, it becomes necessary to systematically characterize and classify the types of defects and correlate to possible causes. This paper attempts a systematic compilation of defects along with a simple procedure to spot them by means of optical and infrared inspection as well as electrical inspection. Furthermore, an attempt is made to initiate the development of a complete methodology and guide for on-site PV inspection that may also be employed for a pre-check of newly installed PV panels on site.

Keywords: Optical Inspection, Infrared Thermography, Defects of Solar Modules, Hotspots

1. Introduction

The installation of Photovoltaic systems in Greece skyrocketed from 2009 onwards because of the high feed-in tariffs introduced and the corresponding regulations for domestic rooftop PV applications. Since August 2012 new regulations imposed a temporary tax to all operating PV plants and a severe reduction in feed-in tariffs. By December 2013, the total installed photovoltaic capacity reached 2,419.2 MWp, out of which the 987.2 MWp were installed between January - September 2013 despite the unprecedented financial crisis. The Greek photovoltaic sector has vastly shrunk in 2014 installing only about 17 MWp. Greece ranks 5th worldwide with regard to per capita installed PV capacity. PV electricity covered 7% of the country's electricity demand in 2014. Due to the vast growth of the sector the need for extensive monitoring of the installations for early defects that could impact production has arisen. Several studies report a number of problems detected in field-aged PV modules [1], [2] but also in new plants [3], [4] using means of both optical and thermal observation as well several image processing techniques for more accurate results. These problems sometimes appear in PV modules as well as in other PV components. Since the majority of installed PV in Greece are 3 to 5 years old, it is necessary to characterize and classify the types of defects and, if possible, their origins. Equally important is the development of a complete guide for on-site PV inspection.

1.1. Monitoring of PV Parks

In the case of utility scale PV plants, monitoring typically serves for comparison of current plant performance with an initial energy yield assessment. To distinguish performance, one should filter the significant variability of insolation. Thus, monitoring should always include both the energy generated and the incoming irradiation. For electricity yield measurements, energy meters or true-rms power meters should be used. The inverter-integrated measurements are usually not sufficiently precise. Nevertheless they are useful for identifying relative changes over time.

Measurements gathered from PV plants comprise power output data at the inverter's level and environmental data (solar irradiance, outside temperature, air velocity). However there is no way to spot defects occurring during PV operation other than those found during on-site inspections of the plants. There are a few methods that can be employed to check for damage on a panel such as electroluminescence (EL), photoluminescence (PL), IR imaging and others. Out of them, infrared thermography is the one not requiring dismounting and disconnecting of the panel from the array to be checked for defects. Through the use of IR imaging, faults and damage that are otherwise invisible to the naked eye can be seen in the form of hot-spots. The origin of hot-spots may vary and an attempt to correlate defects found during the optical and thermo graphic inspection of PV parks with the power output is presented in this paper.

1.2. Performance Deterioration

Degradation in PV modules means a gradual deterioration of the component or system characteristics that can affect the ability to operate within the allowed tolerances. Manufacturers' quality assurance procedures usually consider a PV module as degraded, whenever its output power falls below 80% of nominal value [5]. PV modules' performance can be compromised by several factors, such as temperature, humidity, radiation and mechanical shock [6]. Each of these factors can cause various types of degradation. The IEC 61215 standard establishes the parameters for determining the modules degradation and performance. The tests include visual detection of defects in insulation and leakage currents [7]. It has been stated that the degradation rate of PV systems is less than 1% per year on the majority of the systems [8]. However there is a lack of adequate documentation about the effects of local climates on PV systems as the degradation rate may vary from region to region.

1.3. Objectives of This Work

The main objective of this work is to investigate optically and thermo graphically observable faults in PV installations. A significant number of normal photographs along with the respective infrared thermographs were compiled from regions of possible faults, aiming to correlate the measured temperature field on the panel surface with optical and electrical findings. The data were extensively compared and correlated and typical results are presented here. The hot-spots that were observable at the infrared spectrum are correlated with the normal photographs of the same parts of the panels. A second objective of this work is to quantitatively assess the effect of the observed hot-spots to the electricity produced by the PV installation, as a next step towards a workable inspection methodology. Hot spots have been addressed in a number of previous studies [9], [10]. They fall into two broad categories: a) "light hot-spot" when power losses are about 4% due to a 10°C temperature difference in the cell's surface, b) "strong hot-spot" when power losses are about 10% due to a 18°C temperature difference in the cell's surface.

2. Main Types of Faults in PV Panels

Inspection of PV panels is a quality assurance procedure that is increasingly employed, in various forms, by several PV panel manufacturers, before the lamination process takes place. These inspection procedures are completed in less than 1 minute and spot the existence of micro cracks, cell edge deterioration, electrically inactive parts of cells, low generation cell areas, low generation cells (for mismatch), irregular distance between cells, crystal defect, ribbon misalignment etc. In case of spotting defects that exceed the performance limits set, the panel may be readily repaired before proceeding to the lamination.

On the other hand, an inspection procedure for the PV panels and electrical installation of in-use PV parks should be also embodied in a PV park monitoring process. This inspection process may lead to the detection of a number of faults that may be categorized as follows:

(1) Damage to the PV panel or panel covers, of the following types:
- Breakage of the glass protective surface
- Bubbles and/or tears to the polymer (Tedlar) cover of the backsheet
- Corrosion of metallic frames
- Damage to the panel insulation
- Failed solder bonds of the PV cells

(2) Hot spots to the panel surface, which are observable by infrared thermography. A hot spot is a PV cell or a group of cells being at significantly higher temperature than the rest of the cells of the panel, because it behaves as a purely ohmic load, draining energy produced by the neighboring series - connected cells. This behavior could be due to the following reasons:
- Deterioration of the PV current due to dust or dirt accumulated on its surface
- Damaged or broken up cells (mechanical damage, break of protective layers)
- Partially shaded cells (usually met in residential installations)
- shunt resistance problems
- resistive heating due to improper cell interconnect

(3) Errors in the laying out of the electrical installation – bypass diode etc

(4) PID effect (Potential Induced Degradation)

This phenomenon, first observed in the seventies, leads to a sudden decrease of PV panel efficiency. The general mechanism of PID is that voltage bias related with leakage currents pass from silicon active layer through the glass to the grounded module frame [10]. Module leakage current to the ground increase with ambient temperature and relative humidity [10]. PID degradation depends on polarity and potential difference between cell and ground [11]. The most common test to detect PID is electroluminescence imaging, thermal (IR) imaging, measurements of open-circuit and operating voltage, IV curves and dark IV curves [12]. There exist recovery methods for affected panels [11], therefore it is important to inspect the panels.

The diagram of Figure 1 summarizes typical faults by means of a correlation between the type of fault and the possible decrease in the energy production.

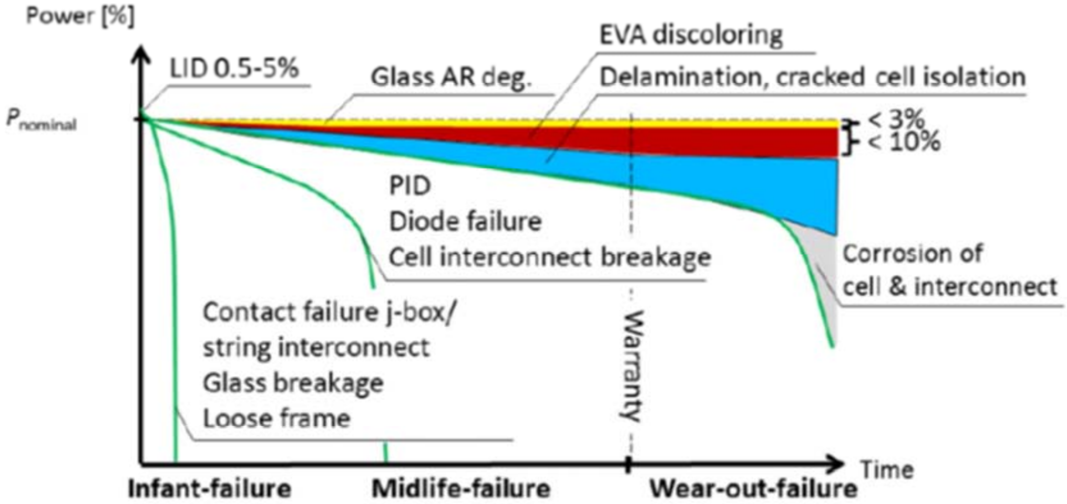

Figure 1. *Typical faults of PV modules and the effect of faults on the electric power in correlation with time [13].*

The significant differences in behavior of the various types of faults should be clear from this Figure. There exist faults that are not detected immediately because they do not result in a considerable decrease in the energy production. Thus it is important to create a diagnosis method for these fault types. IR thermography is a good candidate in this direction.

The hot-spot heating effect

When a hot-spot initiates in a cell due to one or more of the above mentioned reasons, a change in the electrical behavior of the cell takes place. The defective cell is forced to pass a current exceeding its generation capabilities. Thus it becomes reverse biased, entering the breakdown regime and subsequently sinking power instead of sourcing it. The amount of electrical power dissipated is equal to the product of the module's current and the reverse voltage developed across the cell. From a heat-transfer point of view, the relation between the additional dissipated power and the consequent temperature rise in the defective cell can be given by the following equation [9]:

$$P_{\text{conv}} = h \cdot A \cdot (T_2 - T_1),$$

where P_{conv} is the additional dissipated power (in W), A is the area (i.e. the cell) in direct contact with air, h the convection coefficient (of the order of 10 – 30 W/m^{2}K based on air velocity, T_1 is the initial temperature of the cell and T_2 is the increased cell's temperature due to hot-spot heating. That is, the reverse-biased cell dissipates power, in the form of heat, leading to excessive efficiency degradation of the related PV module [9]. The severity of this degradation directly correlates with the heat dissipated under reverse bias and, consequently, with the cell's temperature increment; typically, a 10◦C increase in the cell's surface temperature causes about 4% power loss (light hot spot) while an 18◦C increase reduces the power about 10% (strong hot spot) [10].

3. Routine Inspection Procedures

A routine PV installation inspection should comprise the following 3 stages:

- Optical inspection
- Inspection by infrared thermography
- Electrical inspection

3.1. Optical Inspection

Optical inspection of PV installations is a useful tool that can give us a quick view of the general condition of the installation, focusing attention to possible fault regions. Significant effort has been made in the past, aiming at the compilation of an inclusive catalog of the PV system faults that are observable by optical inspection [14], [15], [16]. Moreover, specific procedures in the form of questionnaires have been compiled. One should mentioned as an example, the NREL technical report TP-5200-56154 [17] which includes a detailed questionnaire for the recording of all types of problems that could be met during an optical inspection. The most usual problems observed are the following:

- Yellowing.
- Delamination.
- Bubbles.
- Cracks in the cells
- Defects in the anti-reflective coating
- Burnt cells

3.2. Inspection by Infrared Thermography, Suggestions and Guidelines

Inspection by use of infrared thermography is more powerful, because in the infrared spectrum one can observe certain faults that are not visible to the naked eye [9]. Infrared thermography makes visible a temperature representation of the installed panel's surface, without any need of disassembly or placement of probes. Regions of higher panel surface temperature that are readily observable at infrared (hot spots), are candidate places of faults.

The manufacturers of thermography equipment have developed technical guides for thermographic inspection, avoid faults in the procedure that could spoil the results of the inspection [16], [17], [18]. According to these guidelines, the measurements should be made in good insolation conditions in the range of 500 – 700 W/m^2, clear sky conditions to avoid cloud shading during shooting. Measurements in calm weather conditions are required for the temperature field not to be affected by enhanced convection. The camera maybe aimed to the front or the back of the PV panel. Infrared recordings from the front of the PV panel exploit the fact that the protective glass cover has an emissivity of ε=0.85-0.90 at the wavelength range of 8-14 μm (long wave) where most of the panel's emitted power occurs. Thus the temperature field of the panel surface becomes more readable. The reflections from the sun or surrounding objects on the glass may spoil the overall infrared image. For this reason, the shooting should be done not directly perpendicular to the panel, but at 5-60^o angles as shown in Figure 2. On the contrary, infrared images taken from the back of the panel take advantage of the absence of reflections, without compromising image quality, because of the fact that the tedlar polymer material of the backsheet has a high emissivity at the range of interest (ε=0.90). Shooting from the back has the disadvantage of the blocking of the view by the metallic supporting frame members, making certain parts not accessible to thermography. Due to the above reasons, shooting from the front and the back faces of the PV panel are combined, selecting the necessary viewing angles and field of view to extract useful information and avoid the problem of "false hotspots".

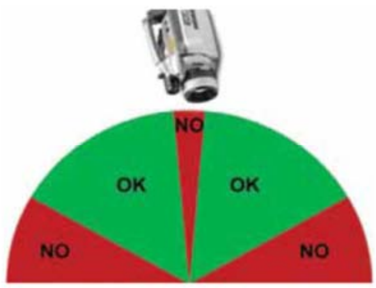

Figure 2. *Correct viewing angles of PV panels during thermographic inspection proposed by manufacturing companies of thermographic equipment.*

The minimum requirements for installation and monitoring of a PV system are presented in the guideline IEC62446 [19]. This document includes a chapter devoted to thermographic inspection. Insolation conditions exceeding the 400 W/m^2 level are required, (ideally 600 W/m^2) and steady clear sky conditions required for the temperature field to be clearly observable. Infrared shooting should be done from both sides. All PV panel arrays must be checked, with special attention to junction boxes and all electrical connections.

3.3. Electrical Inspection

Electrical inspection includes measurements with clip-on multimeters, general multimeters, PV analyzers and special equipment. Electrical inspection measurements provide an equivalent degree of performance and safety. In order to check that the pv installation works safely, it is demanded to check:

- continuity of protective earthing
- polarity test of all DC cables
- insulation resistance of DC circuits

Pv analyzers are able to measure the I-V curve of pv modules and string in order to be compared with I-V curve of the manufacturer's datasheet. Multimeters are able to measure string open circuit voltage and short circuit current. It is also useful to measure solar irradiance and panel temperature in order to compare with STC and NOCT conditions using thermal characteristics and equations below.

$$I_{SC} = I_{SC(STC)}(1 + \alpha_{isc}(T - 25)) \quad (1)$$

$$V_{OC} = V_{OC(STC)}(1 + \beta_{voc}(T - 25)) \quad (2)$$

4. Study of Characteristic Type of Faults

Inspection of five PV installations was carried out. (Four PV parks of 100 kW peak power each, along with an additional roof top PV installation of 10 kW power). A FLIR Thermacam S45 camera was employed in the measurements. The camera is connected to a laptop PC by means of a firewire cable. The infrared photographs are processed by the specialized software "Thermacam Researcher" [20]. The measurements were carried out in the period from November 2014 to April 2015 in the greater area of Larissa (4 sites) and Trikala (1 site), all located in Central Greece. Measurements were carried out in a variety of meteorological conditions, comprising days with low, high and average insolation conditions.

4.1. Cell Mismatching

An example of this type of fault can be seen in Figure 3. This photo was taken on a 2-years old PV panel. As seen in the Figure, 2 cells from this panel are very dark-colored compared to the rest of the panel's cells. Infrared thermography shows that these cells have also higher temperature than the rest of the cells. The faulty region is shown to the left of the Figure and the respective thermogram with the hot spot to the right. The temperature diagram produced from the processing software (Figure 4) indicates a temperature difference of 5°C between the faulty region and the neighboring cells. The thermogram was taken from the back of the PV panel. According to the literature, the most probable cause of a hotspot is the installation of PV cells with different characteristics on the same panel [21], [22]. During the 24-month operation of the PV park to-date, no significant deterioration in the efficiency was observed. Thus, one cannot conclude if the observed difference is due to a malfunctioning of the PV panel or to an initially darker color of the cell, or even to the onset of a hot spot.

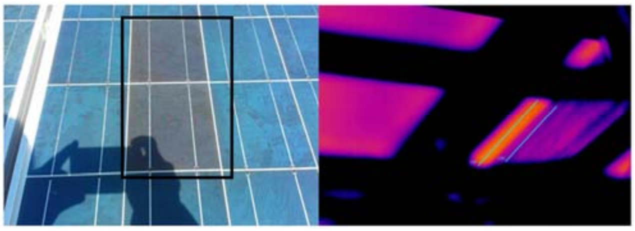

Figure 3. *Normal take of a PV panel (left) and the corresponding thermography (right) taken from the back side. The cells with different color can be clearly seen and the corresponding hotspot that appears.*

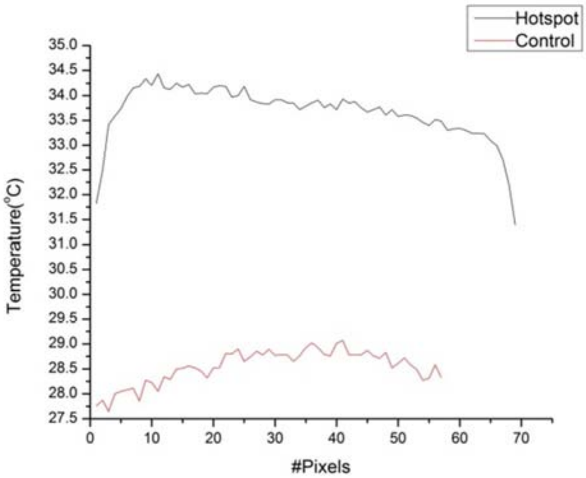

Figure 4. *Temperature profiles along the two parallel, oblique lines shown on the thermogram of Figure 2.*

4.2. EVA Membrane Color Discoloration (Yellowing)

An observable difference in the external surface color of certain PV cells was observed in a number of panels. It should be mentioned that these are PV panels of the same manufacturer and the same age with the above-mentioned. This fault is due to the discoloration of the protective EVA (ethylene vinyl acetate) membrane, which is placed in-between the cells and the protective glass. A certain degree of discoloration (yellowing) is observed in the photo at the left of Figure 5. This yellowing of the membrane is observed in a large part of the panel's surface. According to other researchers [23], [5], [24] this phenomenon is caused by a change in the membrane's chemical composition due to the effect of UV radiation and high temperatures. Several cells with increased temperature can be seen in the respective thermogram to the right of Figure 5. The temperature difference varies in the range from 4.5°C (cell #1) to 2.5°C (cells # 2, 3), as shown in the respective temperature profiles of Figure 6. The thermogram was taken from the front of the panel, because shooting from the back was hindered by the frame. It is possible that other regions exist with increased temperature. Moreover, the temperature difference could be higher than the above mentioned. This is a typical fault observed in several PV panels in this installation.

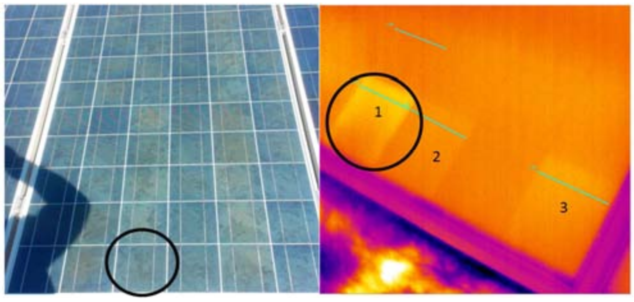

Figure 5. *Normal photo of a PV panel (left) and the corresponding infrared photo (right). The cells affected by discoloration (yellowing) can be clearly seen and the corresponding hotspots that appear.*

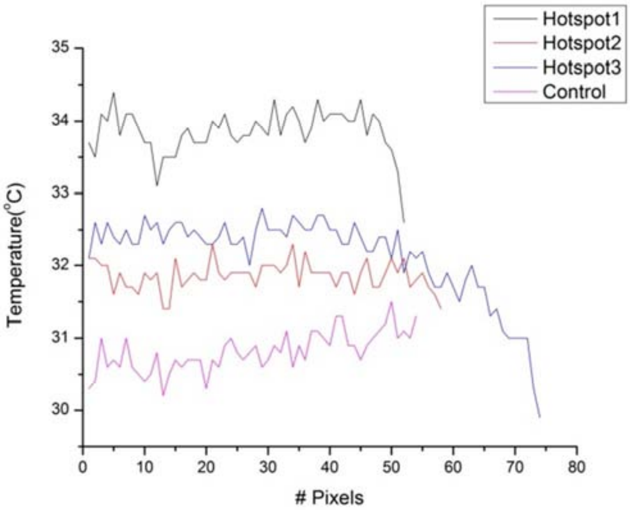

Figure 6. *Temperature profiles along the six parallel lines shown on the thermogram of Fig. 5.*

4.3. Mechanical Damage (Breakage of Protective Glass)

A PV panel with apparent breakage of its protective glass was spotted in the same installation. A photograph is presented in Figure 7. The protective cover has broken in two places and cracks propagated to cover most of the panel's surface. This resulted in the intrusion of humidity inside the panel structure. The results from infrared thermography (Figure 8) revealed three hot spots with significantly higher temperature than the neighboring cells. The temperature difference varies from 22 to 40°C (Figure 9). The image was taken from the front, in order to show a panoramic view of the panel. Closer thermograms taken from the back, revealed significantly higher temperature differences of the order of 50 °C (Figure 10). This difference could be attributed in part to errors due to diffuse radiation from the background, during the front shootings. Moreover, the closer thermograms reveal a more detailed temperature distribution inside the cell, with regions of different temperatures in the same cell, with differences as big as 35°C. These could be due to the existence of cracks at the cell's surface, a fact that could not be confirmed due to the specific position of the panel at the highest horizontal line that was not easily accessible. The specific thermal behavior is explained in the literature [24].

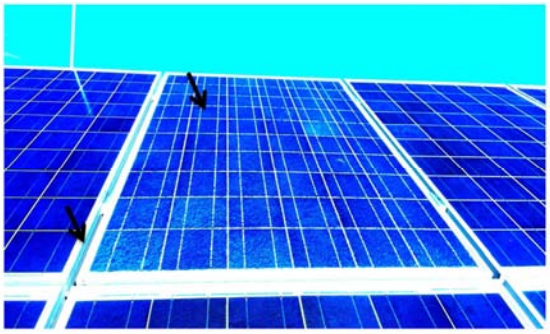

Figure 1. *Panel with mechanical damage (protective glass) in two areas highlighted by arrows.*

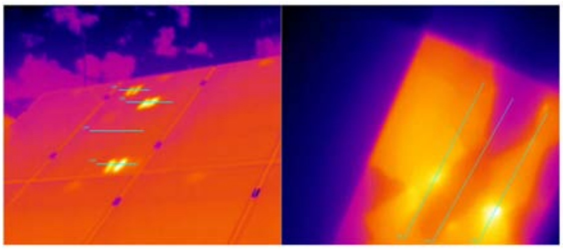

Figure 2. *Thermographic view taken from the front of the problematic PV panel with the cracked glass on the left. Close up view taken from the rear side of the same panel on the right where areas with different temperature are shown.*

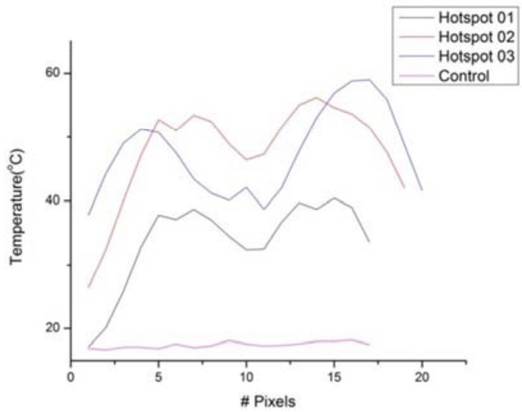

Figure 9. *Temperature profiles of the problematic areas of the panel of fig. 7-8.*

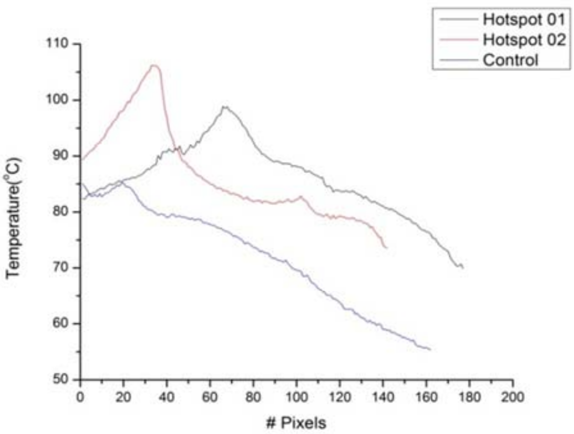

Figure 10. *Thermographic profiles of the back side of the panel of fig.7-8.*

4.4. PID Effect on PV Cells

According to the findings of other researchers [11], it is possible to observe and record the phenomenon of PID by means of infrared thermography. A series of measurements were carried out in a roof-top PV installation to confirm these findings. Optical inspection of the installation did not reveal any possible faults. However, the results of the infrared thermograms showed that a significant percentage of the installed PV panels suffered from PID. Some of the findings are observable in Figure 11. The phenomenon is especially observable with the cells that are closer to the metallic frame. The temperature difference is in the range of 3 to 4°C (Figure 12). Infrared thermograms were received also from the back side for confirmation (Figure 13). Again the processing of the thermograms indicated a temperature difference of 3°C.

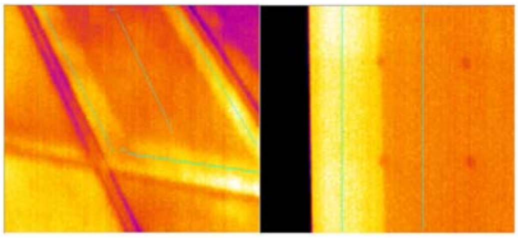

Figure 11. *Thermographs of PID affected panel. Takes from the front (left) and back side (right).*

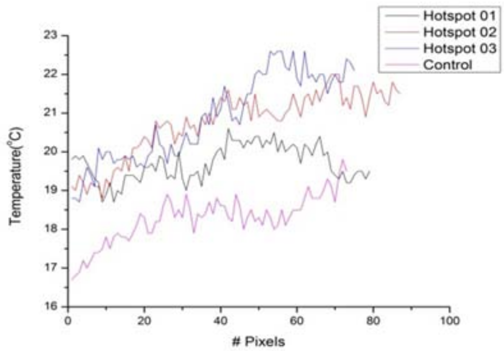

Figure 12. *Temperature profiles of the front side of the PID affected panel shown on Fig.11.*

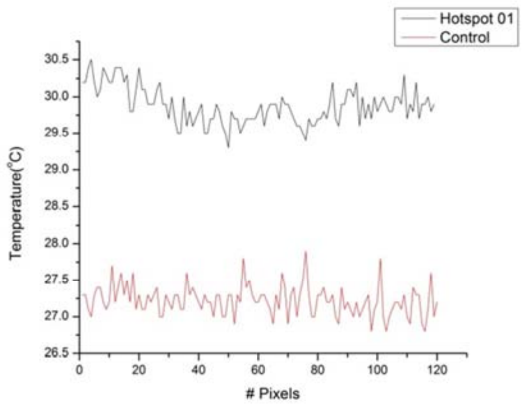

Figure 13. *Temperature profiles of the back side of the PID affected panel shown on fig.11.*

4.5. Observable Hotspots Linked to no Apparent Optical Fault

Several hot spots were found during inspection in two different PV installations, in cells with no visible faults (Figures 14, 16). The temperature differences observed were of the order of 3°C (Figures 15, 17, 18). It is not yet confirmed if the observed hot spots point to a fault in its initial stages that is not yet visibly apparent, or if the specific type of fault is not visible to the naked eye.

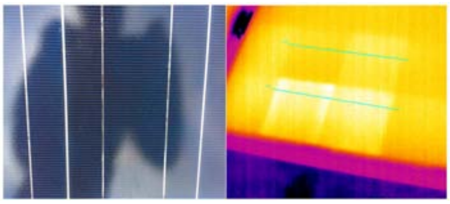

Figure 14. *Hotspots appearing on a thermograph (right) of cells with no visible damage (left).*

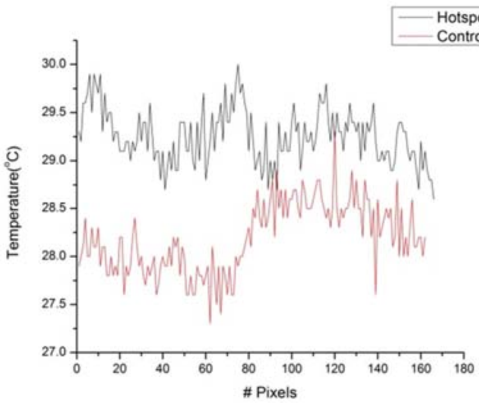

Figure 15. *Temperature profiles of the two parallel lines seen on the thermograph of fig.14.*

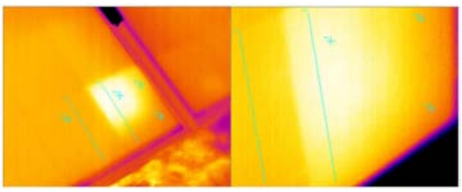

Figure 16. *Thermographs taken from the front (left) and back side (right) of a PV cell with no visible damage.*

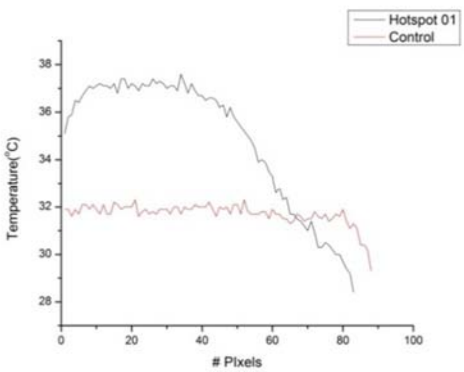

Figure 17. *Temperature profiles of the two parallel lines seen on the thermograph of fig.16.*

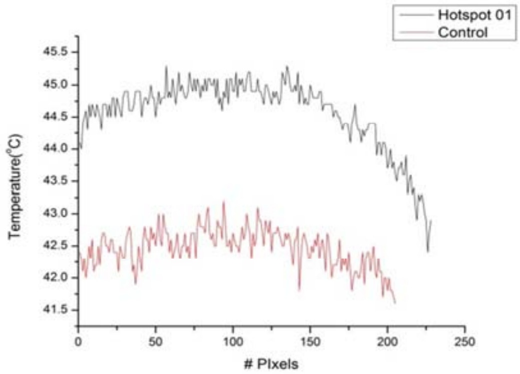

Figure 18. *Temperature profiles of the two parallel lines seen on the thermograph of fig.16.*

Another case with a remarkable temperature difference without apparent optical fault is the image of figure 19. In the specific PV panel, most of the cells have similar temperatures except for one cell that has a temperature of 80°C. However, no performance decrease is observed yet. Monitoring of this case could lead to future results of this hot spot.

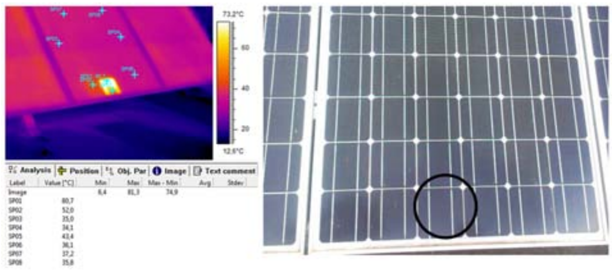

Figure 19. *IR images of pv panel that has not optical fault , however it has an a cell with remarkable temperature difference.*

5. Impact of Faults on Electricity Production

Monitoring data from the operation of the inverters installed on the PV park #1 (in which the faults presented in Figures 4, 6 and 15 were spotted) were collected and processed. The specific PV panel shown in Figure 6 is installed in the same series connected to Inv1. This specific inverter produces 5% less electric power than the rest of the inverters in this installation. This should be attributed to the faulty performance of the specific panel, because no deviation was observed in the past with these inverters. According to the above mentioned classification of hot spots, a temperature difference of 18°C may result in a 10% power loss. In the specific case, temperature differences exceed 35°C, however, the observed power losses are only 5%. This could be attributed to overproduction of the other panels in the string. Further investigation is needed. Moreover, another inverter, namely, Inv6 which is connected to PV panels shown in Figures 4, 15, produces 1% less electric power compared with the rest of the inverters (apart from the above-mentioned Inv 1). This slightly reduced electricity production from this series could be due to the fact that several panels from this series present a yellowing of the EVA membrane. The diagram presented in Figure 20 shows the electricity production during the 3rd of March 2015, which was the specific day when the inspection with thermography took place. During the time interval from 11.00-13.00 where the infrared thermograms were received, it is apparent that the inverters Inv1, Inv6 produce less power. In order to confirm that this is a systematic deviation in performance, Figure 21 presents a diagram of the electricity produced during the first 10 days of March. The trend is clearly observable for all days.

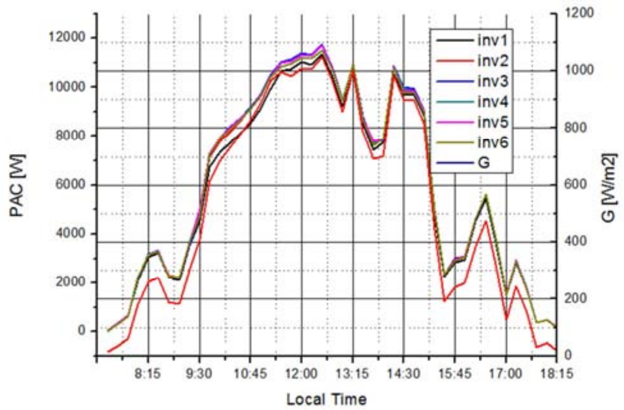

Figure 20. *Graph of daily electricity production of a 100 kW PV plant and solar insolation on March 3rd, 2015.*

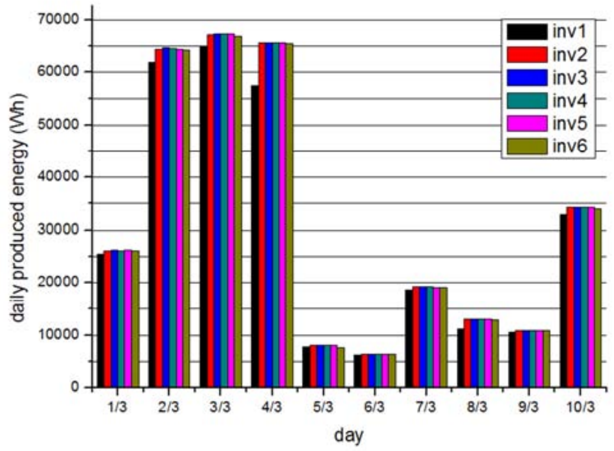

Figure 21. *Electricity production of the same PV plant in the period from 1 to 10 March 2015.*

6. Development of a Draft Diagnostics Procedure

The experience gained from the carrying out of inspections, led to specific suggestions for an optimal way to schedule and carry out the respective measurements. Several standards are in preparation related to the necessary steps that should be followed during an inspection of a PV installation by infrared thermography. A "Standard for Infrared Inspection of Installed Photovoltaic (PV) Systems" was issued in 2014 by the Infraspection Institute [25]. Two additional standards are at the development stage, from the International Solar Energy Society, German Section [26] and from the International Electrotechnical Commission (IEC) [27], respectively. An optimal inspection procedure should converge on the following points:

- Based on the PV panel manufacturers' suggestions, sufficient insolation conditions should prevail, between a minimum of 500 W/m^2 and an optimal level of 700 W/m^2. This was confirmed by our experience, since the faults were not observable during clouded days. Even in days with insolation close to the minimum of 500 W/m^2 several problems were met with the measurements.
- Good quality measurements were succeeded during conditions of low wind speed, where convection coefficients are lower and temperature differences more enhanced.
- The inspection must be carried out in closed circuit conditions (regular operating conditions), because the faults are only observable with electrical load.
- It is necessary to control the measurement errors whenever the measurement takes place from the PV panel's front. It should be mentioned that this type of measurement offers a panoramic view of the PV panel's surface, a fact that cannot be attained by a measurement from the back. However, front measurement induces a significant error due to the effect of diffuse radiation that should be carefully corrected by taking duplicate measurements in the respective places from the back. Measurements from different angles and different distances are very useful because their combined processing further increase resolution and visibility of the various faults.

This diagnostic procedure may also be employed for a pre-check of newly installed PV panels at the installation site. This is increasingly requested by several clients, because of the fact that the panels could suffer damages during shipment from the factory to the installation site.

7. Conclusions

- IR thermography is a promising diagnostic technique because it allows a quick and reliable inspection of a grid-connected PV park, with no loss in energy production.
- Infrared thermography supported by optical inspection was extensively applied to fault detection in 4 PV parks and 1 roof-top PV installation.
- An attempt is made to correlate observable defects on installed PV panels with hotspots appearing in IR images of the same panels.
- In most cases there is indeed a connection between observable faults and hotspots however in a few occasions such a connection cannot be made since there aren't any observable defects.
- Monitoring data from the operation of the inverters installed on one PV park were collected and processed

to quantify the observable hotspots with losses in electricity production. It was found that two out of the six inverters of the plant produce 5% and 1% less electric power respectively. This deserves further investigation, since temperature differences in the first case exceeded 35°C and one would expect even higher power losses.

- The resulting experience is employed in the development of a procedure that could be routinely applied to the health monitoring of PV installations.
- This procedure may also be employed for a pre-check of newly installed PV panels on site, which is increasingly requested by the clients.

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Nomenclature

G measured irradiance [W/m^2]
T measured module temperature [K]
P_{ac} Electric power produced by PV park [kW]
a Temperature coefficient of P_{MAX}
I_{SC} short-circuit current [A]
V_{oc} open-circuit voltage [V]
α_{isc} Temperature coefficient of I_{SC}
β_{voc} Temperature coefficient of v_{oc} [%/°C]
h Heat transfer convection coefficient [W/m^{2}K]
A Measured area [m^2]
P_{conv} Power lost through convection [W]

Abbreviations

IEC International Electrotechnical Commission
NREL National Renewable Energy Laboratory
PV Photovoltaic
EL Electroluminescence
PL Photoluminescence
IR Infrared
EVA Ethylene vinyl acetate
STC Standard Test Conditions
NOCT Nominal Operating Cell Temperature

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