Photovoltaic Panel Failure Prediction Using a Thermal Imaging Camera

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***Abstract* — The aim of the study - based on domestic and foreign sources - is to show the inspection possibilities of thermal imaging cameras which used in industrial and civil areas. During the introduction of the topic, this paper will introduce the most important metrological requirements and practical knowledge of thermography. The paper focuses on photovoltaic panel inspection and failure detection. The paper will discuss the monitoring possibilities. Some common thermal camera operator errors, accuracy and credibility of the measurements are also presented.**

***Keywords* — thermal imager, heat camera, IR camera, PV inspection, photovoltaic panel inspection, PV error detection, photovoltaic panel error detection**

I. Introduction

With the help of thermography, it is also possible to check the quality required during the production of photovoltaic cells and to check the solar panels during operation. This article discusses the condition assessment of solar panels in more detail. The advantage of this solution is that high-power solar parks can also be inspected in a short time, thus increasing operational reliability.

Examination of the electrical parameters (characteristic curve) of solar panels or strings shows a deterioration in efficiency, but the location of the fault and the type of fault cannot be determined. The thermal imaging test can be used to determine the location of the fault and to determine the type of fault.

Thermographic condition assessment helps in fault prediction, economical operation and maintenance. The thermographic examination also covers the electrical cables, connections and equipment, the rise of their temperature above the operating value indicates the location of the fault. For solar cells, however, more knowledge is needed to perform a more complex study.

II. Theoretical Background

Before inspecting and evaluating solar cells and panels, it is a good idea to review their operation in order to understand the causes of thermal effects that indicate fault phenomena.

The solar cell is a pn junction, the photons of the incoming solar radiation pass through the n-type layer, and then, giving off their energy in the depletion region, they generate free charge carriers. The charge carriers carry work as they pass through the load.

The internal photoelectric effect can be achieved with both thick-layer (single-crystal silicon, polycrystalline silicon) and thin-film (amorphous silicon) technology. The testing of compound semiconductor or electrolyte-based solar cells is not substantially different from the testing of silicon-based solar cells.

The voltage achievable with a solar cell is approximately 0.5V. By connecting the cells in series, the voltage of the module can be increased, thus increasing the efficiency of energy transmission. If one of the cells connected in a row fails or is shaded, the efficiency of the whole row is reduced. Within the solar panel, the solar cells connected in series are divided into substrings. The substrings are connected in parallel with a bypass diode. In the event of a substring failure, the solar panel will remain operational with reduced capabilities (Fig. 1).

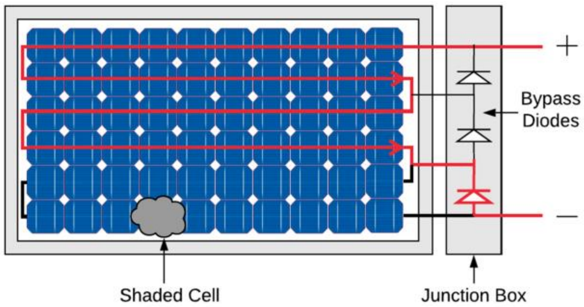

Figure 1: Solar panel bypass diode [1]

Fig. 2 shows the different connection options between PV modules and PV inverters. Based on power output, location, reliability, cost and efficiency system properties, there are four main topologies.

The central topology connects several thousands of PV panels to one inverter. PV array has hundreds of PV strings connected in parallel, and each string has hundreds of PV panels connected in series. The string topology connects one PV string with one inverter. The multistring topology connects one PV string to a dc–dc converter, and then a few dc–dc converters are connected to one inverter. The module integrated topology connects one inverter to one PV panel.

III. Typical Faults and Errors

Faults in solar systems lead to inefficiencies and other more serious faults. The causes of the fault can be traced back to the manufacturing, transport, installation, operation and environmental causes.

Electrical fault, due to their nature, is contact fault, short circuit and incorrect polarity. Control faults include non-optimal operating point operation and bypassed strings or modules. Cell-level defects are caused by fractures, cracks, cell aging, their typical form of failure is short circuit, open circuit, PID (Potential-Induced Degradation).

Electrical and mechanical faults indicate improper transport and installation. Inefficiencies are typically the result of poor design, shading by vegetation or contaminants, and are rarely caused by aging alone.

Visually perceptible inclusions, color deviations, delamination are not significant defects. The oxidizing effect of water penetrating along fractures, dents, and hairline cracks, as well as short circuits and open circuits in the silicon layer, cause a significant loss of power. Defects that are not visible to the naked eye can only be detected by indirect instrumental testing.

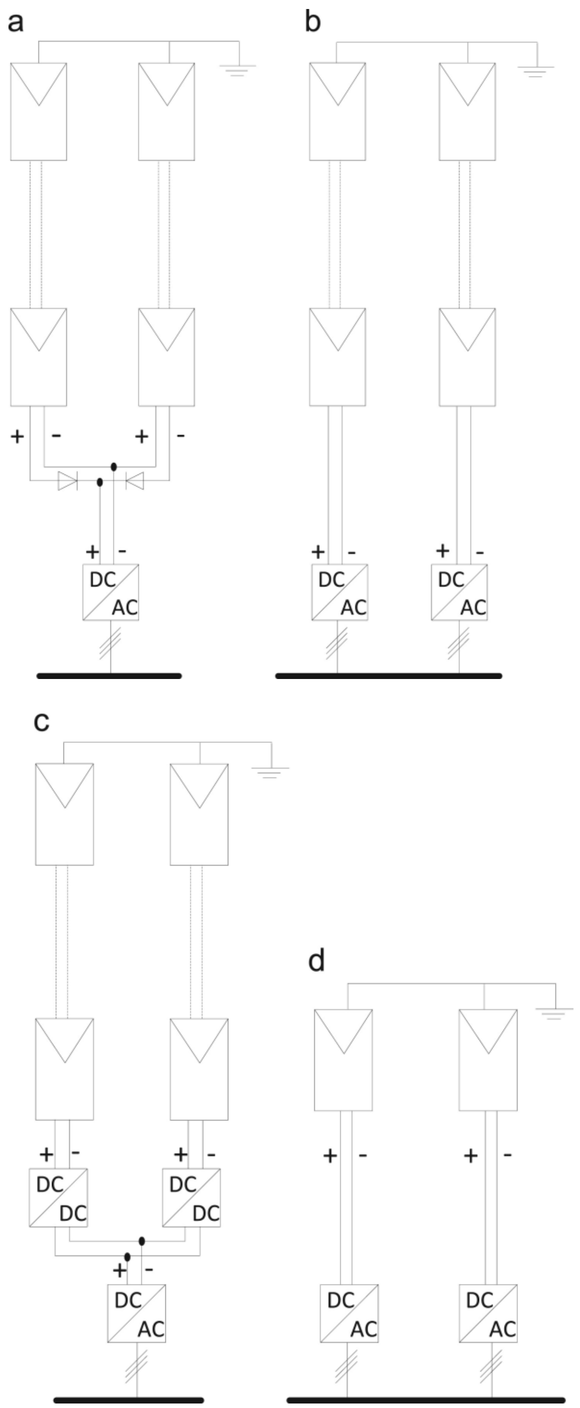

Figure 2: PV inverter topologies: central (a), string (b), multistring (c), and module integrated (d) [2]

IV. MEASUREMENT SUGGESTIONS

In the case of thermographic inspection of all equipment, direct sunlight should be avoided. It is worth avoiding due to the reflection of solar radiation as well as the effect of heat.

However, intense sunshine is required to perform outdoor measurements on solar cells. To detect a fault, it is necessary to have temperature differences caused by the fault. The detection of the error phenomenon is made more difficult by the surface reflection of the panels, but the choice of a professional examination angle helps the observation. [3]

The cell or panel being tested must meet the following criteria. The test must be in loaded operating condition. The minimum power of solar radiation must be at least 600 W / m2. Cloud cover should be less frequent than cumulus clouds (2/8 Cumulus). The test object must be free of precipitation. The wind speed is a maximum of 20-29 km / h (4 Beaufort). During the test, the irradiance shall not exceed a rate of change of 10% / min. If this happens, the measurement can be resumed after a settling time of 10 minutes. [4]

For thermographic condition surveys, compliance with general criteria is also the default, such as ensuring proper viewing angle and resolution, and professional documentation of the measured equipment and measurement.

The inspection of electrical elements can reveal undersized, overloaded, oxidized, damaged, faulty cables and connections, as well as faulty electronic equipment.

Examination of solar cells and panels can reveal faults in the contacts between the cells (increased resistance, open circuits). The error signal can be the temperature rise indicated by the bypass diode between the substrings or the blocking diode between the modules, the temperature difference of the unloaded, polarity faulty, short circuited, shaded cells. The effects of cracks, microcracks, fractures and other degradation can be indicated. [5]

Thermal camera testing of solar cells is more expensive than electroluminescence testing, but the need to break the joints of the panels and the need for external power supply can be avoided. Thermography allows for quick in-service inspection.

When inspecting large systems with thermal imaging, it is also necessary to comply with occupational safety regulations. In the case of high-voltage equipment, the safety distance must be taken into account, and the measuring location must be chosen carefully from the point of view of thermal reflection.

V. MEASUREMENT DIFFICULTIES

When performing a measurement, the greatest difficulty is the proper examination and evaluation of sunny reflecting surfaces. Measurements can be made with long-wave bolometer thermal imagers, knowing that the angle of observation greatly influences the measurement results (Fig. 3). The emission factor of the measured surface also depends on the viewing angle and the temperature of the tested glass surface.

At PV module thermograms that are two source of radiation. The first is the black body radiation from the module the second is the reflected environmental radiation (Fig. 4). The thermal inspection needs the PV module surface temperature without the influence of the environmental radiation. The black body equivalent temperature of the sky must be subtracted from the thermal image of the module.

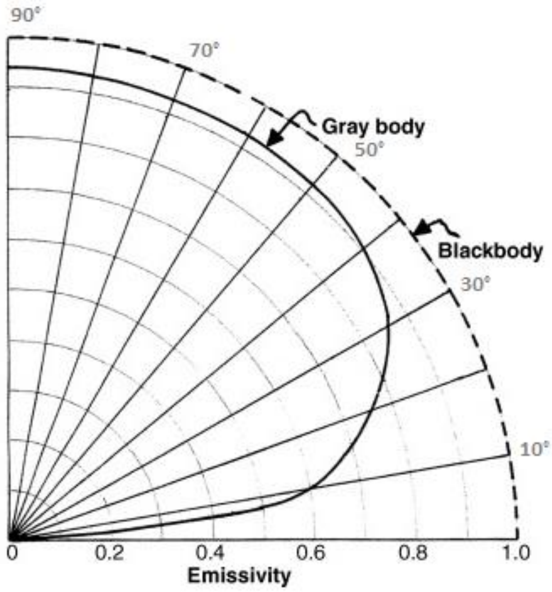

Figure 3: Thermal image with angle-dependent reflections [6]

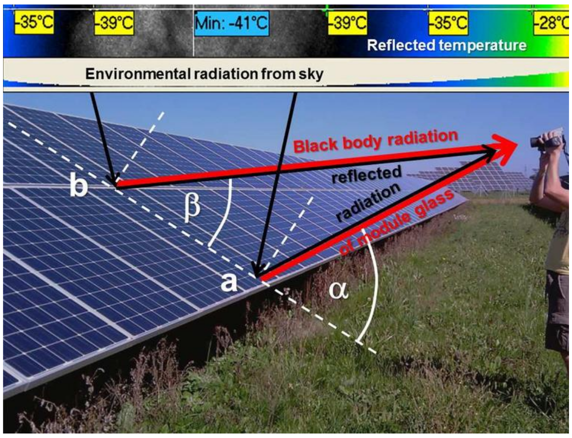

Figure 4: Observation angle for thermal camera measurement [7]

If the angle of inclination of the solar panels (relative to horizontal) is 45° and the angle of incidence of solar radiation during the measurement is 50°, the angle of observation must be kept below 40° (below 85° with respect to the surface of the module) to avoid reflection.

To keep the emission factor of the glass surface of the solar panel at an acceptable value, the angle of observation must be kept above 30° relative to the surface of the solar module.

The relatively low resolution of thermographic measuring instruments also limits the measuring distance. The loss of a cell results in a change in the thermal image with a surface area corresponding to its size. The cell contacts and solders also cause local temperature changes (~ 3x3 cm), the detailed thermal image is justified for their detection.

VI. PROPOSED THERMAL IMAGER

Due to the temperatures to be measured, it is advisable to choose a long-wave thermal imager. Emission factors for reflective glass surfaces, on the other hand, justify the use of medium-wave thermal imagers with a filter, but the temperatures to be measured are low. [8]

Temperatures between 20° C and 100° C are expected to be measured. It is advisable to choose lower-priced, long-wave (7..8μm - 12..14μm), matrix or scanning type, bolometer thermal imagers. The use of medium-wave photon detector thermal imagers is in most cases uneconomical. [9]

The measuring range must be at least between -20..0° C and 150..250 ° C. The lower level of the lower limit of the measuring range provides a lower level of image noise. The resolution should be higher than 320x240 pixels, the proposed lower limit is 640x480 pixels. [10]

The geometric resolution should be 2 mrad or less. Display the smallest area to be detected by at least 3 pixels. The modest geometric resolution results in a inspection point close to the surface to be measured, which would lead to shading of the solar panel. [11]

The resolution in the temperature range should be a minimum of 80mK, but a value of 50mK or better is recommended. Fault locations on solar panels are expected to show significant temperature differences, but thermal cameras with better temperature resolution are able to provide evaluable results even at lower irradiations. [12]

The frequency of the image refresh rate is not relevant for installed thermal imagers (scanning thermal imagers), a minimum image refresh rate of 50Hz (matrix thermal imagers) is recommended for manual testing, and a minimum image refresh rate of 120Hz for aerial photographs (microbolometer thermal imagers). [13]

The speed of the scan is increased by the presence of a function with autofocus and enabling composite imaging. Surveying larger areas is aided by the ability to save GPS coordinates and take continuous shots. [14] [15]

If the limit value is exceeded, the automatic alarm function greatly facilitates scanning troubleshooting, and the possibility of thermal image mounting reduces the time of post-production. [16] [17]

Work is accelerated by the use of models that allow lens replacement. [18]

VII. PRACTICAL EXAMPLES

Thermal camera monitoring of solar modules can be done from a tripod, mobile platform, or a telescopic pole or UAV can be used. [19] In all cases, keep in mind that in order to measure correctly, the panels cannot be shaded for extended periods of time (Fig. 8). [20] [21]

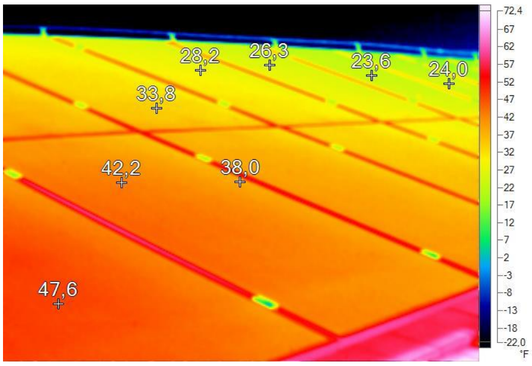

Figure 5: Incorrect observation angle

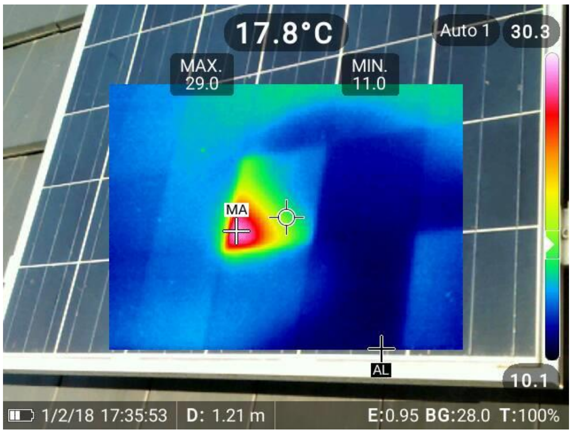

Figure 6: Starting solar cell short circuit

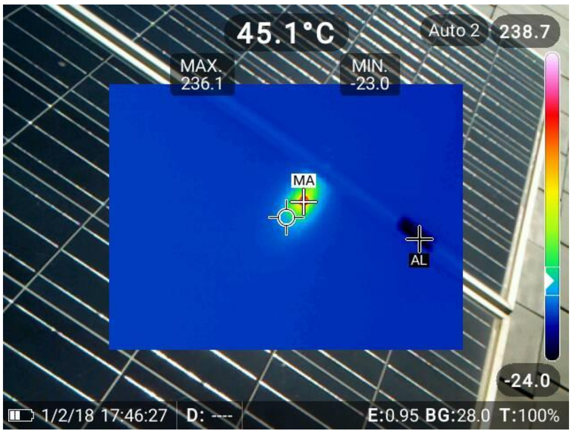

Figure 7: Inclusion due to manufacturing defect

If reflection is suspicious in the measurement (Fig. 9), you may want to change the angle of observation. If the measured surface temperature changes, the reflection is real, it is necessary to add a new observation point in order to eliminate the reflection. If the measured surface temperature does not change, the thermal image is correct. [22] [23]

Figure 6 shows a partial cell temperature increase, it is predicting a solar cell short circuit. Point heating of the inclusion due to a manufacturing defect, it will not cause a

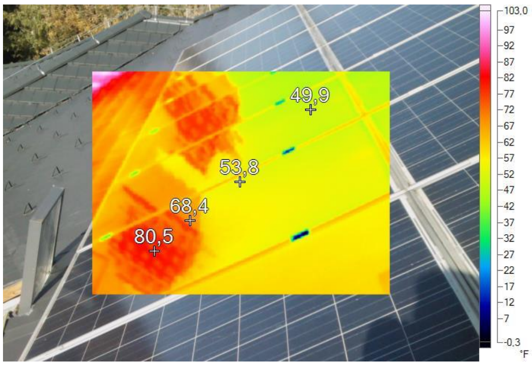

Figure 8: Incorrect measurement due to shaded PV panels

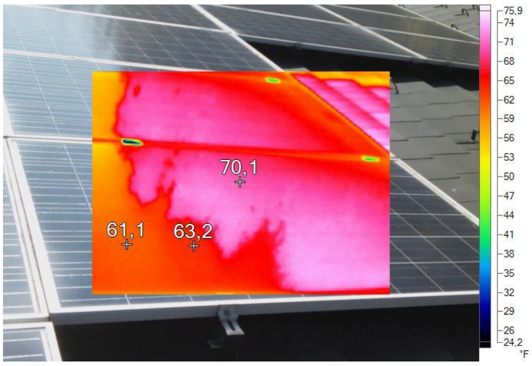

Figure 9: Incorrect measurement due to environmental reflection

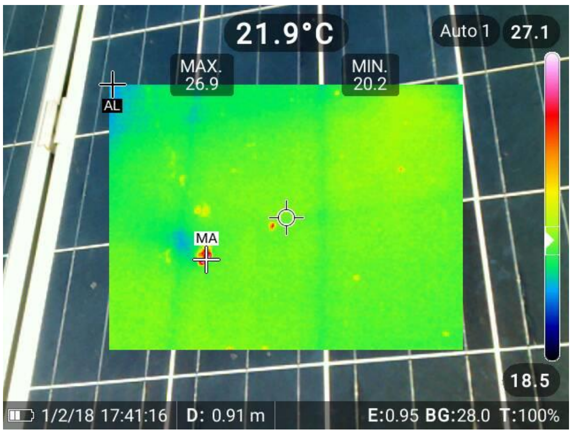

Figure 10: Warming due to pollution

failure later (Fig. 7). Figure 10 shows warm spots due to surface pollution, it is recommended to clean the surface to prevent efficiency loss. Figure 11 and Figure 12 shows two different inspection angles about slightly increased temperature terminal boxes. The phenomenon refers the imperfection of electrical connections and predicts their failure.

CONCLUSION

The article attempts to introduce some typical mistakes that can be made during thermographic measurements and how to eliminate them. This paper proposes some further useful measuring recommendations for reducing measurement errors in the area of thermal imaging diagnostics. Related to photovoltaic panels, the proposed techniques are makes more reliable measurements. The authors are convinced about the high industrial usability of the shown adjustments.

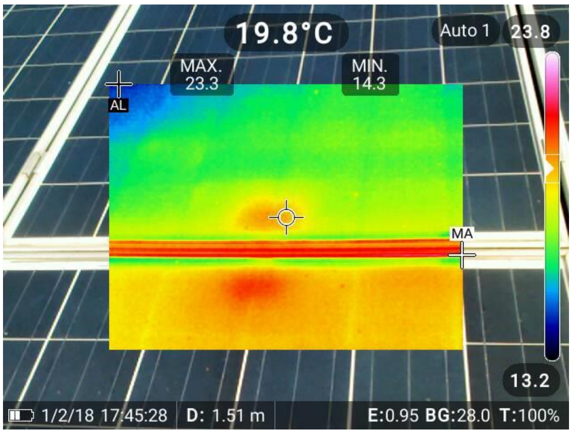

Figure 11: Warming due to pollution

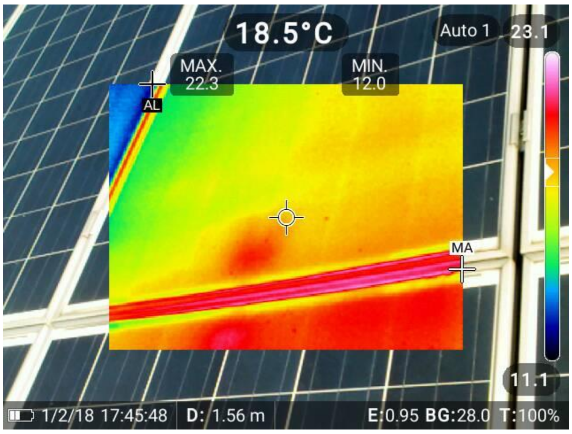

Figure 12: Warming due to pollution

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