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Optimisation of Electroluminescence setup for characterisation of Photovoltaic module degradation

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Abstract

Electroluminescence (EL) is a useful characterisation tool for the early detection of performance limiting defects such as micro-cracks, unwanted impurities inside photovoltaic (PV) module cells and grain boundaries[1][2]. Most micro cracks result from the manufacturing process, transportation, and handling during storage and installation. After deployment, micro cracks can become more severe due to thermal cycling and dynamic wind loading. In order to correctly interpret EL images and be able to compare images taken at different degradation stages, the images need to be taken under similar resolution, integration time, applied current as percentage of short circuit current and environmental conditions. This paper discusses these settings and how best to optimise them to efficiently and accurately image degradation present in PV modules. The modules used in this work are two monocrystalline modules (A and B of 60 and 72 cells respectively). Degradation of PV modules such as Potential Induced Degradation (PID) or micro-cracks can affect the long-term reliability and profitability of PV installations. This paper describes and identifies the optimum settings (camera and voltage bias) at which module performance degrading defects and resistive properties may be observed. The EL method is fast and non-destructive and can be used to assess modules prior to deployment.

Keywords: Electroluminescence, degradation, shunt resistance, series resistance, PID

1. Introduction

1.1. Introduction to Module Degradation

Photovoltaics (PV) is the process of converting sunlight directly into electricity using solar cells. The increasing need for renewable power has been limited partly by module degradation defects that module suffer before and after deployment such as micro cracks, shading and Potential Induced Degradation (PID). Performance limiting defects lower the general power output of a power plant [3]. PV power production and sustainability decrease due to resistance and corrosion[4].
A micro crack is a very small crack on a cell that is not visible by naked eye. Micro cracks in modules are visible in solar cells through EL images and microscopes. Micro cracks may occur during lamination and soldering or transportation and installation. Due to thermal cycling certain micro cracks, can become more severe and depending on their orientation, result in areas of the cell being disconnected from the rest of the cell. Cell finger contact breakage results in weak or no electrical contacts with areas of the cell close to the broken fingers.

PID is a type of degradation that occurs in modules due to leakage current to the mounting structure of the PV module [5]. The leaked current results from a large bias voltage between the cells and the frame of a module. In recent years PID is considered to be one of the main contributors for a drop in solar power output from large PV plants. The size of leakage current between the frame and cells increases with an increase in temperature, humidity and string voltage resulting in a larger potential difference between the module and frame. PID can be observed in an EL image as a “chessboard” pattern with darker cells observed around the edges of the module.[6]. It is also observed when comparing dark I-V (Current-voltage) curves taken before and after PID occurred.

1.2. Electroluminescence

Electroluminescence (EL) imaging is a powerful diagnostic tool that can yield optical and electronic properties of a solar cell.

Micro-cracks, cell shading and cracks are some of performance limiting defects observable through EL imaging. Electroluminescence results when radiative recombination of charge carriers in a semiconductor pn-junction occurs. As a result the variation in the number of minority charge carriers active in the cell is proportional to intensity of luminesce detected during EL imaging. The spatial distribution of low EL intensity is therefore indicative of the presence of impurities and defects in the crystal structure that limit radiative recombination processes and that may have been introduced during cell manufacture [7].

At low forward bias, at approximately 10% of the module's short circuit current (Isc), PID and defects of the depletion region are prominent. At high biases, defects lying in the bulk substrate and affecting carrier diffusion become more prominent and are imaged[8].

Studies from Potthoff *et al*., 2010 shows that in an EL image, local luminescence intensity $\phi_{(x)}$ is given by

$$\phi_{(x)} = K_{(x)} \exp\left(\frac{V_{(x)}}{V_T}\right) \quad \text{For}\, V(x) >> V_T \,, \ldots\ldots\ldots\ldots \; 1$$

Where V_T is the thermal voltage, $V_{(x)}$ is the spatially dependant voltage drop across the localised resistance path of interconnectors and $K(x)$ is a factor related to the optical properties of the module and camera settings [9]. The optical and electronic properties of a solar cell materials vary greatly, making it possible to assume that cells luminescing with the similar intensity have same operating voltage V_{op} given by

$$V_{op} = V_T . In\left(\frac{\phi_{(x)}}{K}\right) + R_{ext} I \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where, $R_{ext} I$ is voltage across the external connectors and the module total voltage V_{mod} is given by

$$V_{\text{mod}} = \sum_{i=1}^{Ncell} V_{op} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where, N$_{\text{cell}}$ is the number of cells. R_{ext} is negligible hence the term can be ignored.

1.3. Series and shunt resistance

Dark current-voltage (I-V) semilog curves are used to estimate series and shunt resistance. In dark I-V measurements carriers are injected, rather than being photo-generated as is the case for illuminated measurements. In dark I-V measurements the measurements are taken in the dark as opposed to outdoor light I-V measurements which are often subject to irradiance variation during measurements. The module behaves like a diode, as such information such as ideality factor (n), saturation current (Io), shunt resistance (Rsh) and series resistance (Rs) can be accurately obtained from dark I-V graph. A PV module may be modelled using a single diode model according to equation 5 below[10]

$$I = I_O[\exp(\tfrac{q}{nkT}(V - IR_s)) - 1] + \tfrac{(V - IRs)}{Rsh} \;\ldots\ldots\ldots\ldots\ldots 5$$

Fig 1 shows a typical dark I-V characteristic curve with the effect of parasitic resistances on the characteristics in different voltage regimes illustrated. In the high voltage region increased series resistance is indicated by deviation from linearity, while an increase in current in the low voltage region is indicative of shunt resistance decrease.

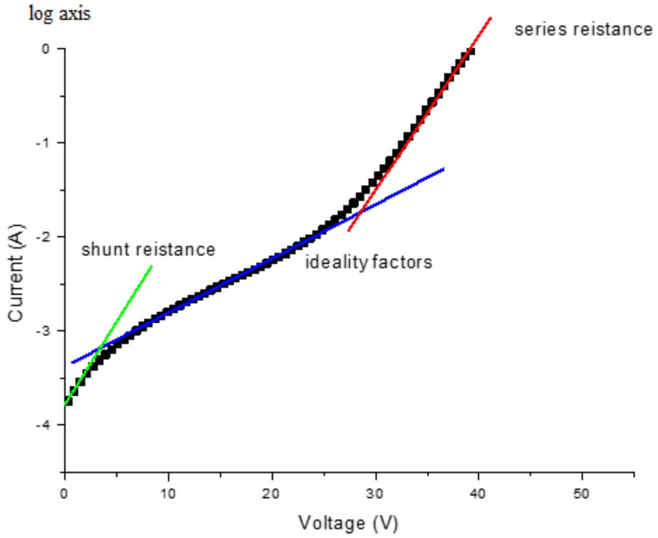

Fig .1. A semilog dark I-V graph for the PV module [11]

2. Experimental procedure

2.1 Electroluminescence

The EL setup[7] comprises of a Si CCD (silicon charged couple device) camera used to capture the EL image, a power supply to inject the required current in forward bias. The set up in this experiment is such that the camera is fixed on a frame that can move side to side and up and down and the frame holding modules moves back and forward as shown in fig. 2. The experiment takes place in the dark to ensure correct detection of EL radiation which falls out of the visible wavelength of between 1150 to 1500 nm. The power supply and the computer are located outside the dark area and are shown in fig. 3. The power supply is controlled by a LabVIEW program.

Fig.2. EL set up

2.2. Dark I-V Measurements

The dark I-V measurement procedure involves placing the module in the dark room to eliminate photo generated current. An Agilent E3646A dual output power supply injects current through the module in forward bias. Current and voltage are measured simultaneously using two Agilent 34401A digital multimeters. The two digital multimeters are connected such that one is across a shunt resistor (0.05Ω) to measure current and the other across the module to measure voltage. The resulting direction of current flow is opposite to that when the cell is exposed to light. Light I-V curve measurements were done using a AAA rated solar simulator at PVinsight laboratory under STC conditions. The power measurements were done before and after the module was subjected PID stress. The measurements were done with maximum current of 6 Amps and a maximum voltage of 48 Volts. The condition of the room was kept at 25^{O}C.

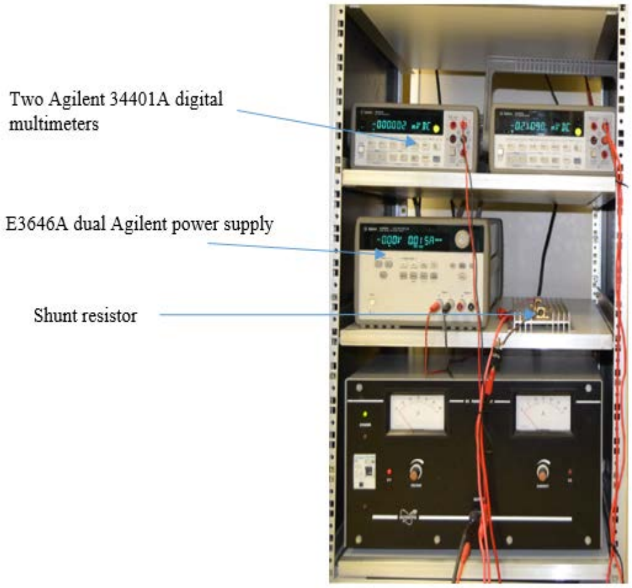

Fig. 3. Power supply set up

2.3. PID stress test

EL imaging, light and dark I-V measurements were done on the monocrystalline module before and after the module was subjected to PID stress test. The PID stress test was carried out in a controlled environment. Temperature was maintained at 25ºC, humidity at 60 % RH, for a period of 96 hours. The module was biased at 1 000V using Chroma electrical safety analyser 19032-P. Throughout the experiment the magnitude of the leakage current was monitored.

3. **Results and discussions**

The two mono-crystalline Si PV modules used in this study had the specifications as listed in the Table 1 below. The modules were chosen to illustrate the value of the optimised EL defect identification set up developed in our laboratory. EL full module image with the best resolution was obtained with a module-camera distance of 3400 mm, 0.36A for low-current EL and 3.61A for EL at Isc, and the integration time was 30 seconds.

Module	**No. cells**	**Module size(mm)**	**Voc (V)**	**Isc (A)**	**Pmpp. (W)**
Module A	36	950 X 450	21.8	3.67	60
Module B	72	1200 X 550	46.0	3.61	120

Table 1. Monocrystalline Si modules specifications

3.1. *Optimised EL imaging for defect identification*

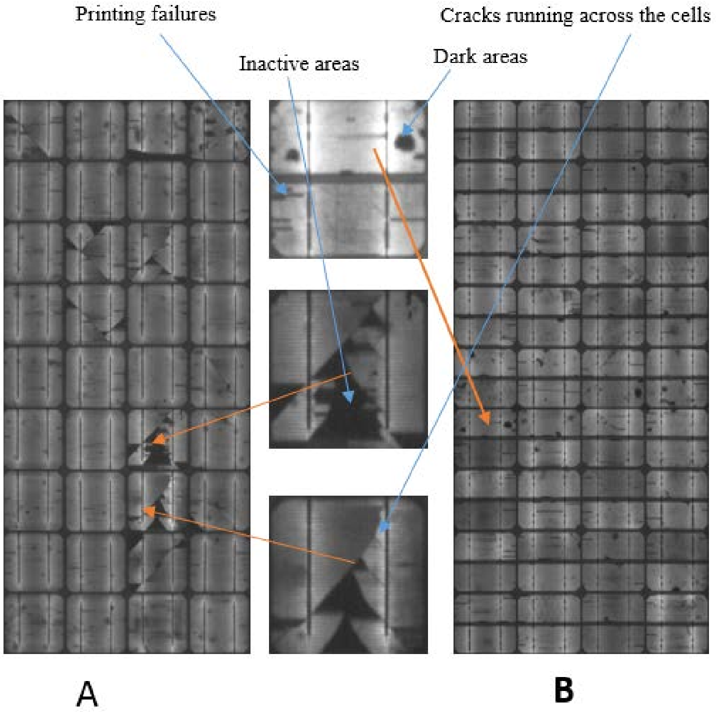

Fig. 4. Typical EL images of two monocrystalline Si modules

The typical EL images in fig. 4 shows defects such as Micro-cracks and cracks, printing failures, dark area and inactive areas.

3.2. Optimised EL Imaging for PID identification after 96 hours of voltage stress.

In order to illustrate the effect of PID and its characterisation using the techniques describe above, module B (72 cell module) was subjected to PID stress testing. Prior to the PID test the module was subjected to thorough visual inspection and it's performance parameters were also measured under STC. (STC: Standard Test Conditions, Temperature 25^{0}C and Irradiance of 1000W/m^2). The visual inspection showed no signs of any defects or degradation. The performance and device parameters are listed in table 2 below and compared to post-PID parameters as discussed below. Fig. 5 shows EL images recorded before PID stressing and afterwards. Fig. 5(a) is the pre-PID Isc EL image, (b) is the post-PID EL image at Isc and (c) the post-PID image at 10% Isc. In addition to observing the typical defects such as micro cracks, printing failures, "tyre tracks" in the high current images, PID presence may also be detected by EL. However, low current EL is a more reliable test for the presence of PID. In (a) no PID is evident, however, the EL image in (b) reveals that PID has taken place as a result of the high voltage and high humidity stressing. EL images taken at low currents (c) are not very clear for the identification of the typical defects mentioned above, however, the "chess-board" type patterned image is more visible and the effect of PID is apparent on more cells than observed in (b).

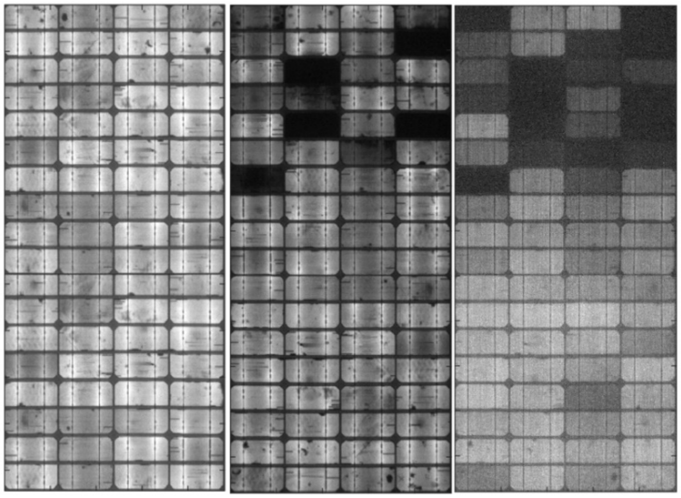
a)EL before PID b) EL at Isc after PID c) EL at 10% Isc after PID

Fig. 5. EL images of a monocrystalline module before and after PID stress

3.3. Light and Dark I-V curves

Table 2 below lists a summary of PV modules device parameters before and after the PID stress. The light I-V measurements were taken at STC using AAA solar simulator. Shunt resistance decreases due to increase in surface recombination and accumulation of sodium charges on the passivation layer. At higher voltages the series resistance increases slightly while the fill factor (FF) and maximum power decreases. The decreases in power output by about 14% indicates the severe damage PID causes on solar cells.

	Voc	Isc	P_{MPP}	FF	Rsh	Rs
Before PID	44,31	3.49	116,99	0,56	8453,90	2,14
After PID	43,61	3.53	102,24	0,51	2589,00	2,17

Table 2. Module parameters before and after PID stress.

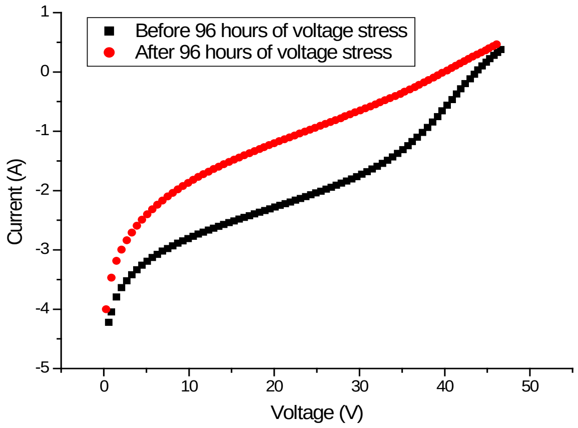

Fig. 6. Dark IV curve of the modules before and after PID.

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4. Conclusion

Electroluminescence is a powerful non-destructive defect identification tool. In this work low current EL has been successfully used to identify PID degradation. EL images taken at 10% Isc can be reliably used to quickly identify cells affected by or susceptible to PID. Defects such as finger contact disconnects, cracks, dark spots and micro cracks have been identified. Generally, EL imaging is critical before a module is certified to be in good condition for field deployment. The systems developed in this work enable the evaluation of the onset of PID and the imaging of defects to precisely determine the extent of their performance limiting effect, both at low and Isc EL imaging.

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