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Investigations of Delamination Fault in Photovoltaic Panel Using Thermographic Image Analysis

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ABSTRACT: Photovoltaic (PV) solar energy can only be cost-effective if the PV module operates reliably for 20-30 years in environment condition. The performance of PV modules can be radically affected by faults occurring mainly under real field conditions. So, there is need for research on PV modules. The temperature within the PV cell unevenly rises due to the defects in the cell. It is very important to monitor the temperature of PV panel. Infrared thermography (IRT) plays a major role in determining the severity of the problem. This paper investigates the delamination faults of the PV panel using thermal image of the panel. The thermal image of the panel are captured using FLIR T420bx thermal imager. In this paper histogram statistical features such as mean value and standard deviation are extracted and used for analysis.

KEYWORDS: PV Panel, Fault Diagnosis, Infrared Thermography, Image Processing, Histogram.

I. INTRODUCTION

In renewable solar energy resource is plenty and freely available across the globe. The photovoltaic (PV) system which convert sunlight to electricity, is a promising technology which is increasing rapidly throughout the world during the past decade. The PV systems have become very reliable and are considered one of the potential substitutes for power supply needs in every areas. PV module cost accounts for 75 to 85% of total PV systems cost. With the advancement in PV technology the cost of PV module has declined steadily and is further expected to decrease [1].

The price economics related with the PV systems is only effective if the systems operate reliably for more than 20 years. Reliability issues about several parts of PV plants are listed in [2]. The long term performance of PV modules and their overall reliability can be radically affected by faults occurring mainly under real field conditions, transportation and installation. In real field condition the PV cell performance, reliability and efficiency is strongly temperature dependent of the internal parameters such as junction temperature and external parameters such as ambient temperature, insolation level, wind speed, wind direction, tilt angle, dust and shadow solar radiation, humidity and operating voltage. There are many correlations between the PV cell temperature, and the other variables such as ambient temperature, local wind speed and solar radiation flux/irradiance. Both the electrical efficiency and the power output of a photovoltaic (PV) module depend linearly on the module's operating temperature. . If there is any defect on the PV panel then there will be change in the nominal temperature of the PV panel [3]. Therefore, the temperature plays an important role on PV module and the direct monitoring has to be done under actual outdoor condition [4]. Direct monitoring of operating PV modules is done with the Infrared thermography (IR). It comprises a method able to specify the 'signature' of a potential fault to a thermal image pattern by witnessing its physical location within the defective module. In addition, effective, though usually simple technique of histogram analysis for thermal image processing can provide a comprehensive diagnosis with regard to the condition, performance and efficiency of each

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module. Infrared thermography (IRT) plays a major role in predictive and preventive maintenance of PV panel and determines the severity of the problem and it allows a reliable evaluation of the state of health of the panel and at the same time the detection of the actions needed during the maintenance [5]. IR thermography is a challenging direct monitoring method which is capable of detecting and diagnosing defective PV modules, both during the manufacturing stage and under real-field conditions. So the reliability of the PV panel is investigated by using the infrared thermography [6]. This paper gives the electric performance of the PV panels under different atmospheric conditions by using thermographic images and the analysis of the image with the histogram.

II. PHOTOVOLTAICS

Solar cells are electrically connected either in series and/or parallel to provide desired outputs as voltage and current. In order to ensure the reliability and lifetime of solar cells, it must be protected from the various environmental conditions such as thermal cycling, rain and dust etc. when they operate under outdoor condition. Thus to protect solar cells and ensure along operating period, PV module comprises of Transparent front glass, EVA layers, Solar cells string and Tedlaras in Fig 1. Solar cells are protected by sandwiching them between the EVA 2.5mm (Ethylene-Vinyl-Acetate). In the front side, low iron, toughened and textured glass about 3mm thickness provides the mechanical strength to photovoltaic module. A non-transparent, with a multilayer structure consisted of polyester film (PET), laminated between polyvinyl fluoride (PVF) commonly known as tedlar is used as the back sheet [7].

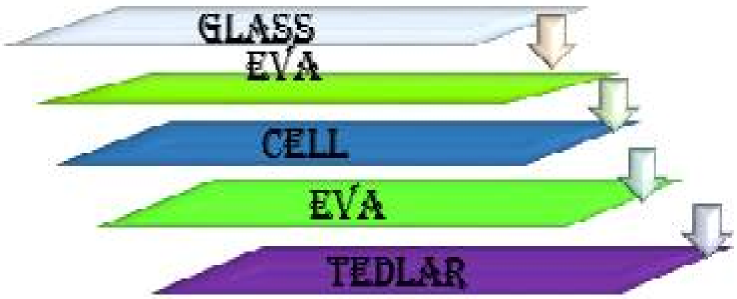

Fig 1. PV module structure

In a PV module of series-connected solar cells the photocurrent flows, when it is illuminated under short-circuit conditions. This photocurrent must be the same throughout every cell and, thus, the sum of all cells biases is equal to zero according to Kirchhoff's circuit law. Hot-spot heating arises when there is at least one solar cell in the PV module that presents an abnormally much smaller short-circuit current than the rest of the cells in the module. In this condition, the defective cell passes current higher than its generation capabilities, becomes reverse-biased, even enters the breakdown regime, and sinks power instead of sourcing it. Moreover the overall current of the module becomes limited by the defective cell when the operating current of the overall series string approaches the short circuit of the cell in that module. The operating temperature of a cell in a PV module can be fairly estimated by the following semi-empirical equation (1).

$$T_{cell} = T_{amb} + \left(\frac{0.32}{8.91 + 2.V_f} \right) .G_T \qquad (1)$$

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Where, $T_{cell}$is the cell's operating temperature (in ^{o}C), $T_{amp}$is the ambient air temperature (in^{o}C), $V_f$is the air velocity (in m/s) and $G_T$is the incident solar irradiance flux (in W/m^2). Thus, as mentioned before, the operating temperature of each cell within the inspected PV module is estimated, with the use of equation (1) and compared with the thermographically measured one which is described in the next section. Hot-spot heating effect is the significant declination between these two temperature values and it is associated with a cell defect, such as a crack or an interconnection mismatch and also the higher temperature results in the degradation of cell wires, encapsulant as well as influences the module lifetime in the field [8].

III. INFRARED THERMOGRAPHY (IRT)

Solar systems are outdoor electrical installations exposed to stresses of wind, snow, rain, melt and freeze cycles, and UV radiation. Due to these exposures it can result in weathering and accelerated corrosion. Therefore, to verify the PV plant's maximum power output. It is very important to monitor the temperature of PV module therefore it allows to detect anomalies before they become failures [9]. According to Planck's black body radiation law, all objects emits infrared radiation and is proportional to their temperature. Since IRT is a non-contact, non-destructive technique that provides significantly more than just a simple temperature measurement of a given point in a PV cell [10]. In principle, an infrared imaging system collects the naturally emitted infrared radiation from the module under inspection and generates its complete thermal image [11]. A thermal image shows relative temperature differences, i.e. thermal gradients, in a color (for example, rainbow) scale palette or greyscale. By inspecting the heat distribution image of the PV module it indicates the increase in temperature due the malfunctioning of the system and it helps in locating the faults and their seriousness can be evaluated. The impetus for adopting a temperature-monitoring method for this analysis lies upon the strong interrelation between the developing surface temperature of a PV module and its 'health' in terms of efficiency. Usually the techniques of thermal image processing. In further analysis thermal signatures of the PV module were performedby applying standard thermal image processing techniques, i.e. image histogram analysis. It provides a complete diagnosis with regard to the condition and, ultimately, performance and efficiency of each module. Basically,in any condition monitoring approach it is essential to obtainthe significant information out of the mass of the raw signalby using the appropriate signal/image processing techniques.Therefore, the above-mentioned thermal imageprocessing delivers useful data for the detection of hot spots thatwitness the presence of defective solar cells and, typically, a PVmodule with subdued efficiency. The fig 2 shows the inspection of PV panel with thermographic camera FLIR T420bx.

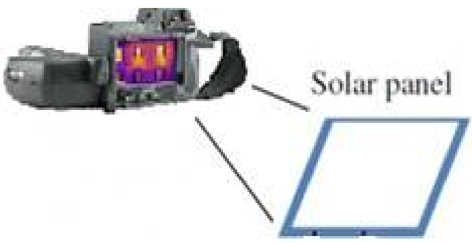

Fig 2. Capturing the solar panel thermal image with FLIR T420bx

IV. RESULTS AND DISCUSSIONS

The experimental setup has been carried out for the two panels. By the experiences under real field, upon IRT of the modules, the defects found in PV1 and PV2 are delamination fault. These faults are explained with the correlations between the each fault type and the histogram.

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4.1 Delamination

In a PV module, the EVA (ethylene vinyl acetate) protects the sensitive cells from weather influences such as moisture, UV radiation and mist. During manufacturing process it is important to laminate the module composite under a precisely defined pressure and temperature and time to ensure that the EVA cures correctly. Due to wrong process parameters or cheap material it can result in a delamination of the EVA later in lifetime. The layers of EVA melted and get a "milky" color. These delaminated solar modules should also be changed. Due to the delamination, moisture can get to the cells which results in cell corrosion. Further, the light transmission is reduced which results the ongoing performance loss. Figure 3 and 4shows delaminated PV1 and PV 2 module with its thermal image which is captured by the FLIR thermal imager. In the normal image of delaminated PV panel 1 and 2 the milky white can be seen, which is spread all over the panel. And in the thermal image the color/tonal distribution of the panel is seen clearly and it is not equally distributed throughout the panel. The color intensity distribution is based on the temperature. The temperature of the panel PV 1 ranges from 46 to 65^{o}C and in PV 2 ranges from 47 to 71.3^{o}C. It can be noticed that in thermal image the certain cell regions are brighter (higher intensity of color in the cells) due to the higher temperature which indicates the defective cells.

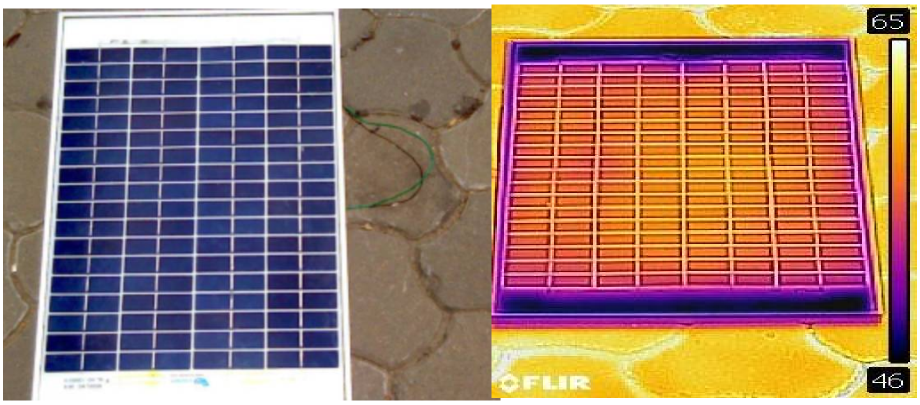

Figure 3. Delamination fault PV 1 panel

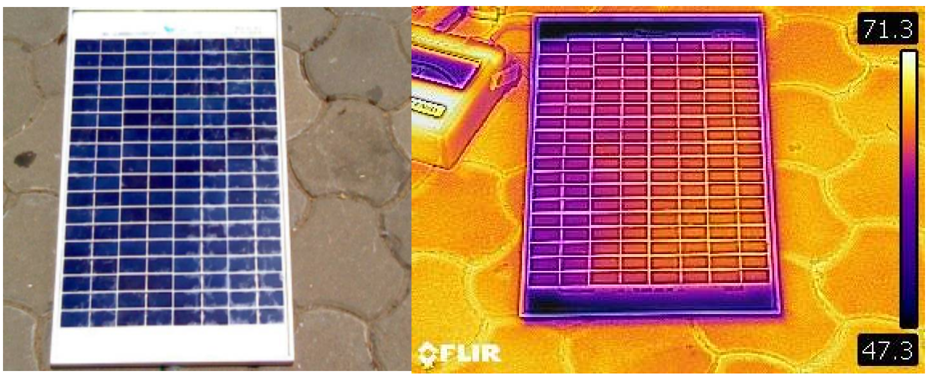

Figure 4. Delamination fault PV 2 panel

4.2 Histogram analysis

The analysis of thermal image gives the possible abnormalities of PV panel. The image processing technique of histogram extracts the features of the modules.It is the basic step of thermal image processing and it provides the pure

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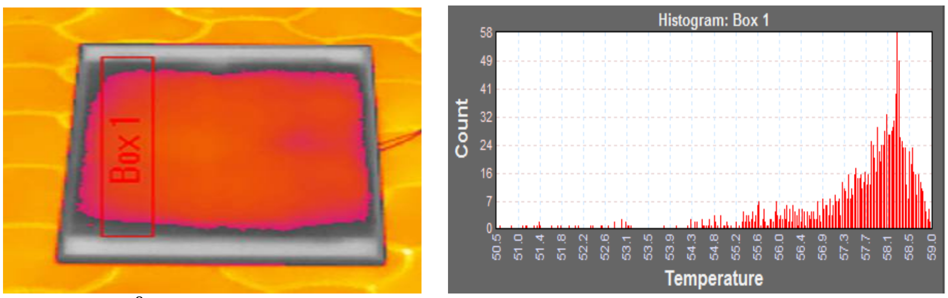
form of information in order to correlate the presence of evolving hot spots in faulty PV modules with their thermal signature. A histogram of the thermal image acts as a graphical representation of the tonal or color distribution in that image. It is a practical and potent tool in detecting abnormal temperature patterns and thus, defective equipment. Mean and standard deviation are the most common statistical-based features that characterize the tonal distribution of an image. The average brightness of a region is defined as a mean of the pixel brightness within that region and it is expressed by equation 2.

$$\overline{g} = \sum_{g=0}^{L-1} g \cdot P(g) \qquad (2)$$

Standard deviation is informative about the contrast of an image and a high-contrast thermal image will have a high temperature distribution. Standard deviation is a key index of possible defects is given by the equation 3.

$$\sigma_g = \sqrt{\sum_{g=0}^{L-1} (g-\bar{g})^2 \cdot P(g)} \qquad (3)$$

According to the semi-empirical equation as mentioned in section 2 the operation temperature of a healthy cell T_{cell}=56.74°C. In this paper, a histogram analysis was applied to box ROIs within the obtained thermal images of PV-1 and PV-2. Focusing on PV-1 module, a vertical box were selected as box ROI. According to the ROI analysis, cells with hot spot is covered in the ROI. Fig 5 present the thermal image and its histograms of ROI, respectively, for the measurement of 1 October at 13:00, with regard of PV-1. In histogram for box1 there is a pixel (Y-axis) distribution in the temperature (X-axis) range from 59 to 62°C. In this there is high dispersed data in the center (172.0, 96.5) 58.8°C which represents the delaminated cells and it should be noticed that there is rise in temperature in delaminated region as compared with operating temperature. The mean and the standard deviation of the box1 is 57.8°C and 1.2 as by above mentioned equation 2 and 3.



Range: 50.8 to 59.2°C - Pixel count: 1456

(a) IR image (b) Histogram feature

Figure 5. Thermal image of Delaminated panel with its histogram

Similarly results were concluded from the histogram analysis of PV2 thermal image. In the thermal image of PV2 the regions were clearly seen and for the ROI analysis a horizontal box were selected as box ROI, it covers from left to right of the cells. The cells with hot spot and the healthy cells were covered in the box ROI. Fig 6 presents the thermal image and its histograms of ROI, respectively, for the measurement of 1 October at 13:00, with regard of PV-2. In histogram for box there is a pixel (Y-axis) distribution in the temperature (X-axis) range from 57 to 62°C. In this there is high dispersed data in the region (116, 103) 62°C which represents the defective cells and there is maximum temperature in that region as compared with operating temperature. And there is less dispersed data in the region 57 to

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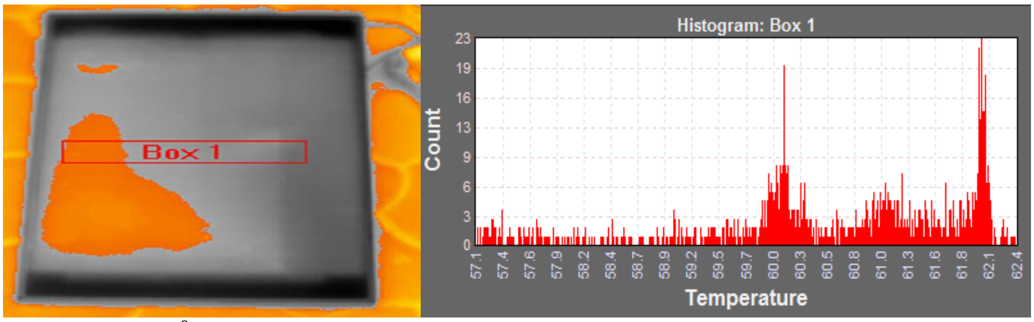
60°C and since it represents the healthy cells, these cells temperature are equal to the operating cell temperature. The mean and the standard deviation of the box1 is 60.6°C and 1.3.



Range: 57.1 to 62.4°C – Pixel count: 1526

(a)IR image (b) Histogram feature

Figure 6. Thermal image of PV2 with its histogram

V. CONCLUSION

This work shows that infrared analysis can be of great importance when used for the efficiency analysis of PV panels as it depends strongly on temperature. The experiment were performed on two faulty panels with a rated output power of 18 W. The temperature was measured by thermographs recorded by an infrared camera. The panel temperature and the power are related to the insolation that varies gradually as the sun moves over the day hours. By observing the thermographs, the PV cells of the solar panel do not generate the same power throughout the panel and the temperature in the panel tends to stabilize over time. The technique of thermal image processing of histogram provided valuable information with regard to the thermal signature and location of hot spots in defective cells within the inspected modules. And also the impact of faults on the PV panels (Fig 5 and 6) by its graphical representation with the statistical features.

REFERENCES

[1] Razykov, T. M., Ferekides, C. S., Morel, D. E., Stefanakos, H., Ullal, S., andUpadhyaya, H. M., "Solar photovoltaic electricity: Current status and future prospects", Elsevier journal on solar energy, Vol.85, pp.1580–1608, 2011.

[2] Petrone, G., Spagnuolo, G., Teodorescu, R., Veerachary, M., and Vitell M., "Reliability Issues in Photovoltaics Power Processing Systems", IEEE-Transactions on Industrial Electronics, Vol.55, no.7, pp.2569–2580, 2008.

[3] Skandalos,N.,and Karamanis, D., "Investigation of thermal performance of semi-transparent PV technologies", Elsevier journal on energy and buildings, Vol.124, pp.19–34, 2016.

[4] Swapnil Dubey., Jatin Narotam Sarvaiya., and Bharath Seshadri., "Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World a Review", Elsevier journal on energy procedia, Vol.33, pp.311 – 321, 2013.

[5] John Tsanakas, A., Long Ha., and Claudia Buerhop.,"Faults And Infrared Thermographic Diagnosis In Operating C-Si Photovoltaic Modules: A Review Of Research And Future Challenges", Elsevier journal on Renewable and Sustainable Energy Reviews, Vol.62, pp. 695–709, 2016.

[6] Vikrantsharma., and Chandel, S. S., "Performance And Degradation Analysis For Long Term Reliability of Solar Photovoltaic Systems: A Review",Elsevier journal on Renewable and Sustainable Energy Reviews, Vol.27, pp.753–767, 2013.

[7] Tsanakas, J. A., and Botsaris, P. N., "An infrared thermographic approach as a hot-spot detection tool for photovoltaic modules using image histogram and line profile analysis", The International Journal of Condition Monitoring, Vol.2, pp.22-30, 2012.

[8] Skoplaki, E.,Boudouvis, A. G., and Palyvos, J. A., "A simple correlation for the operating temperature of photovoltaic modules of arbitrary mounting", Elsevier journal on solar energy materials and solar cells, Vol.92, pp.1393-1402, 2008.

[9] Christian Schuss., Kimmo Leppanen., Kari Remes., Juha Saarela., Tapio Fabritius., Bernd Eichberger., and Timo Rahkonen., "Detecting Defects In Photovoltaic Cells and Panels and Evaluating the Impact on Output Performances", IEEE Transactions On Instrumentation And Measurement, pp.1-12, 2016.

[10] Christy Mano Raj, J. S., and Ebenezer Jeyakumar, A., "A Novel Maximum Power Point Tracking Technique for Photovoltaic Module Based on Power Plane Analysis of I–V Characteristics", IEEE Transactions on Industrial Electronics, Vol.61, no.9, pp.4734-4744, 2014.

[11] Boris Misic., Bart E. Pieters., Ulrich Schweitzer., Andreas Gerber., and Uwe Rau., "Defect Diagnostics of Scribing Failures and Cu-Rich Debris in Cu(In,Ga)Se2 Thin-Film Solar Modules With Electroluminescence and Thermography", IEEE Journal of Photovoltaics, pp.1-9, 2015.