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Supporting Information

A full overview of international standards assessing the long-term stability of perovskite solar cells

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Table S1 Summary of the reviewed standards for photovoltaics

Designed for	**Name**	
Terrestrial photovoltaic modules	IEC 61215-1 (Vers. 2016)	Design qualification and type approval – Part 1: Test requirements
Crystalline silicon	IEC 61215-1-1 (Vers. 2016)	Special requirements for testing of crystalline silicon photovoltaic modules
CdTe	IEC 61215-1-2 (Vers. 2016)	Special requirements for testing of thin-film CdTe based photovoltaic modules
Amorphous silicon	IEC 61215-1-3 (Vers. 2016)	Special requirements for testing of thin-film amorphous silicon based photovoltaic modules
CIGS	IEC 61215-1-4 (Vers. 2016)	Special requirements for testing of thin-film CIGS based photovoltaic modules
Crystalline solar cells	IEC 61215-2 (Vers. 2016)	Design qualification and type approval - Part:2 Test procedures
Photovoltaic modules	IEC 62716 (Vers. 2013)	Ammonia corrosion testing
Crystalline silicon	IEC TS 62804-1 (Vers. 2015)	Test methods for the detection of potential-induced degradation

Table S2 Summary of all test performed in the IEC 61215. Copyright © 2016 IEC Geneva, Switzerland. www.iec.ch

Test	Conditions
Visual inspection	Visual inspection to detect any visual defects that may cause a risk loss, including power output.
Maximum power determination	Measurement of I-V curves at a specific set of irradiance and temperature between 25 and 50 °C and an irradiance between 700 W/m^2 and 1100 W/m^2 using natural sunlight or a class BBA or better simulator
Insulation test	For modules with a system voltage greater than 50 V d.c., dielectric withstand at 1 000 V d.c. + twice the maximum systems voltage for 1 min, followed by insulation resistance measurement at 500 V d.c. or maximum systems voltage for 2 min. For modules with a system voltage less than 50 V d.c., the test voltages are 500 V d.c.
Measurement of temperature coefficients	Temperature coefficients for the current (α), voltage (β) and peak power (δ). See IEC 60891 for more Information and IEC 60904-10 for temperature coefficients at different irradiance levels.
Measurement of nominal module operating temperature	Module operating near maximum power point Total solar irradiance: 800 W/m^2 Ambient temperature: 20 °C Wind speed: 1 m/s
Performance at standard test condition and nominal module operating temperature	Cell temperature of 25 °C at STC and module temperature at nominal module operating temperature Irradiance: 1000 W/m^2 and 800 W/m^2 with IEC 60904-3 reference solar spectral irradiance distribution
Performance at low irradiance	Cell temperature: 25 °C Irradiance: 200 W/m^2 with IEC 60904-3 reference solar spectral distribution
Outdoor exposure test	60 kWh/m^2
Hot-spot endurance test	Exposure to 1000 W/m^2 irradiance in worst-case hot-spot condition
UV preconditioning	15 kWh/m^2 total UV irradiation in the wavelength range from 280 nm to 400 nm with 3 % to 10 % UV irradiance in the wavelength range from 280 nm to 320 nm at 60 ± 5 °C
Thermal cycling test	50 or 200 cycles from -40 °C to 85 °C with current as per technology specific part up to +80 °C
Humidity freeze test	10 cycles from 85 °C, 85 % RH to -40 °C with circuitry continuity monitoring
Damp heat test	1000 h at +85 °C, 85 % RH
Robustness of termination	Test of junction box retention and cord anchorage
Wet leakage current test	Test voltage increase at a rate not exceeding 500 V/s to 500 V or the maximum system voltage for the module, whichever is greater. Maintain the voltage at the level for 1 min.
Static mechanical load test	Three cycles of uniform load specified by the manufacturer, applied for 1 h to front and back surfaces in turn. Minimum test load: 2400 Pa

Hail test	25 mm diameter ice ball at 23,0 m/s, directed at 11 impact locations
Bypass diode thermal test	Bypass diode thermal test: 1 h at I_{SC} and 75 °C 1 h at 1,25 times I_{SC} and 75 °C Bypass diode functionality test At 25 °C perform voltage and current measurements
Stabilization	Three consecutive maximum output power measurements P1, P2 and P3. Output power is determined under standard test conditions.

Table S3 Locations to be shoot with ice balls as described in the hail test. Some locations may require larger ice balls which are given in Table S4. Copyright © 2016 IEC Geneva, Switzerland. www.iec.ch

Shot No.	Location
1	Any corner of the module window, not more than one radius from the module edge.
2	Any edge of the module, not more than one radius from the module edge.
3, 4	Over the circuit near the interconnects (i.e. cell interconnects and bus ribbons).
5, 6	Over edges of the circuit (e.g. individual cells).
7, 8	On the module window, not more than half diameter of ice ball from one of the points at which the module is mounted to the supporting structure.
9, 10	On the module window, at points farthest from the points selected above.
11	Any points which may prove especially vulnerable to hail impact like over the junction box.

Table S4 Ice ball size, masses, and velocity. Hail prone locations may require larger sizes therefore different sizes are given. Copyright © 2016 IEC Geneva, Switzerland. www.iec.ch

Diameter (mm)	Mass (g)	Test velocity (m/s)
25	7.53	23.0
35	20.7	27.2
45	43.9	30.7
55	80.2	33.9
65	132.0	36.7
75	203.0	39.5

Supplementary Note 1 - Detailed IEC 61215 test

The degradation after each sequence shown in Figure 2 should not be more than 5% times a reproducibility factor that is technology specific. Following equation is used to determine stable modules:

$$P_{max}(after\ the\ test\ sequence) \geq 0.95\ P_{max}(initial)(1 - r)$$

r is the reproducibility of the modules which is determined for each certification. r should be lower than 2% for amorphous silicon, CIGS, CdTe and lower than 1% for crystalline silicon. r is verified by comparing the control modules from sequence A after the initial and after the final stabilization, which is measured after completing all tests. If r exceeds the technology specific limit for the control module, the technology-specific limit for r is taken.

References

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