CHANGES OF SOLAR CELL PARAMETERS DURING DAMP-HEAT EXPOSURE

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ABSTRACT

The degradation of PV modules during damp-heat exposure is investigated. Power degradation is analysed in dependence of temperature and humidity during exposure. The module's equivalent circuit parameters are calculated from I-V characteristics measured during ageing. A dose function is developed and degradations of power as well as equivalent circuit parameters can be analysed against the dose, which provides a better understanding of the module ageing behaviour. EL images of modules before and after ageing support the changes of solar cell parameters.

1. INTRODUCTION

A series of (non-standard) accelerated ageing tests have been carried out within the European Photovoltaic Research Infrastructure project SOPHIA including damp-heat (DH), thermal cycling (TC), UV, mechanical loading (ML) and combinations of them, in order to explore different ageing mechanisms and develop a modelling approach for the observed degradation. Current-Voltage (I-V), electro-luminescence (EL) and insulation measurements were carried out to characterise ageing mechanisms.

This paper focusses on the DH induced ageing observed for three different types of c-Si PV modules. The overall power degradation is given as well as the impact of underlying empirical device parameters of the diode model. The degradations of different parameters are then analysed in terms of a derived humidity dose. The key parameters contributing to the power degradation can be identified. Some parameters may start to degrade a few hundred hours earlier than other parameters, which may indicate different ageing mechanisms. Different types of modules have different key parameters, which are related to the module design, materials used and manufacturing process. Qualitative links between different characterisation mechanisms, such as the diode parameters and the cell active area of EL image, are discussed.

2. ACCELERATED AGEING TESTS AND MEASUREMENTS

2.1 Power Degradation and Dose Function

DH accelerated ageing tests have been carried out in a number of different temperature and relative humidity (T/RH) conditions, i.e. 75ºC/85%RH, 85ºC/85%RH, 90ºC/50%RH, 95ºC/70%RH, and 95ºC/85%RH, for up to 6500 hours. Under each condition, two modules of the same type have been tested. Fig 1 plots the maximum power (P_{MPP}) degradation of Module type I over time in dependence of ageing conditions. As shown in the result, this type of modules has severe degradations due to the DH stress, which follows a three-phase degradation pattern of induction, degradation, and stabilisation.

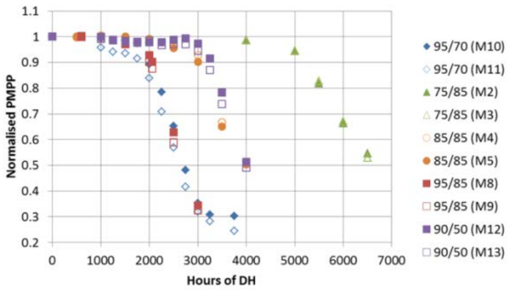

Fig. 1 Power degradation versus ageing time.

The degradation of P_{MPP} can be modelled by a dose function based on the effective humidity RH_{eff} [1] and testing temperature T as shown in Eq. (1):

$$dose(t) = f(E_a, RH_{eff}, T, t) = RH_{eff}{}^{n} * e^{-\frac{E_a}{RT}} * t \quad (1)$$

where E_a is the activation energy, n is a scaling factor, R is the gas constant and t is the testing time. By analysing the degradation rates at different temperatures, the E_a and n can be obtained, which are 49kJ/mol and 0.35, respectively, for the module Type I. Therefore, the degradations under different T/RH conditions can be plotted versus the dose function in Fig 2. All devices appear to follow a same degradation curve, which can be modelled by the modified sigmoid function.

2.2 Diode Parameter Degradation versus Dose

The power degradation behaviour on its own does not provide sufficient information to identify the dominating ageing mechanism. Therefore the solar cell equivalent circuit model is used to identify changes in the module behaviour. The diode parameters are extracted from I-Vs [2] measured at different ageing periods and analysed against the dose obtained by Eq(1).

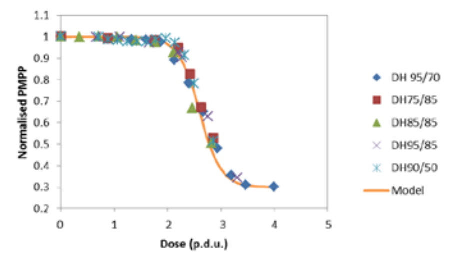

Fig. 2 Power degradation versus humidity dose.

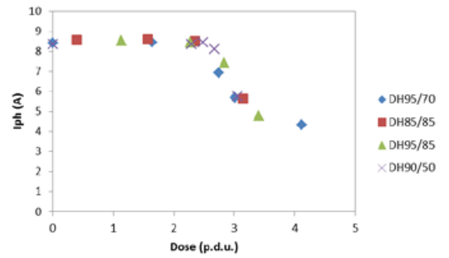

Fig. 3 Photocurrent degradation versus humidity dose.

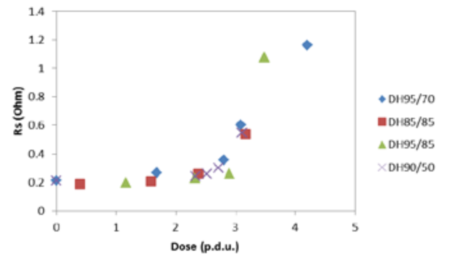

Fig. 4 Series resistance degradation versus humidity dose.

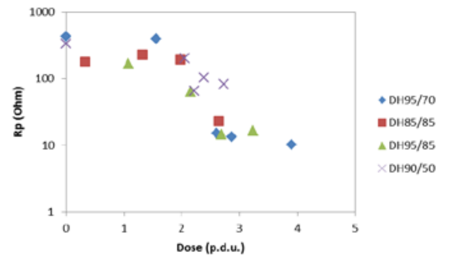

Fig. 5 Parallel resistance degradation versus humidity dose.

For the module type I, the R_S, R_P and I_{ph} are found to be the key parameters which largely determine the power degradation. The changes of the three parameters are plotted versus does function in Fig 3 – Fig 5. It can be also identified from the figures that under different DH conditions, the change rate of parameters are related to the level of stresses. Some parameters start to degrade a few hundred hours earlier than other parameters do, which reveals either different degradation mechanisms or different stages of the degradation.

Each of the parameters follows a similar degradation curve. Comparing these degradation curves to the one of power, one can identify that all parameters stay almost unchanged until certain humidity dose (dose=2, p.d.u.) is seen by modules. The change is firstly seen by R_p, which means the power degradation is driven by degradation of R_p during the first period (dose=2 – 2.5, p.d.u.). During the period (dose=2.5 – 3.5), the I_{ph} and R_s degraded from 8.2A to 4.5A and 0.2Ω to 1.1Ω, which contribute to the reductions in power.

2.3 EL Images

EL images were taken as modules aged. Fig 6 – 7 show the changes in images for Module type I and type II degraded under 95ºC/70%RH at 0h, 2250h and 3750h. Two different degradation patterns are observed. The active cell area of the module type I becomes smaller as the moisture permeates into module from the backsheet. The active area identify locations where the current flowing through and thus it is related to the I_{ph} generation. It is roughly the same time that the I_{ph} started to degrade when the active area became affected.

For module type II, the active cell area is reduced by less than 10% of the total area after ageing. The I_{ph} calculated from its I-Vs shows little degradation. The key parameter for module type II is the diode ideality factor n, which may be related to the cell mismatch in a module. This can be seen from Fig 7 where the brighter and darker cells degraded at different rates.

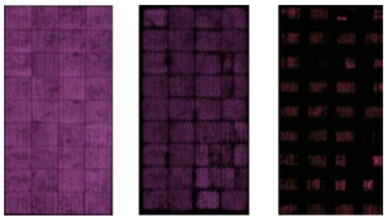

Fig. 6 EL images of Module type I taken at 0h, 2250h and 3750h (from left to right).

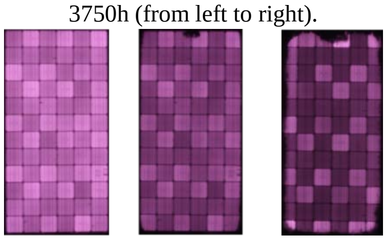

Fig. 7 EL images of Module type II taken at 0h, 2250h and 3750h (from left to right).

4. CONCLUSIONS

The degradations of module power and different diode model parameters are studied in this paper in dependence of the developed humidity dose. It is useful in identifying the key parameter, which causes the power degradation. For the Module type I, the key parameters are R_p, which initiates the ageing, and then the device ageing is driven by the degradations in I_{ph} and R_s.

REFERENCES

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