DAMAGE INFLUENCE OF PV-MODULES ON THE EFFICIENCY OF THEIR WORK

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Abstract: *This paper presents some of the methods for testing photovoltaic modules to detect faults and defects in them. There are results from experimental tests for detecting defects in the modules of the photovoltaic plant installed on the roof of Burgas Free University.*

Keywords: *photovoltaic modules, thermography, defects, damage.*

Introductione

The high quality of solar modules is essential for the efficient and long-term operation of photovoltaic power plants. Modern solar photovoltaic systems must operate reliably throughout the manufacturer's service life. Nonetheless, the occurrence of defects and damages that have a significant effect on their work are very often found in them.

The defect may or may not cause damage to the photovoltaic module. The defect does not necessarily lead to a power loss of the module, but defines a part of it that is different from the ideal photovoltaic module. Defects due to heavy snow loads are considered a module failure if the module is designed for heavy snow loads.

The failure of a photovoltaic module is an effect which impacts the power of the module, which is not restored in normal operation, or a safety problem is created.

Module contamination or damage caused by lightning is not considered as damage to photovoltaic modules.

In order to guarantee the flawless operation of the panels, it is necessary to develop a simple and reliable method of assessing their quality after installation.

I. VISUAL EVALUATION FOR DETECTION OF DAMAGES AND DEFECTS IN PHOTOVOLTAIC MODULES

Most effective and quick way to detect faults and defects in PV modules is visual inspection. The International Electrotechnical Commission (IEC) publishes standard IEC 61853 (BSS EN 61853-1: 2011) which regulates module testing under different climatic and geographic conditions and includes HTC, LIC, HTC, NOCT and STC tests (Table 1).

There is also PV-USA Test Condition (PTC), which is not part of this standard. The visual inspection of the photovoltaic module must be performed before and after the module has been subjected to environmental, electrical or mechanical stress tests in laboratory conditions.

Stress tests are typically used to assess the quality and life expectancy of the modules. The most common stress tests include the effects of thermal cycles, cyclical irradiation, ultraviolet radiation, mechanical stress, hail, outdoor exposure, and thermal stress.

Table 1.

PARAMETER	STC	NOCT	PTC	HTC	LIC	LTC
Illumination (W/m2)	1000	800	1000	1000	200	500
Temperature of the solar element (°C)	25	43÷50	-	75	25	15
Ambient temperature (°C)	-	20	20	-	-	-
Wind speed (m/s)	-	1	1	0	0	0
Height above ground level	-	-	10	-	-	-
Atmospheric mass	1,5					
Light spectrum	ASTM G173-03					

To ensure a good visual inspection of the module, it can be divided into parts and each part is inspected and documented separately with relevant defects.

Table 2.

PV MODULE	DEFECTS
Front of PV module	Bubbles, delamination, yellowing, browning
PV cells	Broken cell, cracked cell, discolored and without reflection
cell metallization	Burned, oxidized
Frame	Broken, scratched, curved
Rear of the module	Delaminated, bubbles, yellowing, scratching, burning
Distribution box (Junction box)	Loose, oxidized, corroded
Wires - Connectors	Separate, fragile, open electrical parts

Standards require illumination above 1000 lx during the visual inspection, taking into account only the defects detected with the naked eye.

Possible defects presented in the standards are shown in Table 2.

Visual inspection is a powerful tool for identifying the reasons for PV module failures or identifying issues that could lead to negative results in the future.

Sometimes the changes associated with the aesthetic look should not be neglected even if the module works well. Visual inspection is very effective for identifying hot spots (incineration marks), stratification, yellowing, junction box failure, and many others.

II. ELECTRICAL MEASUREMENTS TO DETECT FAULTS AND DEFECTS IN PHOTOVOLTAIC MODULES

Variations in the shape of the volt-ampere characteristic (VAC) give information about the damage to the photovoltaic module. If there is only a measured VAC without information about the specific electrical parameters of the photovoltaic module, the Isc current corresponding to a given cell area, the Voc voltage and the fill factor can be estimated.

In addition, the shape of the curve reveals defects: inactive cellular parts due to cell degradation or other causes (network defects), bypass diode short circuit.

With specific data on the photovoltaic module (either from the label or from the manufacturer), they can be compared to the measured values in real terms, which gives a good idea of potential failures and technical problems.

If a previous VAC curve for a given photovoltaic module, measured with comparable equipment and conditions, is available, defects can be assessed.

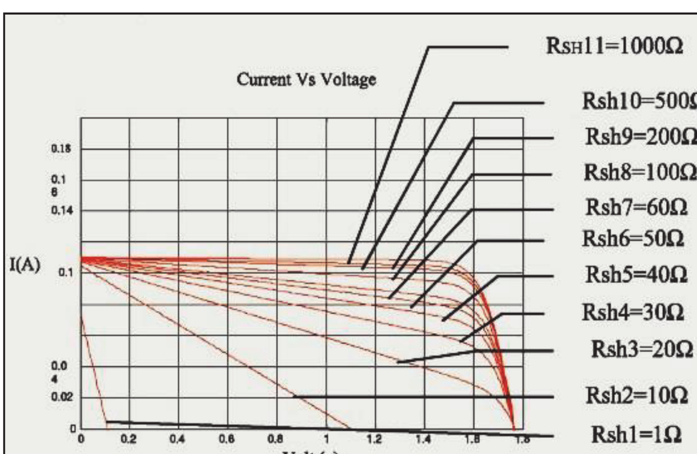

Fig. 1. Dependence of the shape of the volt-ampere characteristics on the value of the resistance

One of the most common defects in photovoltaic modules is the presence of short circuit current points.

This type of defect is actually a localized increase in the value of the electrical current. Points with short-circuit current may result from material defects or be caused by improper operation of the modules.

The different resistances of the short-circuit current points connected in series lead to the formation of different volt-ampere characteristics (Figure 1).

The low resistance of the points with a short-circuit current will lead to a reduction of the voltage. A cell with a lower resistor RSH has lower power. Much of the latest research and development in the field of solar cells is focused on obtaining higher efficiency and lower cost. However, the presence of short-circuit currents caused by module defects leads to reduced efficiency.

Various volt-ampere curves are associated with a different value of FF (Fill factor). This indicator is one of the main parameters by which to judge the quality of the photovoltaic module. The VAC (Volt-Amplitude Characterization) factor of the Grade A solar cells is above 0,7.

There are several types of short-circuit current points caused by defects in the material (such as breakdowns and impurities) or induced in the manufacturing process. It is assumed that the induced defects include linear and nonlinear edge distortions, cracks and defects of the Schottky type, silicon scratches and alumina surface contamination.

The measurement of the Volt Amplitude (VAC) of the module makes it possible to determine the short-circuit current, the open circuit voltage and other parameters.

Typical experimental conditions for measuring the BAC of the module include a natural or artificial light source and a test stand for illuminating the test module. Temperature control of the module is provided. A monitoring system and data acquisition system are being developed to measure the VAC or the current in the module is changed by external load or power supply.

In terms of natural solar radiation can be used instruments for measuring Bax. Real-time testing is typically not in line with standard test conditions (STC, 1000 W/m2, 25° C, AM 1.5 G reference spectrum of BGS EN 60904-3: 2016).

Typically, a solar radiation sensor is used to assess global exposure.

Lower short-circuit current Isc than expected is likely due to the loss of transparency due to browning or yellowing, corrosion of the glass, which reduces light gripping the module or by lamination, resulting in an optical disconnection of the layers.

The shape of the curve changes in a different way if the defects are homogeneous or heterogeneous. The serial resistance in the module can be increased by increasing the resistance of the interconnections, corrosion in the connection box or in connecting and matching connections.

Damage that reduces Voc is poor cell connections, cell-to-cell shortcuts, or bypass diode failure.

The voltage of the open circuit of the module can be reduced and light-induced degradation (LID) of the modules of crystalline silicon or potential induced degradation (PID). Reasons for occurrence of staggered curve segments may be a defect in the bypass diode, damaged cells, or a severe mismatch of PV cells in the module.

III. USING THERMAL IMAGING TO DETECT FAULTS AND DEFECTS IN PHOTOVOLTAIC MODULES

The use of thermal imaging cameras is an optimal method for diagnosing photovoltaic modules with several advantages. The defects of the modules are well detected on the thermal image.

Unlike other methods, thermal imaging cameras can be used to control already assembled modules during the operation of the photovoltaic plant.

Using the thermal imaging camera, defects or potential problems in the modules can be detected until the system has failed.

Basically, there are three different types of thermographic methods for detecting failures in photovoltaic modules.

The most common and most easy to apply technique is thermography under normal conditions. This method allows control photovoltaic modules to be performed under operating conditions.

Pulse thermography and locking thermography allow for a more detailed view of the photovoltaic module, but both techniques should be performed under laboratory conditions.

Thermal imaging or infrared imaging is a non-destructive control that ensures a fast, two-dimensional representation of real-time photovoltaic module characteristics.

It can be used as a non-contact method to diagnose some thermal and electrical damages in photovoltaic modules. Measurements can be performed during normal operation for individual modules as well as for large PV systems.

Thermographic measurements show temperature differences caused by external current or light irradiation of the photovoltaic module.

For measurements in the dark is supplied external current (generally comparable to the short-circuit current Isc). To avoid thermal damage to thin-film modules, it must be ensured that the I_{sc} of the modules is not exceeded by more than 30%.

For more accurate detection of defects, thermography is performed when the photovoltaic module is illuminated. It is necessary to compare the temperature distribution for short circuit, open circuit and maximum power.

The thermography is mostly done via a portable infrared camera. The wavelength of the IR detector used is typically between 8 and 14 μm.

Illuminated (open) thermogravimetric measurements should be performed on a sunny, cloudless day with a radiation of not less than 500 W/m^2. This guarantees good thermal contrast for accurate thermographic measurements.

For this reason, it is advisable to carry out the diagnosis at a minimum ambient temperature, the conditions of a sunny winter day are ideal.

The viewing angle shall be as close as possible to 90° but not less than 60° to the modular glass plane.

The operator must be aware of the reflections possibly received from neighborhood buildings, clouds, etc.

To properly measure the temperature of the module, the camera should be set according to the ambient temperature. The correct positioning of the camera makes it possible to avoid errors and misconduct.

If there is access to the back of the modules, it is preferable to perform the thermography. This minimizes reflections of glass from the sun and clouds. In addition, the temperature contrast on the back is bigger because the solar element is measured directly, not through the surface of the glass.

When the lighting is uniform, cell temperatures may vary by only a few degrees. If the module has defects, temperature fluctuations may be much greater. Differences in temperatures in the order of 10 K between hot spots and normal operating areas in their vicinity are possible.

In addition, it should be borne in mind that there is a temperature gradient in the PV plant due to convection.

Photovoltaic modules must be diagnosed under standard operating conditions, ie under load.

Depending on the type of the modules and the type of malfunctions, measurement without load, as well as short circuit, can provide additional information about the status of the modules.

If parts of the module are warmer than the other parts, they will be clearly visible on the thermographic image. Depending on their shape and layout, these hot spots and areas may indicate different faults.

If the whole module is warmer than usual, it may be a connection problem.

If individual cells or a number of cells appear as hot spots or as a „hot drawing“, the cause is either the presence of defective diodes or the presence of internal short circuits or the presence of internal defects in the crystals.

IV. EXPERIMENTAL THERMAL IMAGING OF PHOTOVOLTAIC MODULES

For the purpose of the study were tested modules from the photovoltaic plant, built on the roof of Burgas Free University.

For the study, 250 Wp silicon polycrystalline photovoltaic modules, which worked for 6 years, were selected. The system includes a three-phase inverter with two MPP tracking devices and two strings connected with eight photovoltaic panels.

One string is only with healthy photovoltaic modules and the other one has a physically damaged module.

Thermal imaging was performed on a FLIR ONE PRO Gen 3 camera at an ambient temperature of 15 °C in the following order:

- Capture at a distance of 4 m from the surface of the modules. This mode of capture does not allow the entire surface of the module to be examined, but only a part of it. In Fig. 2 shows a thermal image of one of the strings showing variations in temperature of the module possibly related to the presence of defects;

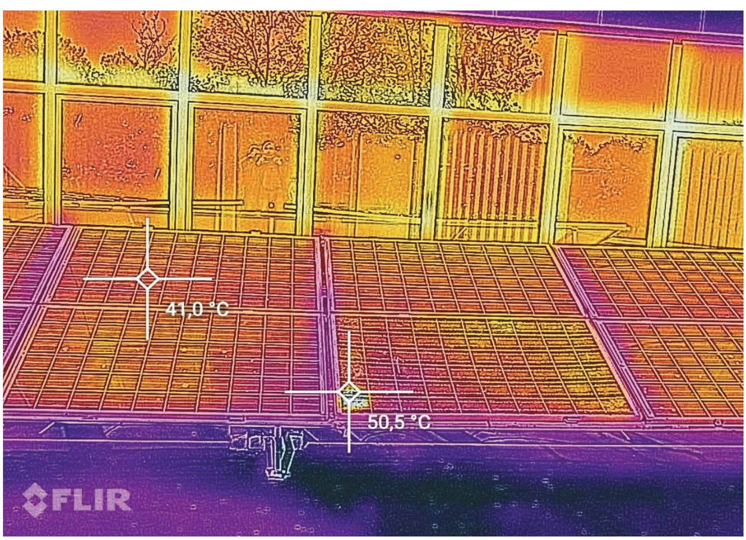

Fig. 2. Thermographic image of a string of a system of eight photovoltaic modules at a distance of 4 m.

• Capture at a distance of 1 m from the surface of the modules. The thermal image becomes clearer and more accurate. In Fig. 3 shows the presence of more cells in which there is an increase in temperature;

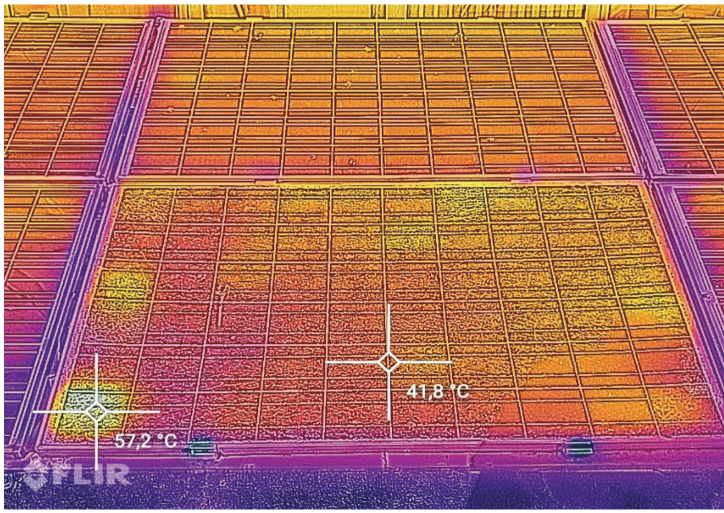

Fig. 3. Thermographic image of a string of a system of eight photovoltaic modules at a distance of 1 m.

• Capture at a distance of 0.4 m distance of the camera over the entire area ofthe modules. In Fig. 4 shows a thermal image of newly discovered cells at a higher temperature.

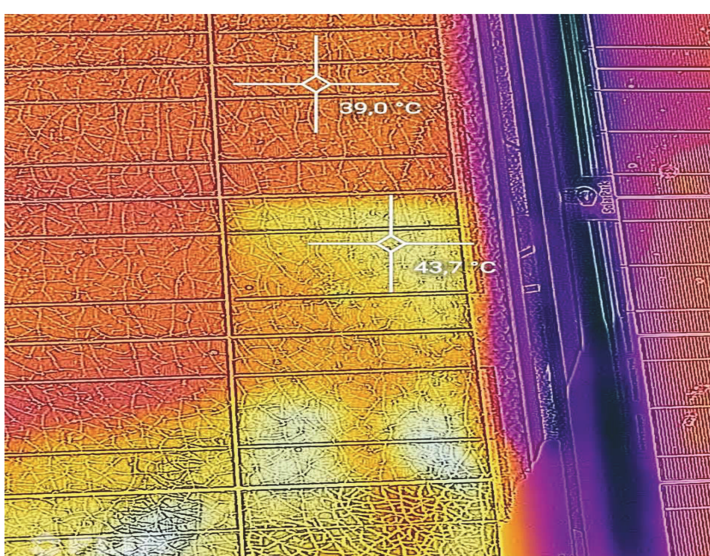

Fig. 4. Thermographic image of a string of a system of eight photovoltaic modules at a distance of 0.4 m.

Conclusions

The diagnostics of photovoltaic modules with the help of a thermal imaging camera allows the rapid detection of defects at the solar cell level or on the whole surface of the modules as well as possible problems in the electrical connections.

The use of thermal imaging makes it possible to control the quality of photovoltaic modules in normal operating conditions of the system and does not require unlocking the system.

Testing of the thermal imaging unit modules can be carried out directly during installation, as well as periodically, during the operation.

At the start of the system, the thermal camera is an indispensable tool because it allows the time to detect manufacturing defects (if any) and to require warranty service.

Establishing high temperature areas is important because the photovoltaic modules contain a large amount of semiconductor elements, and the release of heat into a faulty element can cause damage to the neighboring, i. e. the problem would have grown over time.

Thermal imaging in this sense will allow for periodic incomplete but complete monitoring of the state of the system.

The implementation of such a control method will make it possible to extend the operating time as well as the maximum efficiency of the system.

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