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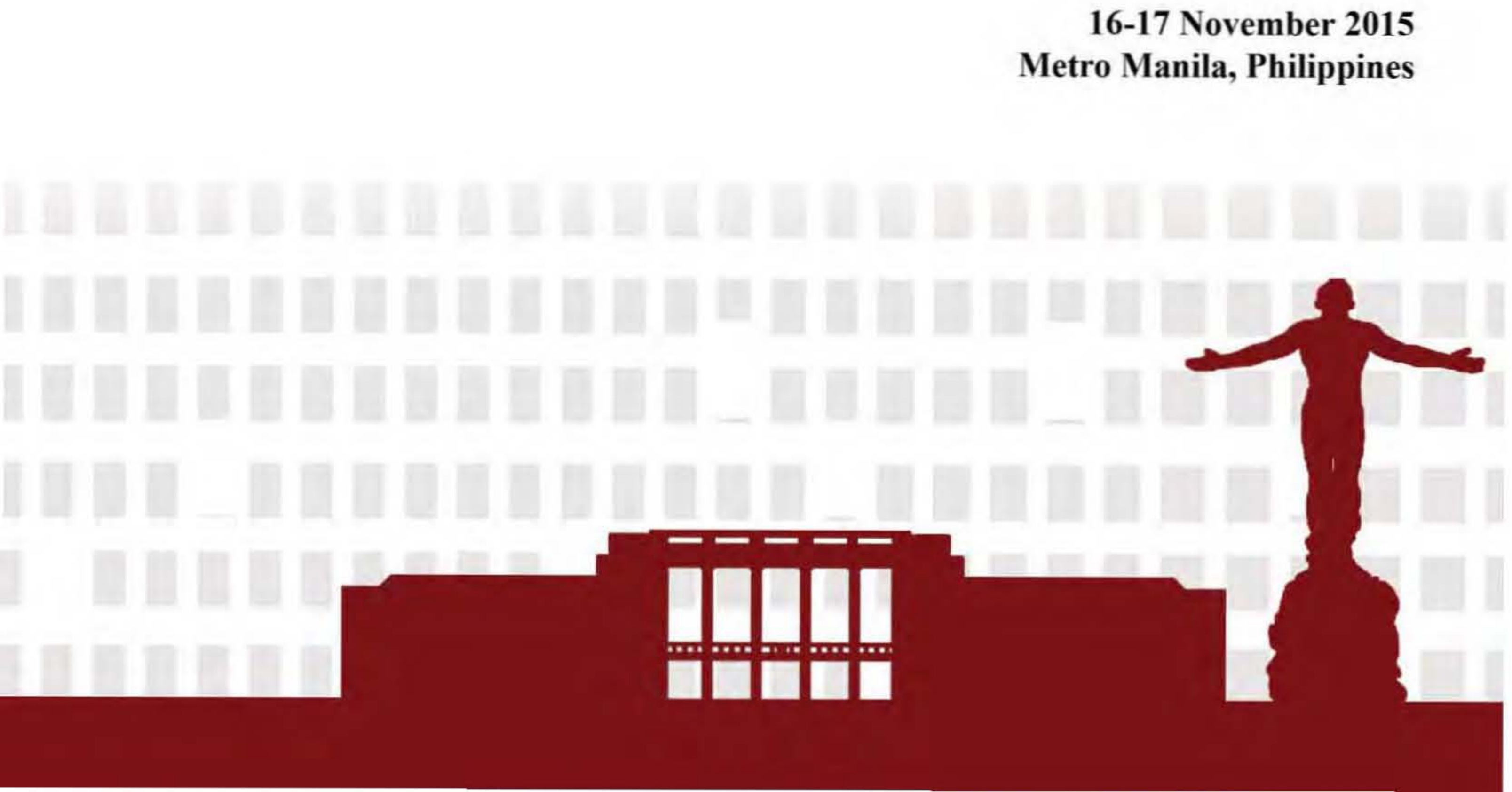

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THERMAL IMAGING TO DETECT HOTSPOTS IN SOLAR PV MODULES

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ABSTRACT

Defects in solar cells affect the overall output of a photovoltaic (PV) module. When there is a defect in a PV module, that specific defect becomes a load so current concentrates to that part. This creates a hotspot which may lead to severe power reduction. Identification of hotspots is one step to creating countermeasures to improve theefficiency of solar PV arrays. To check for hotspots in the photovoltaic modules, infrared (IR) imaging was utilized as an optical tool. IR is contactless and thus (almost) reactionless. Also, it spatially separates radiation source and detector, which means that even very hot or otherwise difficult-to-access objects can be measured. With this, infrared thermography can aid in monitoring the performance of a photovoltaic module years after it has been installed. Likewise, it can provide a better assessment if the solar PV modules are still efficient or should be replaced with new ones. This work used and analyzed the captured IR images of solar PV modules to quantify areas with higher intensitiesand the images were dissected into groups according to its heating intensities through k-means clustering. This allows the classification of hotspots and identification of problem areas in a module.The collected IR images also showed potential causes of hotspots in solar PV modules.

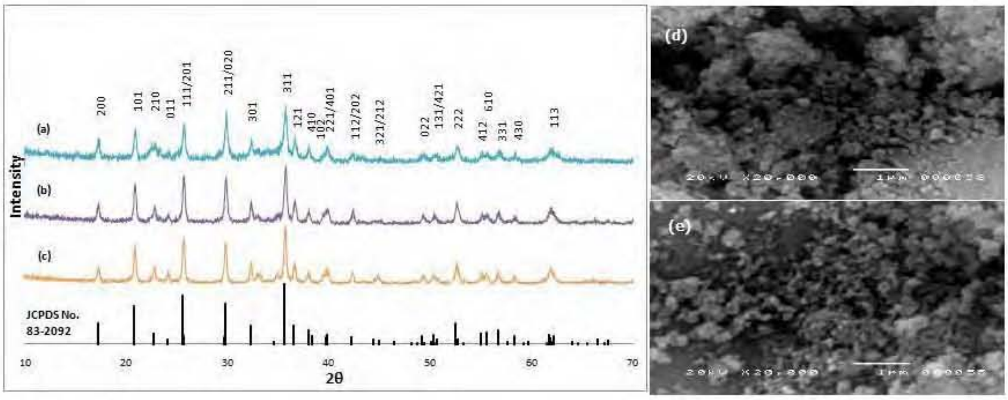
Keywords—Hostpots, Infrared Imaging, Infrared thermography, k-means clustering

Introduction

Solar energy is extensively harnessed across the globe and is seen as a good alternative to oil and other non-renewable sources. It also offers clean energy and is a good investment for electricity generation in the long run. It does not emit any greenhouse gases nor any other pollutants for that matter. In areas where water is scarce, solar power is still working since it requires little to no water. Many countries are realizing the solar energy's capability and is evidenced by the increased solar PV installations worldwide. In the early parts of 2014, the total global solar PV capacity reached 150 gigawatts (GW) [1].

Due to the growing efforts in installing solar PV systems for harvesting energy, knowing its performance condition is beneficial in ensuring that it is optimized. One of the most common reported failures in solar PV system's operation is hotspots. When a PV module, composed of a solar cells connected in series, is exposed to light, a photocurrent is generatedHotspots occur when a solar cell in the PV module produces erratically less current than the string current of the PV module. This happens when the cell is partially or totally shaded, contains a crack or electrically mismatched. Under these conditions, the cell becomes reversed biased and consumes power rather than producing it. [2]. That is, the cell dissipates power, heats up, leading to unwantedefficiency losses of the solar PV module.

At present, conventional performance evaluation or monitoring of operating solar PV systems is primarily done through computer simulations and electrical measurements [3]. However, such methods lack fault detection capabilities. Conversely, temperature-based evaluation methods, such as infrared thermography (IRT), are capable of showing each defect's signature based on its thermal patterns [4]. It was found useful in determining the efficiency analysis of PV plants. Through this, any source of hotspots can be identified to evaluate and quantify its effect on the general module's performance after long-term operation. The study offers a method to utilize low-end infrared camera to identify defects in solar PV module while it is operating.



Materials And Methods

The infrared (IR) images are acquired by using FLIR C2, a portable infrared camera with an IR sensor resolution of 80x60 and a thermal sensitivity of <0.10°C. The camera can display the object temperature within the range of -10°C to +150°C. Emissivity has been set to 0.90 (within the typical value range for glass) and temperature setting for the camera was fixed at 10°C. This parameter compensates for the radiation reflected on the object and those between the camera and the module itself. Distance is set at 1 meter.

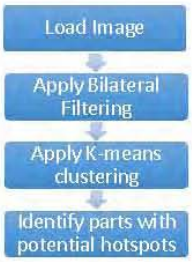


Figure 1. Image Processing Flow

Figure 1 shows the flow of the image processing algorithm. The images taken were loaded to a MATLAB program that uses bilateral filtering and k-means algorithm to cluster the areas with different intensities according to the color gradient. Bilateral filtering is able to smooth edges of images while preserving th edges. K-means clustering algorithm is taken as a segmentation tool because it categorizes the input data points into multiple groups based on their intrinsic distance from each other, in the the study, representing heat intensities.

RESULTS And Discussions

Images of the solar PV module were obtained using an infrared camera. Figure 2(a) shows an IR Image while 2(b) shows a Multi Spectral Dynamic Imaging (MSX) image of the same module. A color bar with corresponding temperatures are shown at the right side of the image. Red areas correspond to about 53.8 °C, the highest temperature in the PV module.

(a) (b)

Figure 2. Original IR (a) and MSX (b) images taken using FLIR C2

The original image was cropped so that FLIR logo and the color bar are excluded and bilateral filtering was applied to smoothen the edges.Using k = 6, the image was segmented into six clusters but the red areas are the ones that is significant in the present study and is isolated as shown in Figure 3. The temperature of this region ranges from 49°C to 50°C.

Figure 3. Clustered image of red parts using k-means

By inspecting the PV module under study, the red area shown in the infrared image contains a crack. This crack may have caused this region to dissipate more power. Hence, produced colors corresponding to higher temperatures. It was also observed that other potential factors that contribute to isolated heated areas include bird droppings as shown in Figure 4. These droppings may be small in size but it still can contribute to a decline in the power output of the PV module.

Also, infrared images of the PV modules reveal that even junction boxes contribute to hotspots. Based on the images shown in Figure 5, junction box temperatures can go as high as 50°C. Areas where the boxes are located are recognizable because of this rise in temperature.

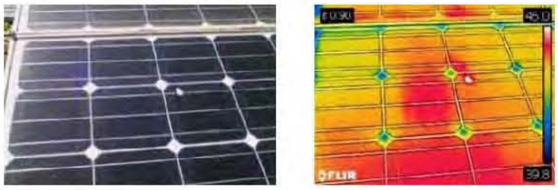


Figure 4. Bird droppings (a) normal photo (b) infrared image

(a) (b) (c)

Figure 5. Junction box (a) seen as red spots in the IR image (b) focused IR image (c) normal image

Summary

In summary, it was shown that infrared thermography can be an effective tool in monitoring hotspots. K-means clustering can be used as a tool in isolating the significant areas under study. The infrared images also revealed possible causes of hotspots among solar PV modules. Anything, no matter the size, that directly covers the solar PV module from the sun contributes to shading. Shading creates thermal stress on solar PV modules and posts a negative effect on its performance.

Acknowledgments

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