ARTICLE IN PRESS

Journal of Science: Advanced Materials and Devices xxx (2018) 1–9

Contents lists available at ScienceDirect

Journal of Science: Advanced Materials and Devices

journal homepage: www.elsevier.com/locate/jsamd

Original Article

Development of 3D graph-based model to examine photovoltaic micro cracks

Mahmoud Dhimish [a,*], Violeta Holmes [a], Peter Mather [a], Chouder Aissa [b], Martin Sibley [a]

[a] Laboratory of Photovoltaics, School of Computing and Engineering, University of Huddersfield, HD1 3DH, United Kingdom
[b] Electrical Engineering Laboratory (LGE), University MohamedBoudiaf-M'sila, BP166, 28000, Algeria

ARTICLE INFO

Article history:
Received 10 April 2018
Received in revised form
4 July 2018
Accepted 8 July 2018
Available online xxx

Keywords:
Photovoltaic
Solar cells
Micro cracks detection
Electroluminescence (EL)
Power loss

ABSTRACT

This paper presents a novel technique to examine the impact of Photovoltaic (PV) micro cracks on the performance of the output power for PV solar cells. Initially, the image of the PV micro crack is captured using Electroluminescence (EL) method, then processed by the proposed technique. The technique consists of two stages, the first stage combines two images using an OR gate, the first image is the crack-free (healthy) solar cell, whereas the second is the cracked solar cell image. The output image from the first stage is passed into the second stage which uses a 3D graph-based model in order to examine the output power loss in the cracked solar cell. In order to examine the effectiveness of the 3D graph-based model, two different cracked PV solar cells have been examined. From the obtained results, it was evident that the micro cracks size, location and orientation are more detectable using the developed technique. In addition, the maximum and minimum output power can also be estimated using the offered technique.

1. Introduction

Micro cracks in solar cells are the genuine problem for Photovoltaic (PV) modules. They are hard to avoid and, up to date, the impact of PV micro cracks on the performance of the PV modules in various environmental conditions has not been reported [1–3]. In order to examine micro cracks in PV modules, several methods have been proposed [4]. Resonance ultrasonic vibrations (RUV) technique for crack detection in PV silicon wafers has been developed [5,6].

RUV technique uses ultrasonic vibrations of a tenable frequency and changeable amplitude. The silicon wafer is constrained by an external piezoelectric transducer in a frequency range of 20–90 kHz. The transducer comprises a central hole allowing a reliable vacuum coupling between the wafer and transducer by applying 50-kPa negative pressure to the backside of the wafer. RUV PV micro crack technique is sensitive to crack length and its location, and can be used to reject or accept wafers. However, it does not identify the precise location of the PV crack.

Photoluminescence (PL) aiming technique was proposed to solve this problem, since it can be used to inspect micro cracks in silicon wafers and PV modules [7]. PL technique can be applied not only at the end of the PV solar cell's production, but also it can be slotted in during the process of production [8].

Y. Zhu et al. [9] proposed a new PL setup that enables inhomogeneous illumination with arbitrary illumination patterns to determine various parameters of solar cells. The results indicate that the use of inhomogeneous illumination significantly extends the range of photoluminescence imaging applications for the characterization of silicon wafers and solar cells.

Most recently, in 2018, the PL images are acquired using the sun as the sole illumination source by separating the weak luminescence signal from the much stronger ambient sunlight signal. This is done by using a suitable optical filtering and modulation of the PV cells biasing between the normal operating point and open circuit conditions [10].

Electroluminescence (EL) technique is another method for the micro crack detection in PV solar cells. EL technique is the form of luminescence in which electrons are excited into the conduction band through the use of electrical current by connecting the solar cell in forward bias mode. This technique is very attractive, because it can be used not only with small solar cell sizes but also, with full scale PV modules [11,12].

The EL method requires the solar cells to be in the forward bias condition in order to emit infrared radiation. The EL ranges from 950 to 1250 nm with the peak occurring at approximately 1150 nm. The Emission intensity depends on the density of defects in the silicon, with fewer defects resulting in more emitted photons [13].

* Corresponding author.
E-mail address: mahmoud.dhimish@gmail.com (M. Dhimish).
Peer review under responsibility of Vietnam National University, Hanoi.

https://doi.org/10.1016/j.jsamd.2018.07.004

Please cite this article in press as: M. Dhimish, et al., Development of 3D graph-based model to examine photovoltaic micro cracks, Journal of Science: Advanced Materials and Devices (2018), https://doi.org/10.1016/j.jsamd.2018.07.004

The EL system should be placed in a dark room, as the image of the cells is being taken by cooled CCD camera, we have already published the configuration and construction of the EL setup in [14].

M. Kontgers et al. [15] investigated the impact of micro cracks on the performance of PV modules using EL imaging method. This research proves that micro cracks do not reduce the power generation of a PV module by more than 2.5%, if the crack does not harm the electrical contact between the cell and fragments. Orientational distribution of micro cracks in crystalline PV cells was firstly presented by S. Kajari-Schröder et al. [16]. PV micro cracks were classified into six subcategories as follows: dendritic, several, +450, −450, Parallel to busbars, and Perpendicular to busbars.

The analysis has been carried out using 27 PV modules using EL imaging technique, where the maximum micro cracks found in the PV modules are parallel to busbars with 50% relative occurrence. Furthermore, I–V curve analysis based on gallium arsenide (GaAs) PV solar cell on silicon substrate for crack-free and cracked PV solar cells have been investigated by S. Oh et al. [17] using EL imaging technique. It was evident that the output voltage of the PV solar cells decreases while increasing the crack size. Moreover, the crack density defined as the total length of the crack liner per unit area, which was found to be in the range from 13.8 to 33.2 cm^{-1} in most investigated solar cell samples.

On the other hand, in 2018, a new micro crack detection method based on self-learning features and low-rank matrix recovery was proposed by X. Qian et al. [18]. Firstly, the input image is preprocessed to suppress the noises and remove the busbars and fingers. Next, a self-learning feature extraction scheme in which the feature extraction patterns are changed along with the input image is introduced. Finally, the optimized result is further fine-tuned by morphological post-processing.

In this paper, EL imaging technique was used to capture the micro cracks in PV solar cells. The EL detection technique is already shown in our previous articles [11,19]. Furthermore, the main contribution is illustrated as follows:

- Technique selection: comparing different techniques to assess crack-free and cracked solar cell output EL image
- Image resolution: selecting the most suitable technique that has an optimum observable output image arrangement, in which it can be used to precisely identify PV crack orientation, size, and location
- Surface analysis: process the desirable image into a suitable system in order to draw a relevant graph-based description for the power loss in the cracked PV solar cell

This paper is organized as follows: Section 2 explains the examined PV module and its electrical specifications. Section 3 and 4 demonstrate various techniques for analyzing the PV crack images and the obtained results, while Section 5 draws a relevant conclusion for the proposed power loss estimation of the cracked PV solar cells.

2. Tested PV solar cells

In this work, the tested PV modules are shown in Fig. 1(a). The total inspected PV modules are ten, where its maximum peak power is 220 W and the number of solar cells is 60 per PV module.

A healthy (crack-free) solar cell is shown in Fig. 1(b), whereas a cracked solar cell is shown in Fig. 1(c). Both crack-free and cracked solar cell images will be processed using various detection techniques, this will be explained in the next section.

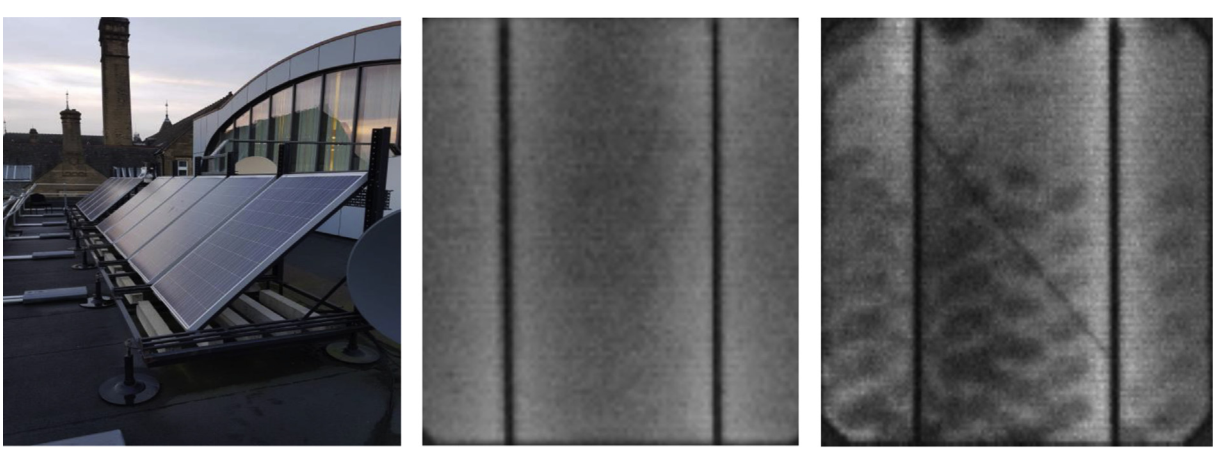
3. Proposed detection technique

This section describes the selection for the proposed EL detection technique. Fig. 2 shows the combination between the healthy and cracked PV solar cells. Six different techniques were used to combine both images, staring with OR gate, ending with subtraction technique. The output image for each technique is also demonstrated in Fig. 2.

As can be noticed, the division technique has no output (fully black PV solar cell image), whereas the second worst output image when subtracting the healthy from the cracked image. However, the best image resolution for the crack is identified using the OR gate (healthy solar cell image OR cracked solar cell image), this result arises because the crack-free image would not add additional noise or cracks to the cracked solar cell image. However, it cleans up the areas which have no micro cracks.

Fig. 3(a) show the output image of the OR gate. As can be noticed, the image lacks filtering for the noise in the areas that have no micro cracks, thus, it is required to create an image with a better resolution. It is worthy pointing that both vertical lines correspond to the solar cell busbars.

The proposed filtering and resolution enhancement technique are shown in Fig. 3(b). The suggested technique consists of three



(a) (b) (c)

Fig. 1. (a) 10 Examined PV modules, (b) Healthy (crack-free) PV solar cell, (c) Cracked PV solar cell.

Please cite this article in press as: M. Dhimish, et al., Development of 3D graph-based model to examine photovoltaic micro cracks, Journal of Science: Advanced Materials and Devices (2018), https://doi.org/10.1016/j.jsamd.2018.07.004