PV MODULE LIFETIME PREDICTION AND QUALITY ASSURANCE AS ADDRESSED BY SOPHIA

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ABSTRACT: The lifetime of a PV module is critical for PV manufactures, developers and end-users as it directly affects the energy yield and so cost of a PV system. The standards IEC61215, 61646 and 61730 are considered excellent for identification of major design issues, but they do not include sufficient testing to be able to predict outdoor performance and lifetime. The objective of the PV Module Lifetime Prediction work-package in the FP7 project SOPHIA was to investigate a standard for lifetime prediction based on combined stress testing of commercially available PV modules. This paper will describe the work performed in testing three module types beyond the standards mentioned above with the aim of developing a quality assurance sequence for PV modules. The goal of this sequence is to provide a tool to identify failure mechanisms and predict lifetimes for different climatic conditions for different module types.
Keywords: see enclosed list of keywords

1 INTRODUCTION

Commercially available PV modules are typically sold with a 20 year or longer warranty for the power output of the modules. There is no sound evidence, however, that the current standards are enough to validate these warranty claims. The lifetime of a PV module is critical for PV manufactures, developers and end-users as it directly affects the energy yield and so cost of a PV system. The well-known design qualification and safety standards IEC61215, 61646 and 61730 are considered excellent tools to identify major design issues and sufficient to filter out early failure issues, but they do not include sufficient testing to be able to model realistic outdoor performance [1, 2]. Several authors have proposed alternative test sequences with the focus on development of a rating system for PV modules. These proposals include extending the tests described in the IEC standards and the addition of extra tests such as dynamic mechanical loading [3, 4]. The proposed test sequences aim to distinguish between the quality in terms of life-time expectancy of PV modules either rack or roof mounted for a range of climatic conditions. A number of authors have reported modelling results relating degradation in extended testing to expect life-time in the field [5, 6]. The objective of the PV Module Lifetime Prediction work-package in the FP7 project SOPHIA was to investigate and establish the research infrastructure needed to develop a standard for lifetime prediction based on a number of combined stress tests of commercially available PV modules. A test-plan was designed with 14 different test conditions including damp-heat at different temperatures and relative humidity, thermal cycling at different temperatures, combined damp-heat and UV-testing and mechanical testing with preconditioning. The tests were performed on sets of three different types of module including a module with heterojunction cells, a module with a thermoplastic encapsulant and a conventional module. Degradation of the modules was followed by characterisation at intermediate steps during testing. The results will be used to identify and model the degradation mechanism and relate the degradation rate in testing to an expected lifetime in the field. The method used will be put forward as a proposal for a quality assurance standard for PV modules.

2 APPROACH

The SOPHIA project is a collaboration between several European PV institutes with the overall aim of developing the research infrastructure at these institutes that is dedicated to the development of PV technology. In the work-package PV Module Lifetime Prediction, the focus was on the use and development of research infrastructure to investigate degradation mechanisms in PV module and to develop a quality assurance test sequence. A number of proposals for a quality assurance test have been made by other institutes and consortia, mostly based on extension of the current design qualification and safety standards. To provide input for the proposed quality assurance, a large number of climate chamber tests were defined. These are summarised in Table 1. Due to the size of the consortium, the number and range of tests could be extensive; far more than could be performed by a single institute.

Table 1: Description of modules included in testing and the materials used in the modules

Module code	A	B	C
Type of cells	P-type	P-type	N-type hetero-junction
Type of encapsulant	EVA	Thermoplastic	EVA
Type of back-sheet	PET	PET	Moisture blocking

The test included a number of conditions based on the climate chamber tests as described in IEC61215, but performed over a range of temperatures, relative humidity and temperature cycle ranges. The aim of performing tests at different conductions is to determine which stress factor is dominant and, in the case of temperature, to be able to calculate activation energies for degradation mechanisms. Other tests included combined stresses such as UV and damp-heat design to better replicate the stresses seen in the field than the standard climate chamber tests.

Three types of modules were chosen to be subjected to the tests shown in Table 1. The modules were selected to cover a range of module and cell technologies. The most conventional module consisted of a multicrystalline p-type cell interconnected by soldering tabs with a conventional EVA encapsulant and a conventional TPT back-sheet. The second module was similar, but made using an alternative thermoplastic encapsulant. Such encapsulants are becoming more widely available. Their advantages include a higher light transmission than EVA, easier and reversible processing and reduced PID degradation in the field. The third module consisted of heterojunction n-type cells with a low-temperature interconnection, an EVA encapsulant and a moisture blocking back-sheet. This type of back-sheet is needed due to the high sensitivity of the amorphous silicon layer on the cell to moisture. A summary of the module types is given in Table 1.

Table 2: Summary of all the tests performed on the module in this work and the institutes where the tests were performed. UV = ultraviolet light, DH = damp-heat, TC = thermal cycling, ML= mechanical load. For the damp-heat tests, two samples of each module type were tested. The module were characterised at regular interval during testing by IV and EL. The test were performed on two modules of the same type where two test codes are shown

Test code	Test type	Temp. (°C)	RH (%)
M1	Dry UV	60	<5
M2, M3	DH	75	85
M4, M5	DH	85	85
M8, M9	DH	95	85
M10, M11	DH	95	70
M12, M13	DH	90	50
M14	DH + UV/DH	85	55
M15	DH + UV/DH	65	55
M16	TC	-40/85	-
M17	TC	-20/40	-
M18	TC	-40/40	-
M19	DH + TC	-40/40	-
M20	ML 5400 Pa	25	-
M21	ML 5400 Pa	-40	-

Prior to testing, all modules were stabilised according to the requirements as given in IEC61215. This was done by outdoor expose of the modules. Stabilisation was followed by complete characterisation including IV tracing and EL imaging to provide a starting point for the climate chamber tests. The modules were then distributed to the partners performing the tests where they were re-characterised to check for damage during transport. The minimum characterisation requirement was IV tracing and EL imaging. Other characterisation techniques were applied depending on the facilities available at the institute performing the test. In this report only the IV tracing, EL imaging and visual inspection will be reported. The tests were continued until a significant amount of degradation was seen or until the end of the project.

3 RESULTS

Of all the tests performed, the damp-heat tests show the largest difference between the three different module types. These differences are highlighted below.

The type A module shows little degradation up to 1000 hours under all damp-heat conditions including the highest temperature and relative humidity (see Fig. 1).

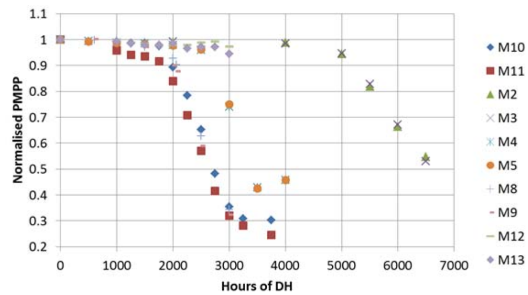

Figure 1: Plot of degradation in damp-heat for module A. The legend correspond to the test codes in table 2

Under the highest temperature (95°C), significant degradation starts soon after 1000 hours, with an acceleration at 2000 hours. A stabilisation is seen after 3000 hours where the module has 30% of its initial power output. At the lowest temperature (75°C), the module remains stable to 5000 hours. The losses are mainly due to increasing fill-factor and lower current. The voltage of the module is unaffected. The influence of differences in relative humidity within the range tested appears to be minimal. EL images of the modules tested at the highest temperature and relative humidity show increasingly dark edges to the cells in the module (see Fig. 2). Yellowing of the metallisation grid on the front of the cell is also seen. This indicates that the metallisation is degraded, possibly by corrosion, so reducing the current and increasing the fill-factor of the module. This degradation pattern is similar to that reported by others for crystalline silicon modules manufactured with EVA [7, 8].

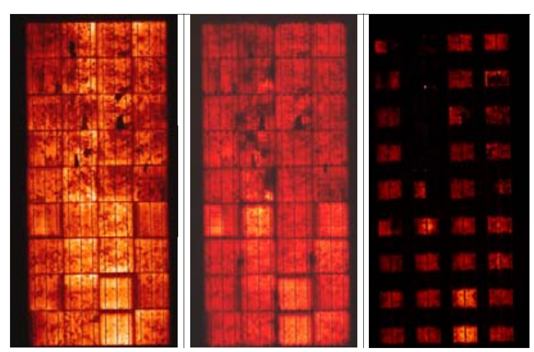

Figure 2: EL images of module A following degradation during damp-heat testing. The left image shown the start condition of the module, the centre image the condition after 2000 hours at 95°C and 85%RH and the right image the condition after 3000 hours. Moisture ingress results in degradation of the metallisation on the cell at the cell

edges resulting in a lower current and higher fill-factor

In UV or UV combined with DH, only a minor degradation in power output is seen for the test time in this work (up to 1500 hours UV, with 2000 hours DH at 85°C and 85%RH). No corrosion or transmission losses are seen in visual inspection or EL imaging. Thermal cycling also causes only minor degradation for module A with a loss in fill-factor depending on the test conditions.

For module B, a different degradation mechanism is observed for module tested in DH above 85°C (see Fig. 3). Below this temperature, the degradation rate is similar to that seen for module A. Above this temperature, the encapsulant starts to melt and can no longer hold the cells and back-sheet in place. The result is catastrophic failure of the module as shown in visual inspection (see Fig. 4).

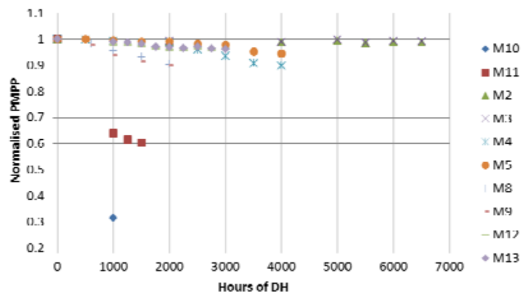

Figure 3: Plot of degradation in damp-heat for module B. The legend corresponds to the test codes in table 2. The module is stable for temperatures at and below 85°C. Above this temperature the module fails catastrophically

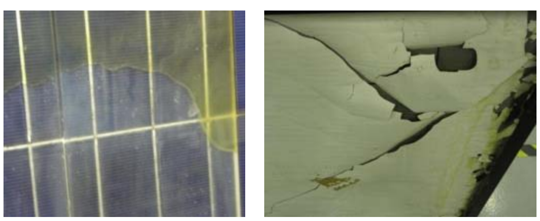

Figure 4: Images showing module B tested above 85°C. The left image shows melted encapsulant on the front of the module glass. The right image shows the rear of the module with the back-sheet fractured by the movement of the encapsulant and encapsulant on the outside of the back-sheet

In UV or UV combined with DH, only a minor loss in current was seen for module B with no corrosion or transmission losses observed. Thermal cycling caused loss in power output after several hundred cycles with crack formation and propagation seen in EL images.

For module C in damp-heat, the module remained very stable with degradation starting between 2000 and 3000 hours at the highest test temperature. Under standard conditions (85°C and 85%RH), little degradation was seen even after 6000 hours of testing. As for module A, changes in temperature are seen to have a larger effect on degradation rate than relative humidity for the ranges tested in this work. EL images show a similar degradation mechanism to module A, though to a much smaller degree. Moisture ingress is seen at the edges of the module and at the opening for the junction with the moisture causing yellowing of the metallisation and dark areas in EL images.

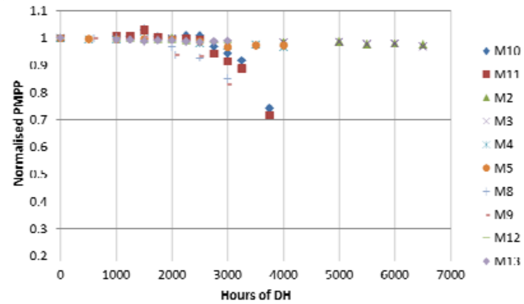

Figure 5: Plot of degradation in damp-heat for module C. The legend corresponds to the test codes in table 2. The module are very stable with degradation at the highest temperatures only seen after 2000 hours

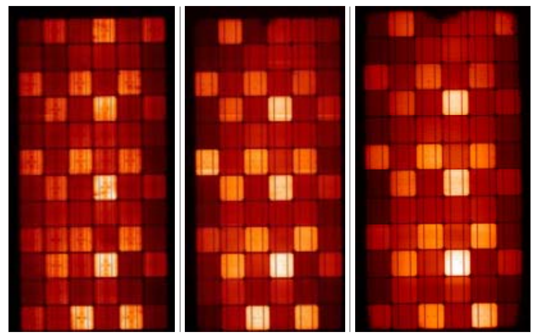

Figure 6: EL images of module C following degradation during damp-heat testing. The left image shown the start condition of the module, the centre image the condition after 2000 hours at 95°C and 85%RH and the right image the condition after 3000 hours. A limited amount of degradation can be seen after 3000 hours with dark areas at the edge of the module and at the location of the junction box

In UV and UV combined with DH, very limited degradation was seen for module C. The module was also found to be very stable in TC and mechanical testing.

4 DISCUSSION AND CONCLUSIONS

The results of climate chamber test outside the standard conditions as defined by IEC61215 show different degradation mechanisms for the three modules tested in this work. In damp-heat, the standard module appears to show a single mechanism related to moisture ingress in to the module resulting in degradation of the metallisation on the front of the cell possibly be corrosion caused by acetic acid generated in the EVA. A reduction in power output is measured associated primarily with an increase in fill-factor and a drop in current generation. The drop in current generation may be related to discolouration of the EVA [9, 10]. The mechanism is accelerated by increasing the temperature at which damp-heat is performed. Changes in relative humidity in the range above 60% appear to have little change on the degradation rate for a given temperature. Degradation of this module in the other tests included in this work is very limited and the time of testing would need to be extended to identify any differentiation between the conditions tested.

For module B in damp-heat, two different degradation mechanisms are seen. At temperatures under 85°C, very little degradation can be measured and the module appears more stable than module A. The thermoplastic encapsulant does not produce an acid on degradation and protects the cell metallisation better from corrosion. Above 85°C the encapsulant loses its integrity and starts to flow. This results in shifting of the cells in the module and cracking of the back-sheet. The module loses most of its power in a short period of time. A module with this encapsulant may get through the standard tests where the temperatures are kept below 85°C, but in the field they may be exposed to temperature close to or higher than this under less than optimal conditions resulting in failure of the module. As for module A, the other tests showed little accelerated degradation for this module type.

For module C, the degradation rate in damp-heat is very low. Under standard conductions the module remains stable up to 7000 hours. This is a result of the use of a moisture-blocking back-sheet and edge sealing. This is required to protect the heterojunction cells in the module. The module appears to be over engineered for the standard conditions that it would be exposed to during climate chamber testing. As for module A, the degradation rate is increased by increasing the temperature during damp-heat, whereas the moisture level appears to have little effect for the same temperature. As for the other two modules, the other test conditions had little distinguishing effect on the degradation rate of the module.

Overall the work has provided a large amount of test data which will be used to model the degradation rate with the aim of extracting an activation energy for a particular degradation mechanism. Based on this modelling a test sequence of quality assurance will be proposed and evaluated using the same modules used in this work. Results of modelling and the initial evaluation of the proposed test sequence will be presented at this conference.

The work has also demonstrated the value of a large project with several partner institutes, because the results received in this work-sharing manner fit together very well. The number of tests and logistics would have made an experiment of this size impossible to be performed by a single institute within such a short time. Spreading the tests between several institutes makes this feasible. It also allows the institutes to learn from each other's approach to testing and characterisation and highlights the need for more standardisation of this type of test.

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