Failure Analysis Capabilities for PV Systems

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Abstract: - PV power systems may be subject to unexpected ground faults, like every other electrical system. Installed PV systems always have invisible elements other than those indicated by their schematics. Capacitance, resistance and stray inductance are distributed throughout the system. Leakage currents associated with the PV modules, interconnected array, wires, surge protection devices and conduit add up and can become large enough to look like a ground-fault. In this paper a non-destructive method based on IR thermography is put into evidence and experiments are made. Solar panels measurements where made with the use of infrared thermography. Hot spots invisible to naked eye where put in evidence and dust accumulated particles over different surfaces where also detected and analyzed.

Key-Words: - hot spots, IR thermography, failure prediction, preventive maintenance, PV fault systems.

1 Introduction

The reliability of photovoltaic modules has always been one of the most important subjects as reliability and lifetime is the key for overall system performance and warranty. Photovoltaics (PV) reliability has gained increased attention as the photovoltaics industry has rapidly grown and the numbers of module makers have increased too.

PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantial. There are other factors that affect the output of a solar power system. These factors need to be understood so that the customer has realistic expectations of overall system output and economic benefits under variable environmental conditions over time.

In the presented paper different types of photovoltaic (PV) defects are reviewed and an experiment is made using non-destructive techniques to analyze visible and invisible defects for the PV array.

2 Failure Analysis

As part of failure analysis of photovoltaic modules and arrays, analytical techniques are critical for isolating the defect and its source.

Photovoltaics have seen an impressive growth in the number of field systems. However, the more systems are built the more difficult it gets to keep an overview and to learn from the field experience.

Zero defect manufacturing and production is today’s aspiration for either a single producer or the whole industry. Defects and, especially, cracks in the structure of the materials components are crucial for optimum performance and their detection is essential to ensure secure operation and functionality of the final product.

Most problems regarding photovoltaic systems that where identified and regarding multiple systems where: power limitation by inverter to keep upper limit for line voltage, partial shading in PV awnings by upper rows, PV generator operating voltage below inverter input window, power loss due to undersized inverter, gear thing or isolation faults, bypass diode failure, faulty circuit breakers or switches (given by: module, inverter, battery, conductors). The first of these troubles was solved by reducing the set voltage of the distribution network and

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thus allowing a larger margin between operational grid voltage and upper limit of grid voltage. Alternatively, inverters outputs have to been reduced.

In real life costs for PV systems are mainly determined by the initial power output, power degradation and the lifetime of the modules. Therefore, guaranteed and certified quality for the operation of the PV modules is a fundamental requirement which provides the basis for in time profitability and security of the investment. We need to remember that the real world environment has much more variables to offer than a dust free chamber in which they are tested when modules are manufactured. There is a strong need to reduce any source of dysfunction of a PV module.

Depending on the conditions in which the PV panels are installed they need to be periodically checked for visible or hidden defects. A thorough inspection every month or so is not only hard to do, but also time consuming. Think to a power plant of a few MW installed power composed only of solar panels what it would mean. Is practically impossible to take every solar panel and inspect it. So, the idea of infrared thermography came to life, especially giving the fact that this method is also an interactive one and giving the fact that production doesn't need to be stopped when the inspection is made.

Reliability begins before the first hardware is installed. A good planning and design can boost the system performance as well as poor components can compromise it [1]. Many building integrated PV projects are built to demonstrate innovative science that stands behind photovoltaics by it. They intentional use new materials and systems. The use of new module types, or new mounting systems, is increasing the risk factor of component failures.

PV power systems may be subject to unexpected ground faults, like every other electrical system. Installed PV systems always have invisible elements other than those indicated by their schematics. Capacitance, resistance and stray inductance are distributed throughout the system [2]. Leakage currents associated with the PV modules, interconnected array, wires, surge protection devices and conduit add up and can become large enough to look like a ground-fault. PV systems are frequently connected to batteries, standby generators or the utility grid. This complex assembly of distributed power and energy sources, distributed impedance and proximity to other sources of power requires sensing of ground faults and proper reaction of the ground-fault protection devices.

The industry has had products out in the field for some time already and effects of aging of modules, connectors and wiring system can be seen all over [6]. Any of these effects combined are leading to an increase in faults developed in systems.

Short circuits arise primarily from insulation failure or because of poor workmanship. Insulation problems may appear as casing deterioration due to mechanical failure given by aging, vibration, wear, ultra-violet exposure or exposure to over-voltages (lightning). Short circuits may also result from arcing causing damage to insulation.

Positive to negative short circuit faults may appear in areas where the two conductors are in close vicinity such as combiner boxes [5]. A positive to negative fault generally results in catastrophic failure because of the high probability of an arc forming and as a result the whole array voltage and current is potentially available to feed the fault.

A module junction box short circuit within a single string may lead to decreased array output but in an array with two or more strings in parallel it may lead to high reverse currents which may, also, lead to either string wiring failure or module failure.

The main issue with bad joints is that though overheating or because of fracture may lead to an interruption of current or to an arc [4]. Bad joints may occur within modules due to poor quality control by the manufacture. If a failure occurs within a module under normal forward conduction an arc will not usually result if bypass diodes are fitted and operational.

In order to protect shadowed solar cells from breakdown, bypass diodes are applied. Bypass diodes for hot-spot protection of large area modules are sometimes left out [7]. Protection from hot-spots is totally ignored or sought by other means, for example by using several parallel cell strings within a module.

Experience shows that this is a risky path. Paralleling several cell strings within a module does not protect the modules, if partial shading from nearby objects occurs regularly.

Because the series connection of the PV generator forces all cells to operate at the same current (string current), the shaded cell within a module becomes reverse biased which leads to power dissipation and thus to heating effects [8]. If the cell is shaded, its short circuit current is less than the string current so that it is operated at reversed characteristic, leading to power being dissipated.

Leakage currents originate in cell defects and impurity centers in the semiconductor and can be represented by a shunt resistance. At low bias voltages the current is distributed over the whole cell area and heating takes place more or less uniformly [11]. The maximum current density is below the critical limit and the characteristics are stable against thermal effects.

If we want to maximize energy output over lifetime of the PV system, we need to be able to recognize when there is a fault or a reduction in output. We also want to find out what has caused the loss of output and find a solution as quickly as possible, but we don't want to waste too much time and man power on this [10]. PV modules are usually reliable systems, but in practice right balance being the key.

Typical photovoltaic systems suffer from numerous problems that prevent them from realizing their true potential. Many of the present problems stem from power losses – whether due to module mismatch, orientation mismatch, ground faults or partial shading. Other problem comes from system design limitations and constraints, lack of monitoring or lack of analysis abilities. In addition, the absence of safety features poses risks to both workers and maintenance personal.

Current PV systems are typically built from ten to a few hundred PV modules connected in a series-parallel connection. Several panels (10 to 15 typically) are series connected in a string of modules so that a voltage high enough for DC/AC inversion (150V to 800V) is achieved. More power can be added to the system by adding strings. Since the strings are connected in parallel, they have to match the other strings in all parameters, including orientation. The entire array is connected to a solar inverter which is responsible for harvesting the electrical energy. The inverter handles maximum power point tracking the entire array. This is done by finding the DC working point in which the most power is harvested from the array. The resulting power is inverted and fed into the power grid [9]. The inverter is also responsible for conforming to the electrical and safety regulation requirements.

The manufacturing process of PV cells produces cells with relatively large tolerances in their power output capability. To reduce the difference between cells in the same module, they are sorted during manufacturing to different power categories (bins) and modules are assembled with cells from the same bin. This produces panels with smaller tolerance variances in output power [12]. The panels themselves are not sorted, so that today panels that are on the market have a 3% tolerance in output power.

For solar cells the most important mechanism in junction breakdown is the avalanche multiplication which has the origin in the high electric field, into the depletion layer that is generated by the bias voltage. Cells do not have a homogeneous structure, regions with higher impurity concentration of centers exists. At high bias voltages if the current density exceeds a critical limit the cell is irreversibly damaged by thermal breakdown (burnout) that forms a shunt path in the cell structure [13]. At reverse bias the current is locally concentrated, focal-point heating is caused and damage to the cell encapsulation is to be expected (hotspot).

To avoid thermal overload and the formation of hot spots, sub-strings of cells inside the interconnection circuit of modules are bridged by bypass diodes. This measure limits the bias voltage of the shaded cell and therefore dissipated power too.

Partial shadowing has been identified as the main cause for reducing energy output for grid-connected photovoltaic systems. Impact of the applied system configuration on the energy output for partially shadowed arrays has been widely discussed [15]. Nevertheless, there is still much confusion regarding optimum grade modularity for such systems.

Shading effect occurs when part of the panels array are shaded which can be caused by a number of different reasons, like shade from the building itself, light posts, chimneys, trees, clouds, dirt, snow and other light-blocking obstacles.

Shading on any part of the array will reduce its output, but this reduction will vary in magnitude depending on the electrical configuration of the array. Clearly, the output of any shaded cell or module will be lowered according to the reduction of light intensity falling on it. However, since this shaded cell is electrically connected to other shade less cells, their performance may also be lessened since this is essentially a mismatch situation.

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and is in the amount of to at least 2% loss in system power [14]. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep them below 3% for the all system.

Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season.

Cell manufacturers generally provide no information about the behavior of their cells under reverse biased condition, but an infrared image can provide the needed feedback to anticipate any internal cell decaying process.

3 Experimental Results

In this paper defects invisible to the naked eye are determined and analyzed using the temperature factor for PV panels for different environmental conditions. For the presented case measurements were made using and IR camera on the Politehnica University of Bucharest solar power plant – figure 1.

Partial shading occurs when part of a panel or panels are shaded, causing different levels of illumination on the cells in the panel. This can happen due to shade from the building itself, light posts, chimneys, trees, cloud fronts, dirt, snow and other light-blocking obstacles.

As the study shows, defects are not completely rendering a solar panel unusable, but parts of it and those parts are creating domino effects on the surrounding areas and if not taking preventive measures, not only the solar panels in which solar cells are defective, but bigger portions of the power plant can fail.

Fig. 1. University Politehnica of Bucharest, Faculty of Electrical Engineering Power Plant.

Shading in any part of the array will reduce its output, but this reduction will vary in magnitude depending on the electrical configuration of the array. Clearly, the output of any shaded cell or module will be lowered according to the reduction of light intensity falling on it. However, since this shaded cell or panel is electrically connected to other shade less cells and modules, their performance may also be lessened since this is essentially a mismatch situation.

Decreased output from an array with partial shading can be significantly greater than the output given by the illuminated area. This is because of the output from the illuminated area, for which the loss of power from shade less modules dramatically reduces the output operating voltage and remaining modules cannot operate at their designed individual peak points.

Thermography provides helpful assessment for loose connections which can be cause by a number of reasons, load imbalance into cables, corrosion and increased current impedance. These methods offer fast detection for hot spots, making it much easier determining the severity of the problem and help establish the time frame in which the equipment needs to be repaired.

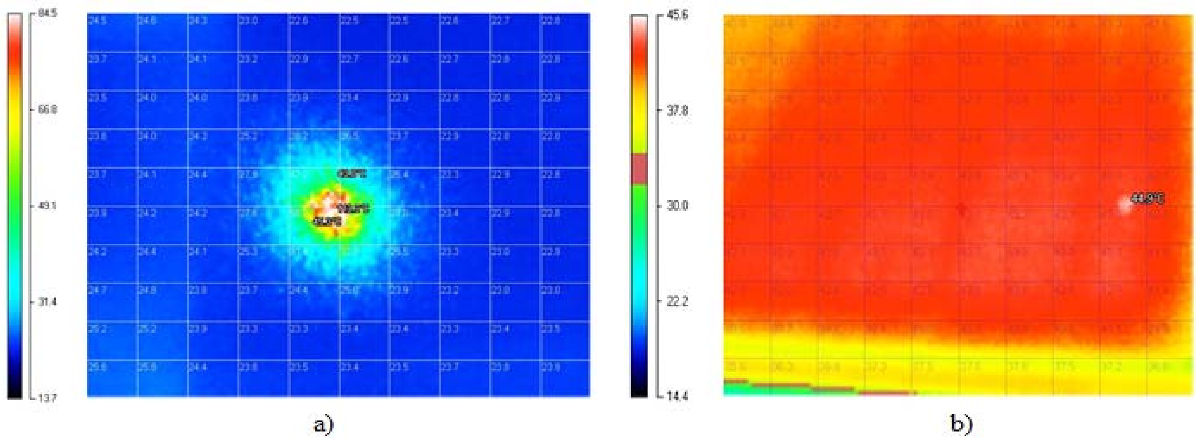

Fig. 2. Visible hot spots resulted as dirt and impurities got stuck to the panels

As the temperature coefficient for the power peak of PV modules is negative, it is very important to monitor their temperature in order to verify that the PV plant produces the maximum energy. Moreover, to monitor the temperature allows detecting anomalies before they become failures. Then, thermography can give meaningful support just for this aim.

Since a solar cell is forward bias in operation, any shunt current reduces the efficiency of the solar cell. Shunts may be caused by electrical defects of the pn-junction, which may generate lattice defects, as well as by technological imperfections of the production process.

IR thermography is currently used to detect local imperfections in the production process, for this case local variation is used to detect the current density across solar cells.

In figure 2 there are hot spots detected, without externally visible damage on the panel surface. Thus, the problem must be attributed to internal causes, corrosion being one possible candidate. Invisible hot spots corresponding to areas where the internal structure of the panels is beginning to decay is visible with an IR camera help.

A thing that is good to be remarked is that some spots are by their nature invisible to the naked eye, contrary to the dust and impurities deposits, but with the infrared equipment even those ones are easily seen removed as quickly as possible- fig. 2.

Infrared analysis allows a reliable evaluation on the state of health of the power plant and, at the same time, the detection of the actions needed for maintenance.

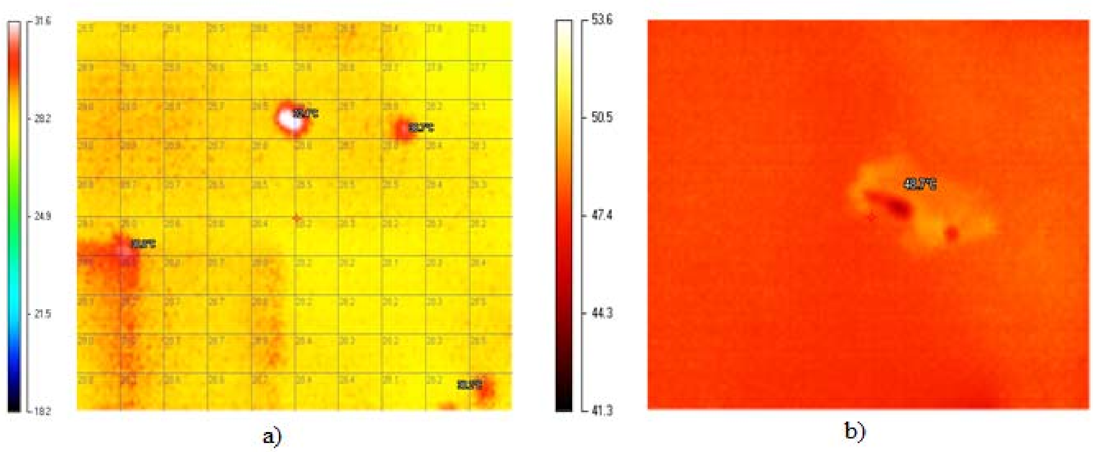

Fig. 3. Internal structural defect of a PV cell.

The work has shown that the infrared analysis can be usefully utilized for the efficiency analysis of PV plants. In fact, efficiency depends strongly on the temperature of the PV modules and an overheating causes a decrease of the produced energy.

In figure 3 hot spots are detected, without externally visible damage on the panel surface. Thus, the problem must be attributed to internal causes, corrosion being one possible candidate. Invisible hot spots corresponding to areas where the internal structure of the panels is beginning to decay is visible with an IR camera help.

Grown-in or structural defects in electronic materials as well as electronic discharges or conducting particles are possible reasons of unwanted leakage in electronic devices. These currents may result in a decrease of the efficiency for a produced assembly or, even, in its complete failure.

A thing that is good to be remarked is that some spots are by their nature invisible to the naked eye, contrary to the dust deposits, but with the infrared equipment even these ones can be seen and problems be removed as quickly as possible.

Refined thermal methods are needed to detect a wider variety of shunt conditions, particularly those below a solar cell's metallization layer.

Increased temperature can cause components to fail, potentially resulting in unplanned outages and injuries. Thus, is also part of the case regarding photovoltaic panels, but increasing temperatures also occurs when shunts are created by dust and all other kinds of impurities, physical material defects and/or structural defects.

4 Conclusions

Current photovoltaic system designs are focused on the optimum conversion from electrical power conversion to radiating power. This model is useful when designing the installed capacity of photovoltaic systems, but insufficient to address different types of tasks on a network electro-assembly.

As it was to be expected best IR thermographic testing images resulted during sunny days with low relative humidity.

Even though the problem areas are having a very low surface difference temperature from the solar panel itself existing and forming hot spots can be observed from early time.

One of the main advantages of IR thermography used for solar cell fail detection compared to other testing methods is the short time required to do a complete set of measurements without needing to shut down the equipment or part of it or, even, preparing any probes. Defects as small as a few millimeters across can be seen with no additional contact connections or sensors being required with the help of an IR camera.

According to the observations made, IR thermography is a fitting way to detect invisible defects in their first stages of development, localize the problem in a very short time and taking measures to avoid further damage.

Infrared thermography is a fitting way to evaluate temperature performance factor and solar parameters of an integrated solar energy system

Infrared thermographic method for fault analysis regarding PV systems is in course of development and as it can be seen above the results are pretty easy to interpret and analyze.

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