

ANALYSIS OF EFFECT OF THERMAL CYCLING TEST ON PHOTOVOLTAIC MODULE USING EL TECHNIQUE

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ABSTRACT

To improve PV module's lifetime and reliability, it is essential to understand the mechanisms and causes that degrade module performance over time under different climatic conditions. In this study, our main aim is to correlate the degradation of module power with physical changes that are generated in the cells over time. The poly-crystalline silicon 200W modules are subjected to long term accelerated tests (testing to be continued until failure occurs) and cell level defects are characterized using electroluminescence (EL) technique. The characterization is done periodically to analyze the trend of physical changes occurring in the module under aggravated stresses and degrading module's performance. Also, change in series resistance under thermal stress is analyzed as it has a direct impact on module's output power. Iterative simulation based software and EL images have been used to estimate series resistance of the cells.

INTRODUCTION

After the fabrication of a high power photovoltaic (PV) module, the most critical aspect is the duration for which the module can produce useful power. Reliability and lifetime of photo-voltaic (PV) modules are key factors to system performance and warranty and thus are extremely important as far as PV business is concerned. Outdoor field testing is an accurate method in estimating module lifetime. However, since PV modules commonly come with twenty five years of warranty, testing modules in field for that long period is not feasible. Thus, due to time constraints, many accelerating aging tests have been derived over the years for testing reliability of PV modules. The accelerated test protocols established by organizations like IEC and UL have been adopted worldwide as official tests to evaluate module quality and reliability standards.

To improve the reliability and thus lifetime of modules, it is extremely critical to analyze the effects of environment on the performance of modules and understand the exact causes of module degradation. Electroluminescence (EL) imaging is fast becoming an important non-destructive technique to diagnose the cell level defects in the module. It has been shown by Fuyunki et al that the electroluminescence intensity of multi- Si cell under forward bias is directly proportional to the minority carrier diffusion length [1]. Hence a dark areain an EL image signifies an electrically inactive area. EL test generates a defect map of each cell of the module which can be used to evaluate the degradation of cells.

Series resistance (R_s) of the module is one of the most critical parameters to evaluate module performance. Changes in series resistance can substantially affect module's output power and

hence it would be quite useful to estimate the changes in cell's series resistance under various environmental stresses. O. Breitenstein et al [2] have developed a fast converging iterative method to calculate the local series resistance of the cell using EL images.

In this work, main focus is given to analyze the changes developed in cells during different accelerated tests using EL technique and correlate those observations with module's power degradation. Change in cells' series resistance post Thermal cycling test is also analyzed using Breitenstein method.

EXPERIMENTAL

In this work, we have used Electroluminescence (EL) technique to study power degradation mechanisms in poly-crystalline silicon modules (6" sixty cells) as they undergo thermal cycle test (TC 400 cycles between +85°C and -40°C with a dwell time of 30 minutes at the temperature extremes) The experiment flowchart is shown in figure 1. The modules were fabricated under a control trial. The cells used in modules were taken from three different production classes based on current generated at maximum power point (I_{mpp}). One module for each sequence, fabricated under identical conditions, was used as experimental control. After sun-soaking of modules in 5 kWhr/m² intensity, EL images were captured using senovision camera (Model HR-830) at three different current values and this was repeated during different stages of environmental tests. Breitenstein method [1] and a simple matlab program were used to compute series resistance maps of individual cells for each module. The failure is defined as degradation of power by more than 20% from initial value (post sun-soaking)

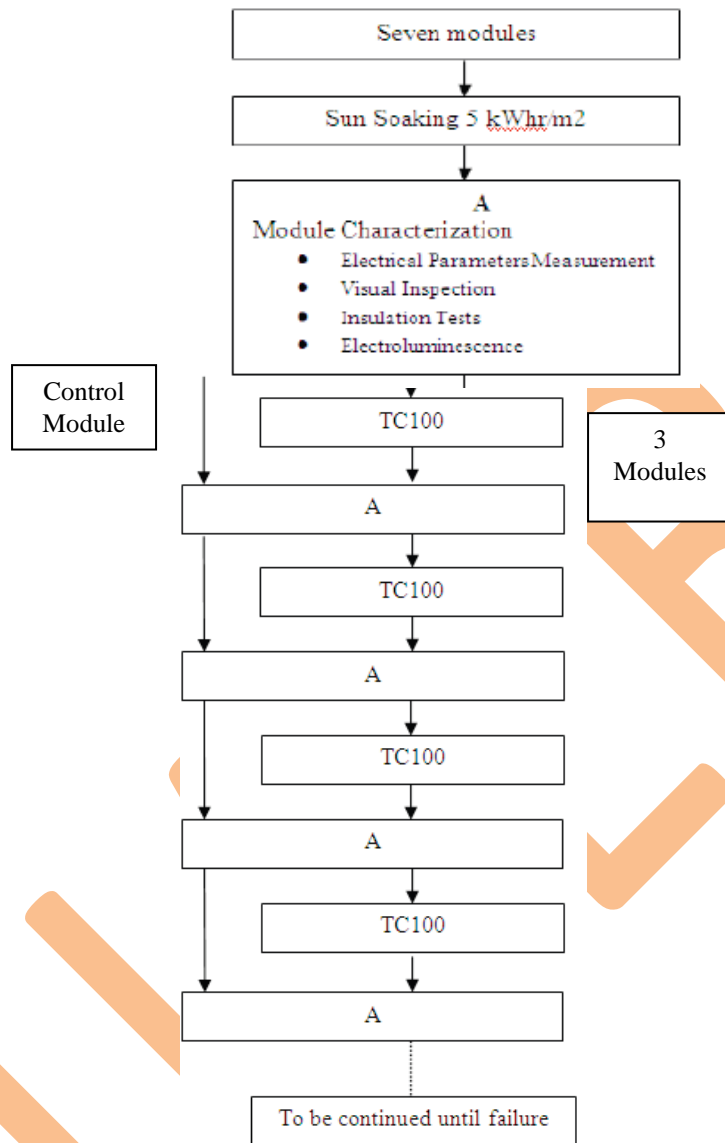


Fig.1 : Experiment Flowchart

RESULTS

IV and EL results post TC-400 and DH3000 tests are given below. Series resistance results post TC200 are also given below.

Thermal Cycling Test

Figure 2 reflects the typical trend in change of electrical parameters during thermal cycling test. Here, change in critical electrical parameters - maximum power (P_m), short circuit current (I_{sc}), open circuit voltage (V_{oc}), and fill factor (FF) – of a module after each batch of 100 thermal cycles are plotted.

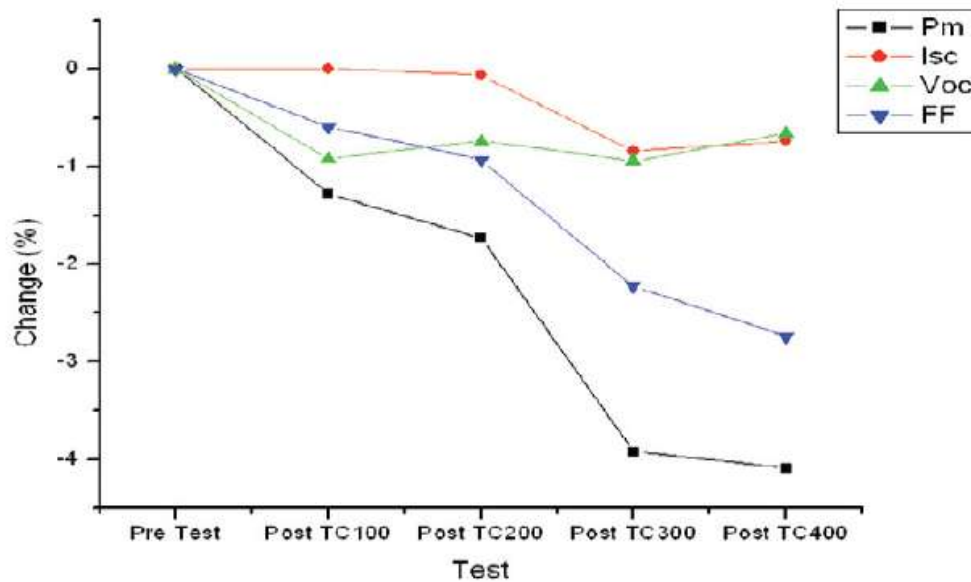


Figure 2: Typical trend of change in electrical parameters during thermal cycling test

Post TC400 test, all samples showed a degradation in output power less than 4.1%, which is not substantial considering IEC qualification test specifications (passing criteria is defined as not more than 8% power degradation post TC200). As can be seen in figure 2, the power degradation is driven by both loss in fill factor and short circuit current. Also, a near linear degradation in power is observed. This trend in change in electrical parameters is explained below using electro-luminescence results.

Figures 3-5 are EL images of two cells of a module and represent typical defects developed during thermal cycling test. Capturing all cell defect images of all the modules in this paper is not possible, but these images give enough evidence of increase in cell defects with increasing thermal stress. Particularly post TC300, large number of cells defects, mostly micro-cracks (figures 3c, 4b, and 4c) and finger defects (figure 3e and 4a), were observed. Few cracks led to detachment of a part of the cell from bus-bar resulting in in-active regions. The effect of this can be seen in figure 2 which shows a prominent reduction in short circuit current and fill factor post TC300 test. Also, few dark spots were observed in cells (figure 5a and 5b), which later led to cell cracks as can be seen in figure 3c and 3d. Some of these spots were already present in the cells before test and some developed during test. The reason behind this is still not clear and further studies are under progress to understand this in more detail.

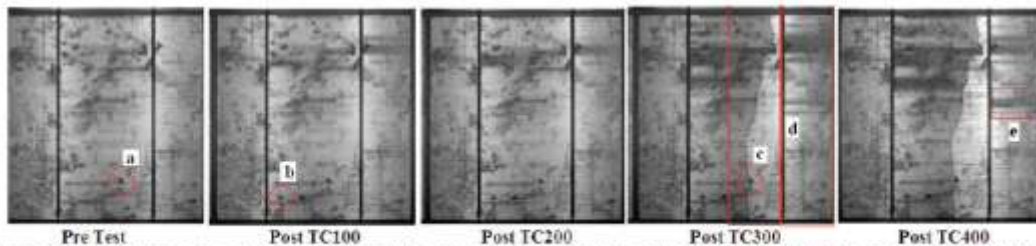


Figure 3: Cell EL images post each batch of 100 cycles a) Dark spot in cell pre test b) Few dark spots developed during TC100 c) Dark spot leading to crack during TC300 d) & e) Finger related defects increased during TC300 and TC400

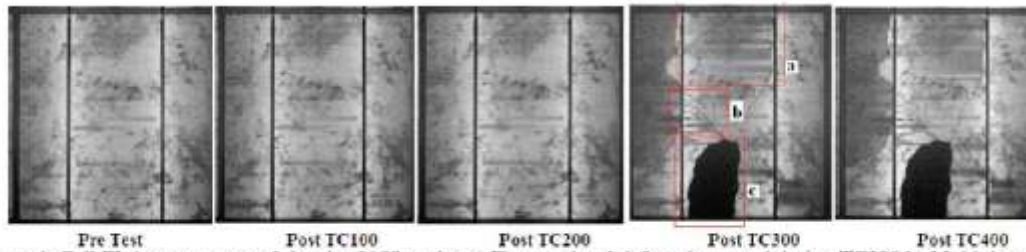


Figure 4: Cell EL images post each batch of 100 cycles a) Finger related defects increased during TC300 b) Multiple micro-cracks developed during test c) Micro-crack leading to detachment of cell part from bus bar thereby creating in-active region

Figure 3e and 4a show finger related defects which affect fill factor by increasing cell's series resistance. Such defects are found to increase after each TC100 test which led to linear reduction in fill factor. As discussed above, using Breitenstein method, series resistance of individual cell can be computed. Figures 5 show EL images and corresponding Rs images of two cells with increased finger defects. The dark areas in EL image correspond to light areas in the Rs map which signifies higher series resistance areas. The series resistance of all the cells of the module is computed and added up to estimate overall series resistance. The module total series resistance post TC200 test is found to be increase by approximately 9.6% which validates the observations (loss in fill factor due to increase in series resistance) mentioned above.

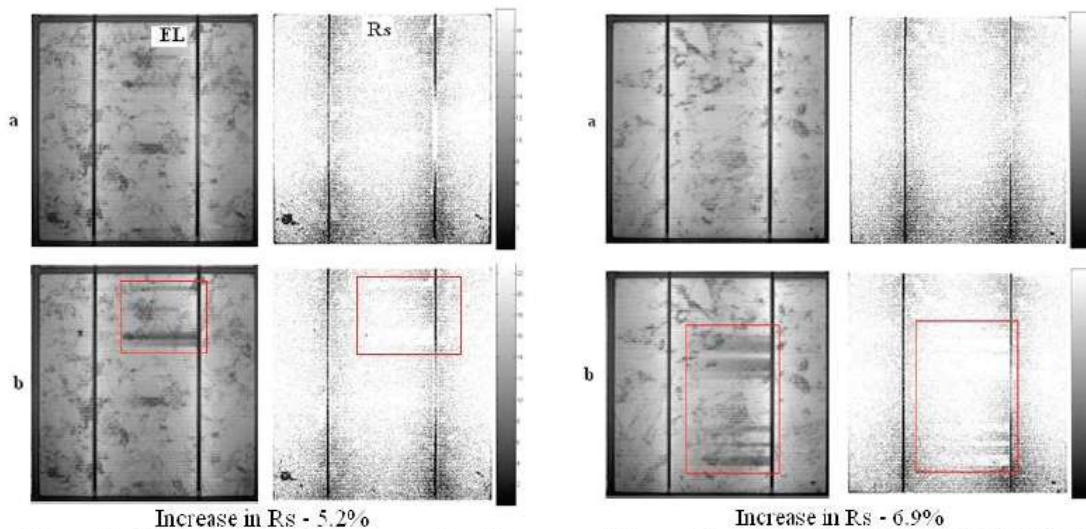


Figure 5: EL images and corresponding Rs maps of two cells a) Pre Test b) Post TC200 Test

DISCUSSION

The investigation of cell defects through EL images revealed quite useful information in understanding the cause and trend of change in power degradation over time. During thermal cycling test, power degradation is driven by loss in I_{sc} and FF due to development of large number of cracks and contact related defects as observed in EL images. This makes sense as thermal cycling test puts lot of mechanical stresses on cell and interconnects which can lead to cell cracks, extension of existing micro-cracks, and degradation of solder joints and cell contacts. The

loss in fill factor due to increase in series is validated by computing the change in series post test using Breitenstein method. The defects caused by thermal cycling test lead to an increase in series resistance of the cells which contribute in power degradation.

CONCLUSION

At the end of both the extended tests (TC400), power did degrade but not reached failure point. However, in order to improve the module's durability, it is essential to understand the causes behind performance degradation. The EL and Rs estimation is done preciously for that and the results revealed lot of information on cell level defects which helped in understanding the possible causes of module's power degradation. Loss in fill factor (increase in series resistance) is observed during both the accelerated tests and is one of the main causes of module degradation. Thus, in order to improve module's reliability, work needs to be done to improve cell metallization and interconnect soldering. Micro-cracks, observed mainly during thermal cycling test, could be critical for long term reliability of modules and thus should be suppressed as much as possible.

REFERENCES

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