Towards Service Lifetime Prediction of Photovoltaic Modules

a joint effort within the Photovoltaic European Research Infrastructure (SOPHIA) project

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Abstract:

The energy yield during PV module lifetime is crucial for PV manufacturers, developers and end-users. The well-known IEC 61215 and 61646 qualification do an excellent job of identifying design, materials and process flaws that could lead to premature field failures, but do not yield sufficient information which can be used to model realistic outdoor performance. A service life-time prediction requires an understanding of wear-out mechanisms and how they are progressing in the presence of different environmental stresses. A series of durability experiments were designed to explore progression of different ageing mechanisms in relation to different severity and combination of environmental stresses. This work is carried out by a number of research teams under the framework of the Photovoltaic European Research Infrastructure (SOPHIA) project.

The experiments were carried out on a number of crystalline silicon commercial modules with different types of encapsulants and backsheets. Different stresses were imposed well in excess of normal certification timescales. The progression of ageing was monitored by several characterisation methods.

This poster reports the degradation in the power. All devices would pass certification, though very different ageing behaviour were observed, which depends strongly on the module type, possibly due to the backsheet. The most differentiation of power degradation showed in damp-heat, but other tests also showed deteriorations in power.

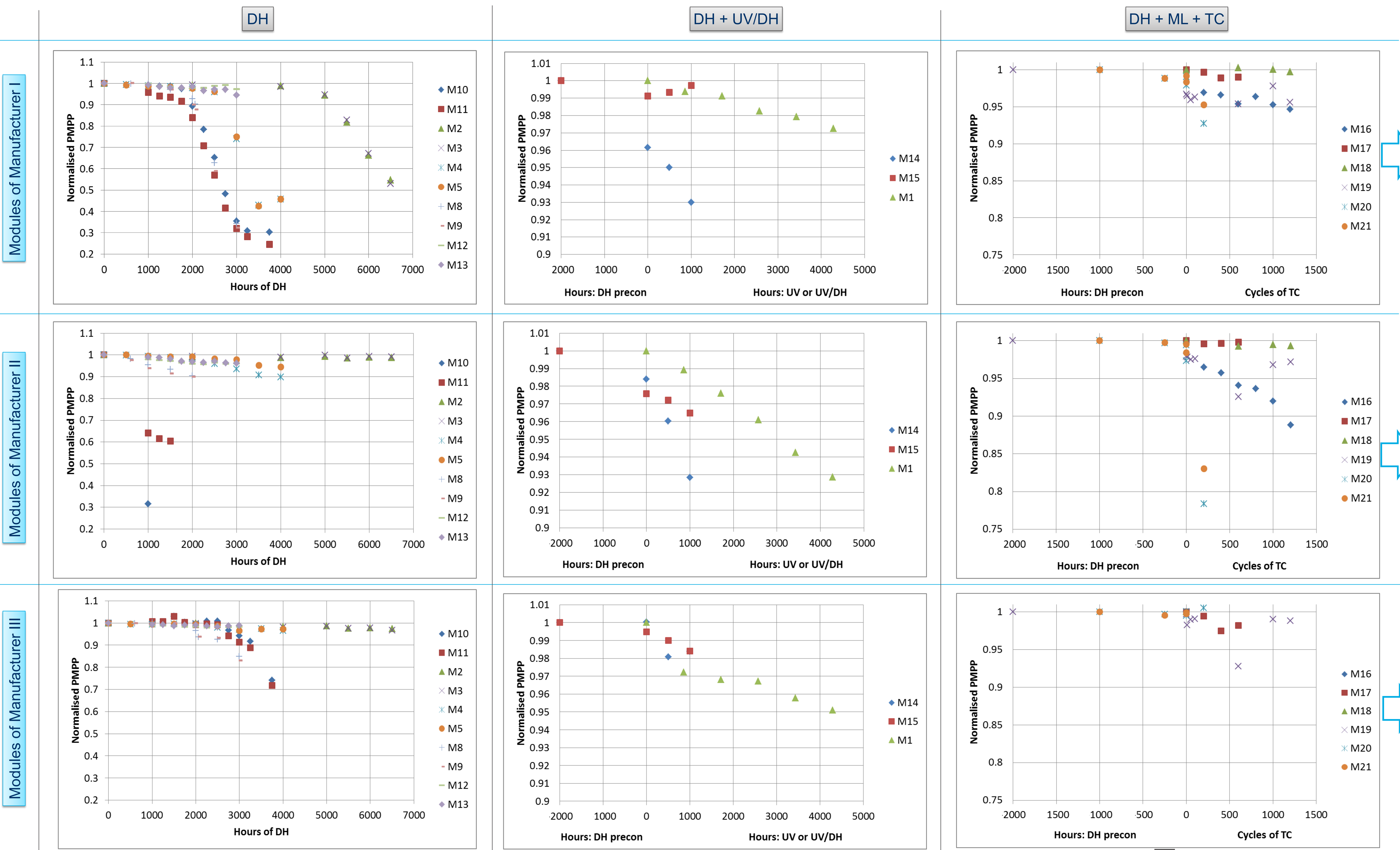
Summary of tests within SOPHIA project

Module No.	Test lab	Test type	T [ºC]	R.H. [%]	UV	Test time intervals [hours] and number of cycles
1	FhG-ISE	Dry UV exposure	~60	<5	140 W/m²	UV 120, 240, 360, 480, 600 kWh/m²
2,3	FhG-ISE	Damp-heat (DH)	75	85		DH 2000, 4000, 5000, 5500, 6000, 6500, 7000, 7500, 8000
4,5	AIT	Damp-heat (DH)	85	85		DH 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000
6,7	ECN	Damp-heat (DH)	95	95		
8,9	INES	Damp-heat (DH)	95	85		DH 600, 1000, 1500, 2000, 2500, 3000
10,11	CREST	Damp-heat (DH)	95	70		DH 1000, 1250, 1500, 1750, 2000, 2250, 2500, 2750, 3000, 3250, 3750
12,13	ENEL	Damp-heat (DH)	90	50		DH 1000, 1250, 1500, 1750, 2000, 2250, 2500, 2750, 3000
14	FhG-ISE	Damp-heat followed by UV exposure (DH + UV/DH)	85 (T_{mod})	55	180 W/m²	DH 2000, UV/DH 500, 1000, 1500, 2000
15	FhG-ISE	Damp-heat followed by UV exposure (DH + UV/DH)	65 (T_{mod})	55	180 W/m²	DH 2000, UV/DH 500, 1000, 1500, 2000
16	AIT	Thermal cycling (TC)	-40/+85			TC 200, 400, 600, 800, 1000, 1200
17	RES	Thermal cycling (TC)	-20/+40			TC 200, 400, 600
18	FhG-ISE	Thermal cycling (TC)	-40/+40			TC 600, 1000, 1200, 1400, 1600
19	FhG-ISE	Damp-heat followed by thermal cycling (DH + TC)	-40/+40			DH 2000, TC 10, 50, 100, 600, 1000, 1200, 1400, 1600
20	AIT	Mechanical loading (ML) 5400Pa	25			DH [85ºC/85%r.h.] 750,1000, ML 1hr, TC 200
21	AIT	Mechanical loading (ML) 5400Pa	-40			DH [85ºC/85%r.h.] 750,1000, ML 1hr, TC 200

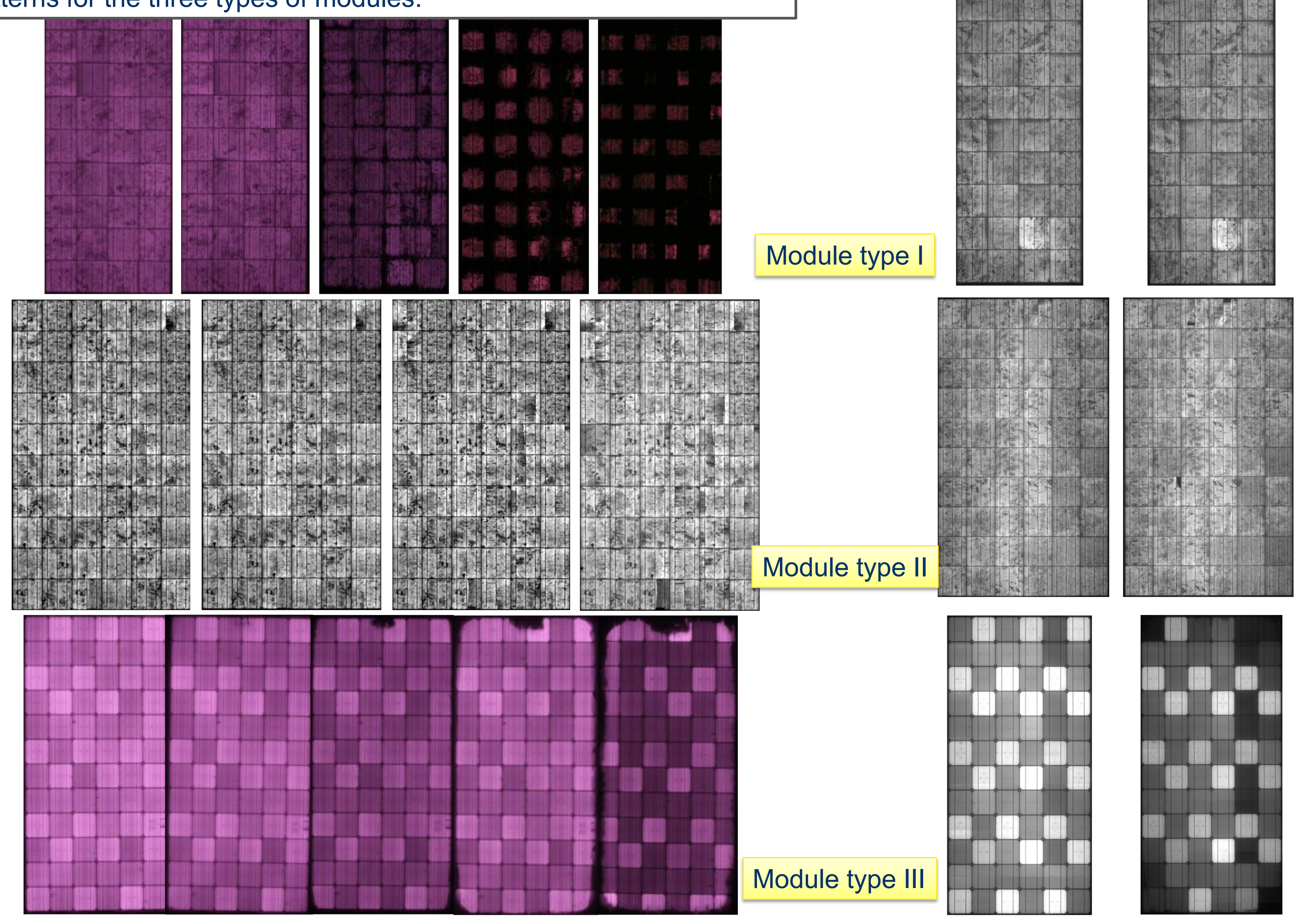
Modules used for testing are commercial modules from three manufacturers

Manufacturers	I	II	III
Type of cells	P-type homojunction	P-type homojunction	N-type heterojunction
Type of encapsulant	EVA	Thermoplastic	EVA
Type of backsheet	Without aluminium moisture barrier	Without aluminium moisture barrier	With aluminium moisture barrier

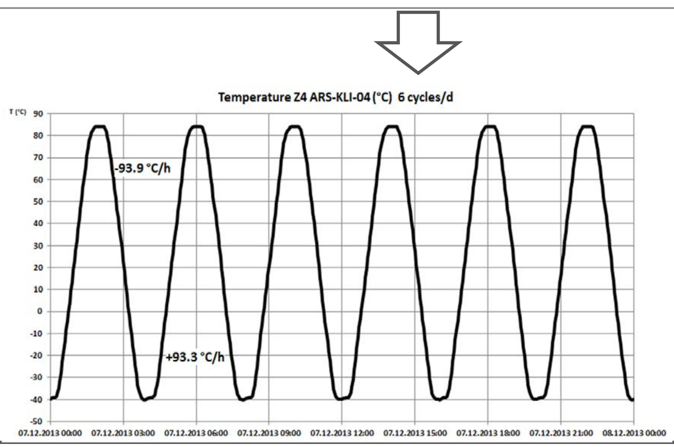
Results: P_{mpp} degradation of the three types of modules under different tests



EL images over DH test (0-4000h). DH induced different degradation patterns for the three types of modules.

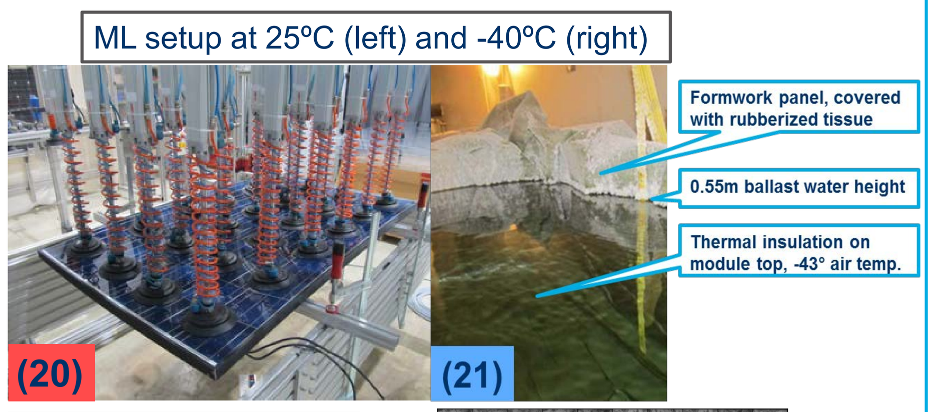


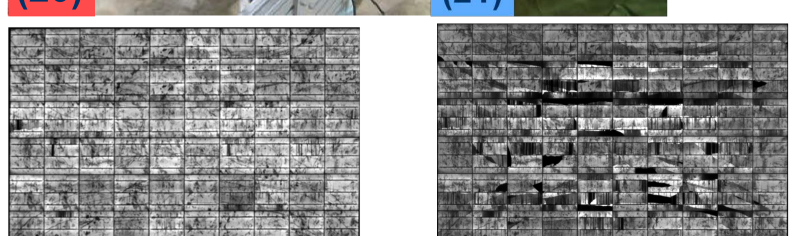
EL images before and after DH+UV. Similar degradation pattern for the three modules



Temperature ramp rate is believed to be crucial for TC, max 100ºC/hour

ML setup at 25ºC (left) and -40ºC (right)





EL images before and after TC that was followed by ML

Summary of degradation behaviour of three types of modules

- DH caused P_{mpp} degradation after 1000 – 4000hrs depending on the levels of T and RH. Losses were mainly due to decreasing I_{sc} and FF (potentially recombination losses, shunting, grid corrosion, increase in series resistance); V_{oc} was not affected by DH. Typical DH ageing.
- UV or DH + UV/DH caused minor degradation in P_{mpp}, which was due to I_{sc} losses. No apparent corrosion or transmission losses due to discoloration.
- TC caused minor P_{mpp} degradation, which was due to the FF losses.

- DH temperature above 90ºC, encapsulant lost structural integrity. This was observed for modules M8, M9, M10, M11, M12, M13 at three institutes. However, not much degradation at lower T.
- UV or DH+UV/DH caused minor degradation in P_{mpp}, which was due to I_{sc} losses. No corrosion, transmission losses due to discoloration.
- TC after DH+ML caused more severe P_{mpp} degradation than DH+TC or TC only. This was due to crack creation and propagation.

- DH caused P_{mpp} degradation at 95ºC after 2000 – 3000hrs.
- The back-sheet was a better moisture barrier and significantly reduced the rate of water ingress. Water ingress was observed starting from the areas around junction box and module corners and edges.
- UV also caused minor P_{mpp} degradation due to discoloration.
- Very stable to stresses of TC and ML. Result of M19 at 600 cycles was due to problems with STC measurement, not due to the ageing test.

Conclusions and future work:

- Module type I degraded severely during extended DH stresses. Module type II were stable to DH provided that the temperature was kept below 85ºC. Higher temperature would cause early failure. Module type III might have similar power degradation pattern as Module type I. However, it has a slower rate of moisture ingress due to an aluminium barrier in the backsheet.
- The degradation pattern (as identified in EL) of Module type I due to cumulative build up of acetic acid has not been seen under outdoor operation.
- DH + UV accelerated the decomposition rate of EVA if comparing Module types I and III results of DH+UV/DH to their results of DH only, respectively.
- Module type II degraded the most by mechanical stresses, whereas Module type III were relatively stable. ML followed by TC caused faster degradation to Modules I and II due to crack creation and propagation.
- Further sequential tests of UV followed by DH and ML will be carried out in order to evaluate the combined effects of tests.
- To model module performance under various realistic outdoor environments, using combination of tests with careful design of testing sequence may be possible.