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Thermal Camera Shooting Method for Measuring Deterioration Status of Photovoltaic Module

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Abstract: There are many reasons for the output degradation of the PV module. The main factors are the higher PV module temperature, the shaded cell or module, the shortened or conducting bypass diodes, the PV array is soiled, degraded and so on. In this study, we have studied the operation method of thermal imaging camera to analyze the degree of deterioration of PV module. The modeling of photovoltaic cells and the principle of generating hotspot were studied and the thermal changes were studied by electrical analysis. In addition, an experiment was performed to analyze the thermal change of PV module using a thermal imaging camera and to predict the deterioration state of the PV module.

Key words: Thermal camera, photovoltaic module, hot-spot, deterioration, changes, analyze

INTRODUCTION

Recently, there has been a lot of interest in the development of the renewable energy around the world due to environmental pollution problems such as global warming, abnormal weather and depletion of fossil fuels. In particular, solar energy has attracted much attention in the renewable energy field as a pollution-free, sustainable and abundant energy source (Molki, 2010; Dunlop, 2003).

There are many reasons for the output degradation of the PV module. The main factors are the higher PV module temperature, the shaded cell or module, the shortened or conducting bypass diodes, the PV array is soiled, degraded and so on. Recently, many studies have been conducted to improve the power generation efficiency of a photovoltaic module by diagnosing a deterioration phenomenon occurring in the photovoltaic module. Especially, there is a growing interest in the development of algorithms and systems that can diagnose the deterioration of photovoltaic modules installed at the power plant site in real time.

Researches have been conducted to predict the increase of internal resistance due to the deterioration of the photovoltaic module and the decrease of the module efficiency using the thermal camera and to suggest a maintenance plan. In addition, by using a thermal camera, it has advantages such as quick and easy measurement and analysis of temperature distribution. However, a detection system using such an infrared camera should be taken in consideration of a change in a measurement angle and a radiation dose (Anonymous, 2011; Spagnolo *et al*., 2012).

In this study, we have studied the operation method of thermal imaging camera to analyze the degree of deterioration of PV module. The modeling of photovoltaic cells and the construction process of photovoltaic system were studied and the thermal changes were studied by electrical analysis. In addition, an experiment was performed to analyze the thermal change of PV module using a thermal imaging camera and to predict the deterioration state of the PV module.

MATERIALS AND METHODS

PV module characteristics

Photovoltaic system: In a PV system, PV cells are connected in series to form a PV module as shown in Fig. 1. A number of PV modules are then connected in series to form a PV string. Strings are further connected in parallel to form a PV array. This arrangement enables low DC voltage and current to be added up to a high output.

PV cell model: The photovoltaic cell can be modeled as shown in Fig. 2 and consists of a variable current source proportional to solar radiation an equivalent diode with opposite polarity to the current of the battery and an internal resistor.

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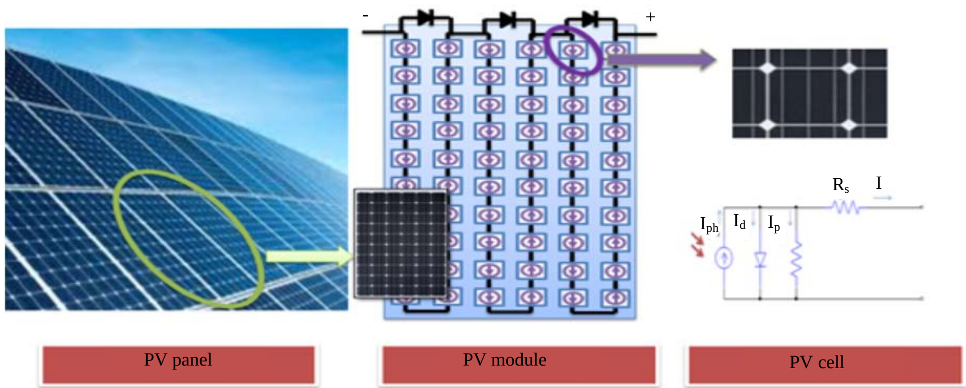

Fig. 1: PV system hierarchy diagram

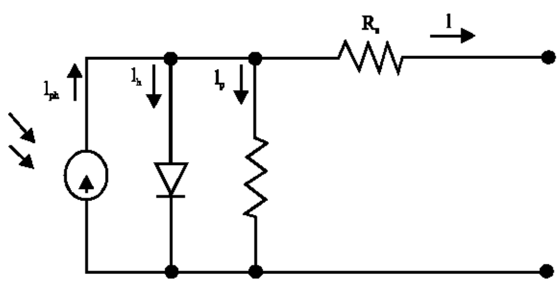

Fig. 2: The equivalent circuit of a solar cell

Output current I:

$$I = I_{ph} - I_O\left(e\frac{V+IR_S}{a} - 1\right) - \frac{V+IR_S}{R_U} \quad (1)$$

Where:

I_{ph} = The photocurrent
I_O = The reverse saturation or leakage current of the diode
V = The Voltage imposed on the diode
R_s = The series Resistance
R_p = The parallel Resistance

The voltage of the photovoltaic module represents a low voltage of about 0.6 V and multiple solar cells are connected in series to have a high voltage.

The occurrence of hot-spot: The PV module voltage is determined by the sum of the number of PV cells inside the module and the PV module output will be limited to the smallest value. In addition, if an abnormality such as shaded, soiled or damaged occurs in these cells, the total current is reduced to the current of the corresponding cell and the generation loss is generated. The photovoltaic cell in which the abnormality occurs operates as a load rather than the power source and the voltage of all solar cells connected in series with the corresponding cell is applied which depending on its position in the string, can be from 5-30 V, so that, the temperature of the cell rises. With 10-20 solar modules connected in series, the DC output of a modern solar system can easily be 400 V. This temperature phenomenon is called hot-spot phenomenon which shortens the lifetime of the module. Therefore, a bypass diode is installed to prevent the above phenomenon and the string including the abnormal cell is excluded from the series circuit, thereby minimizing the power generation loss (Fig. 3).

Deterioration characteristics of PV modules: PV cell and module ageing is a process which naturally evolves with years of module operation in field conditions. Ageing effects mainly include discoloration of encapsulates, degradation of the anti-reflective coating, the formation of hotspots, moisture intrusion, delamination and corrosion, cracks, tears and bubbles in the back-sheet (Kaplani, 2012).

Several ageing effects may co-exist even in the same cell and module while optical, physical, electrical and thermal degradation effects may be linked with to a lesser or greater degree, power and performance degradation of the module. Stronger ageing effects and higher encapsulates degradation rates are encountered in places of hot and dry climate with high ambient temperature and UV flux (Bagavathiappan *et al*., 2013).

Physical basis of thermography

Radiant energy: All materials have the ability to absorb infrared radiation increasing their temperature. Furthermore, any material with a temperature above absolute zero emits infrared energy (Maldague, 2001).The radiant energy is proportional to the fourth power of the object surface temperature:

$$R_t = \varepsilon \times \sigma \times T^4 \left(W/m^2\right) \quad (2)$$

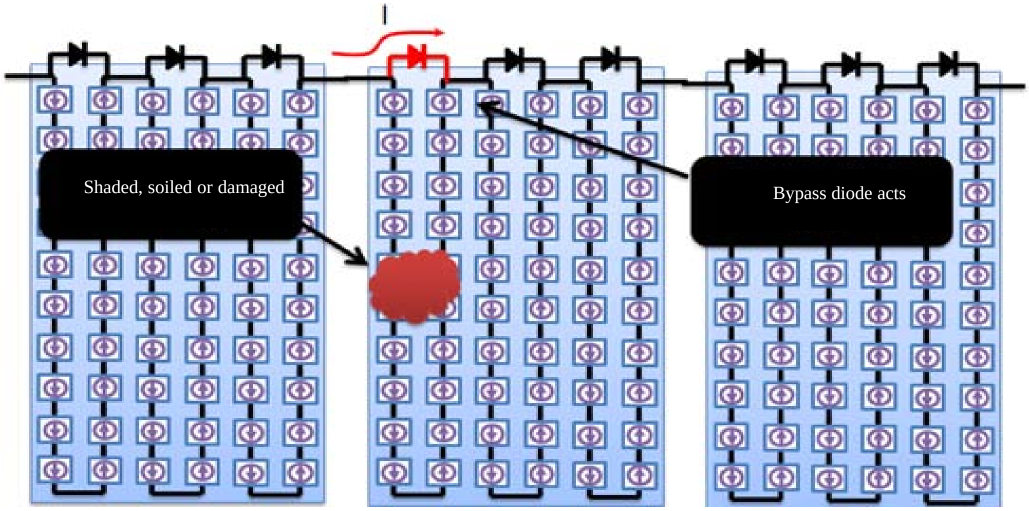

Fig. 3: Principle of bypass diode operating

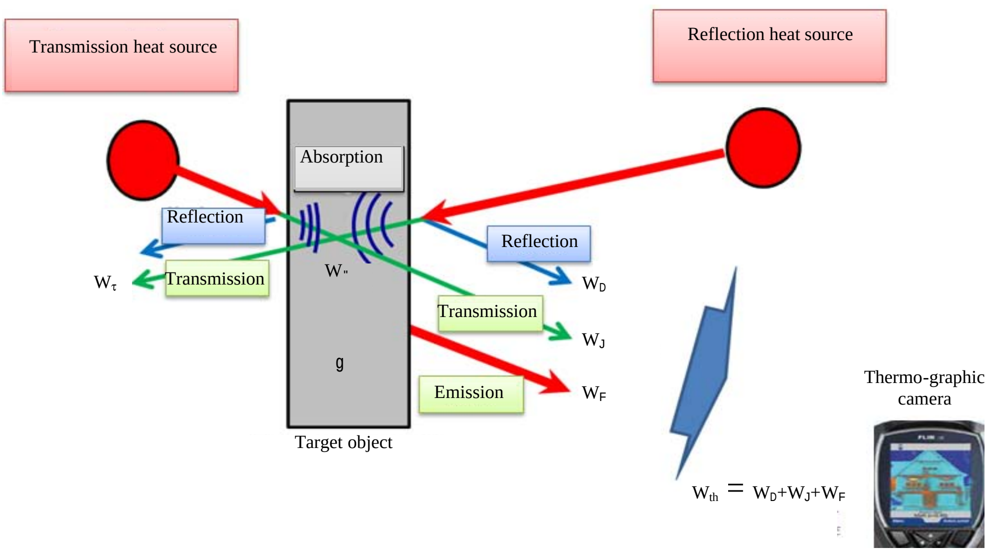

Fig. 4: Principle of thermos-graphic camera

Where:

R_t = The Radiant energy of a body
ε = The emissivity (0≤ε≤1)
σ = The Stefan-Boltzmann constant

Emissivity is defined as the quotient between the radiation emitted by a body and the radiation emitted by a black body to the same temperature. This coefficient allows to classify the bodies like black ones ε = 1 and grey ones ε<1. A radiometric thermal camera measures the temperature of a surface by interpreting the intensity of an infrared signal reaching the camera.

Remote temperature sensing: Remote temperature sensing of a surface relies on the ability to accurately compensate for surface characteristics, atmospheric interference and the imaging system. The surface characteristics that influence the temperature measurement are surface emissivity and reflectivity at the infrared spectral wavelengths. The atmosphere will absorb and emit thermal energy based on its composition and the distance between the camera and the surface (Suarez-Dominguez *et al*., 2015). Finally, the ability to spatially resolve detailed temperature measurements in a thermal image is influenced by image focus, blur and the pixel resolution. The influence of each of these factors on measurement accuracy is highly dependent on the specific measurement application and each must be accounted for and resolved (Fig. 4).

Consideration for capturing thermographic image: The following factors must be taken into consideration in order to obtain accurate thermal imaging.

Emissivity: Emissivity is highly dependent on the properties of the material.

Reflection: Some materials, like most glasses but also metals have the property of reflecting heat radiation as a mirror reflects light.

Reflected light around: When irradiating high reflectance objects, the camera angles should be well defined, so that, reflected light is minimized on the image.

RESULTS AND DISCUSSION

Experiment: In this study, various experiments were carried out with respect to the method of measuring with infrared thermographic camera about the abnormal situation of the PV module. FLIR's VUE Pro R camera was used for the thermal camera used for the experiment. Various experiments were conducted using solar modules.

Thermal imaging analysis by measuring angle: In the first experiment, the angle of the module was changed from 45-135° from the ground to confirm the change of the thermal image. As a result, we confirmed that the best photographing image was captured by 5th capturing angle about 75°. As a result of the experiment, it was confirmed that the capturing angle is important because the result can be different from the actual temperature distribution according to the photographing angle (Fig. 5).

Thermal image according to solar radiation variation: In the second experiment, we experimented how the thermal image changes according to the change of solar radiation. As shown in Fig. 6, image 1 and 2 differ by 2 min but the average temperature difference is 4°C. When we changed the region of interest by 4°C (image 3), we confirmed that the result is similar to image 1. As a result, it was confirmed that the temperature distribution of the thermal image varies with the change of the solar radiation amount and it is expected that it needs to be corrected.

Thermal image according to load connection: In the third experiment, we experimented how the thermal image

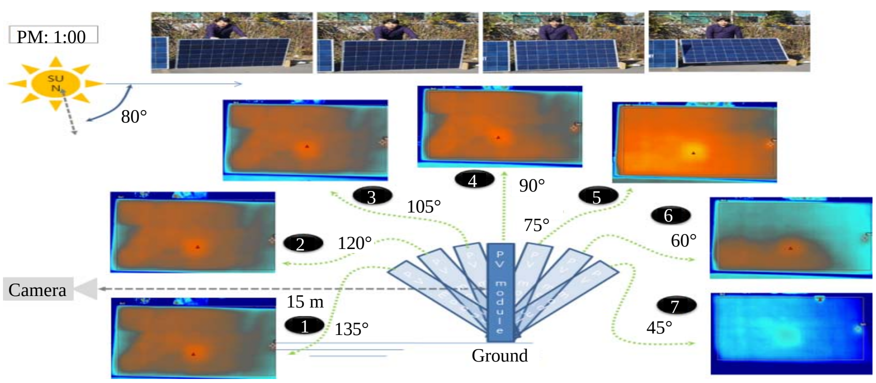

Fig. 5: Thermal image change according to measurement angle

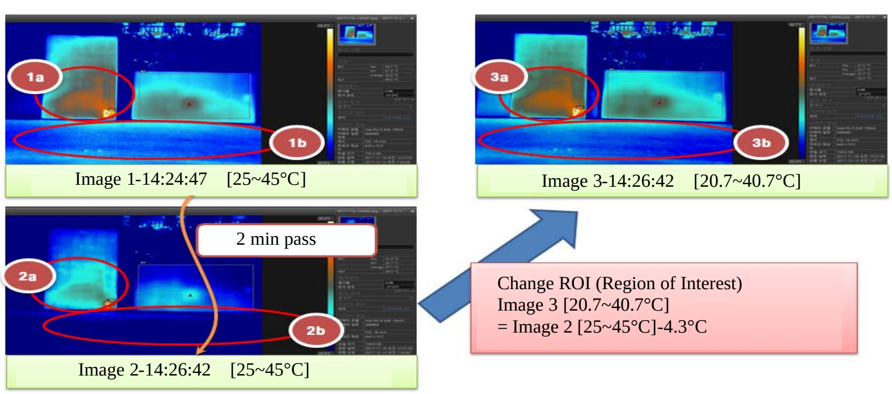

Fig. 6: Thermal image change according to solar radiation variation

Temperature	No. of load (1)	Load (3)
Maximum	46.6	40.6
Minimum	39.8	33.0
Average	43.4	37.5

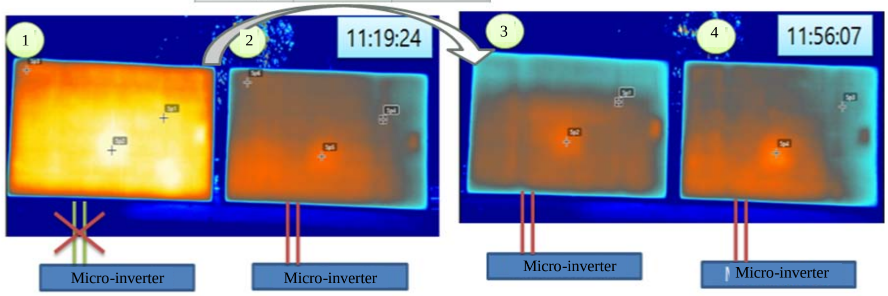

Fig. 7: Thermal image according to load connecting status

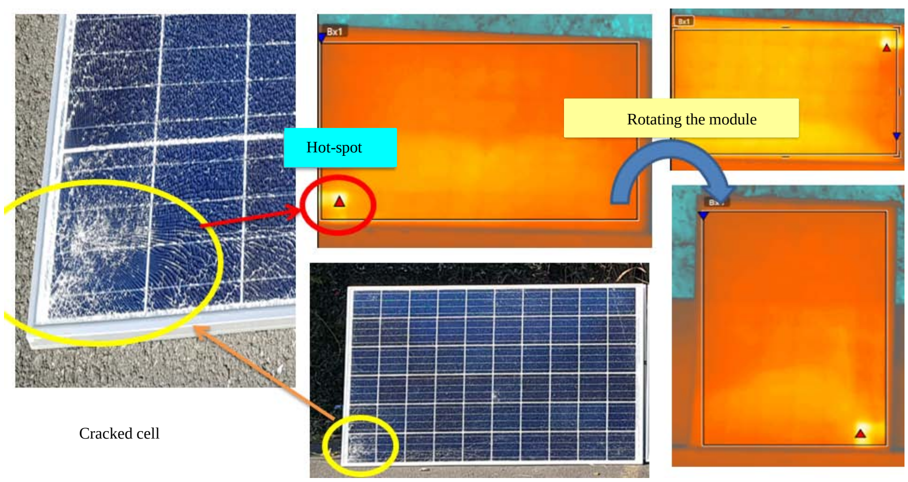

Fig. 8: Thermal image of the PV module when cracked or abnormal material was detected

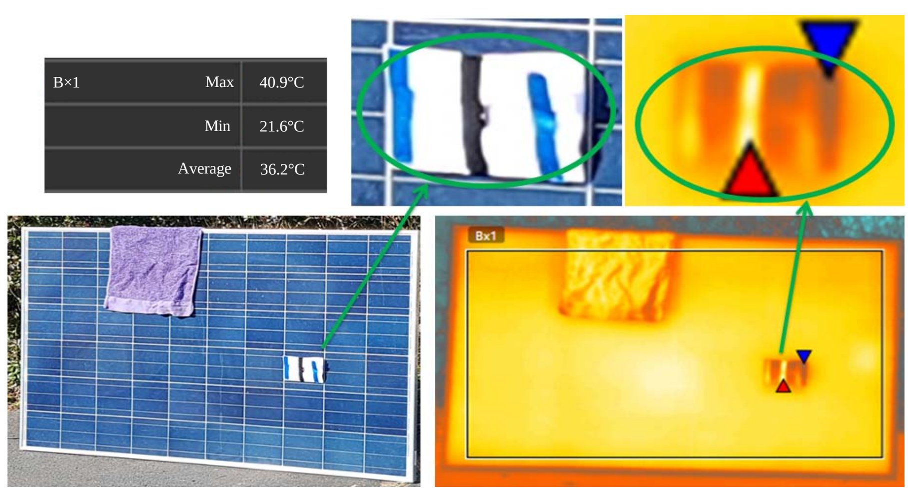

Fig. 9: Thermal image of the PV module when cracked or abnormal material was detected

changes according to load connection (Fig. 7-9). In case of load, it is confirmed that temperature is high due to heat accumulation when not connected and it is confirmed that temperature distribution is lower after connection (Fig. 7).

Thermal image of the cracked cell: The temperature of cracked solar photocell was higher than other normal cells and hot spot occurred. The mean temperature of the cracked module was about 32°C but the hotspot temperature was more than 12°C than the average of 46.2°C. Also, the module was rotated and hot spots were continuously detected (Fig. 8).

Thermal image of the PV module when abnormal material was detected: When abnormal material was placed in the module, temperature distribution was different according to color of the material. It was confirmed that the white material shows a lower temperature and the black material show a higher temperature (Fig. 9).

CONCLUSION

In this study, we have studied the operation method of thermal imaging camera to analyze the degree of deterioration of PV module. In order to understand the deterioration characteristics of PV module, PV cell modeling is performed and the cause of hotspot is described. In addition, the principle of thermal imaging camera and the main considerations in shooting were explained and the thermal imaging method was studied through various experiments. Experimental results showed that the importance of the measurement angle, compensation for the change of the radiation dose, the change according to the load connection condition and the influence on cracks or foreign matter were considered.

RECOMMENDATION

It is expected that the contents of this stduy can be used as an important data for analyzing deterioration of PV module in the future.

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