MEA Renewable Energy Summit 2021

PV module safety and performance standard requirements in extreme environments

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Gulf Renewable Lab

- GRL is a UL-GCC Labs JV company.
- GCC Labs has a strong group of shareholders.
- UL drives the trusted renewable energy in the region and fulfill the demand to localize renewable energy expertise

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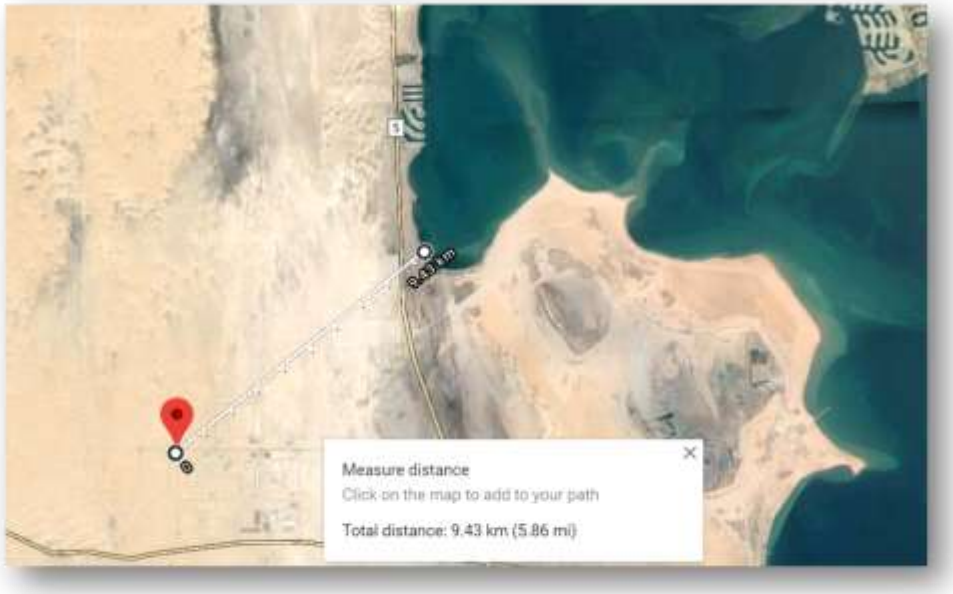
GRL Test Field

- Ambient temperature, the lowest could reach 5 °C and can go high up to 48 °C
- Humidity average in the area reaches 80%
- Opened and sandy area
- Very close to the sea

GRL Test Field



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PV module specifications upgrade for extreme environmental conditions study

Study objectives

1. Understand ambient and module temperatures within the Kingdom

2. Lean more about reoccurring events like sand/dust storms and hailstorms

3. Evaluate the performance and behavior of different technologies of PV modules.

Study Overview

- More than 100 modules
- Six different technologies were tested
- Power and weather data recorded for one year
- Supplemental monthly measurements.

Study Overview

Modules exposed to actual harsh environment for 12 months and monitored for all period.

Monthly measurements were conducted on the modules to track the behavior of the modules.

Two comprehensive tests stage were applied after 4 months and after 12 months.

Results and recommendations after end on the project period.

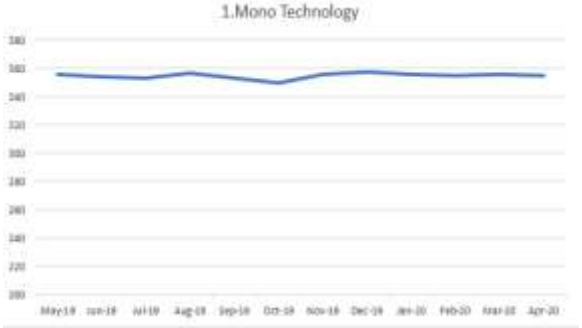
Results And Recommendation

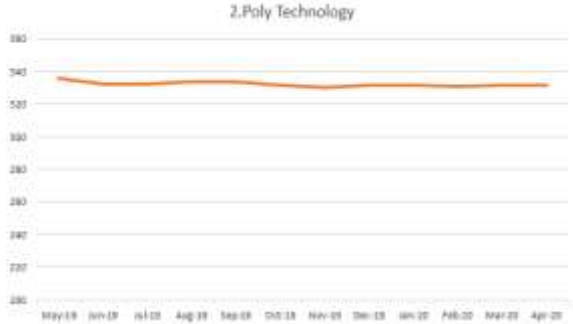
Results

I-V measurement at STC

Testing criteria:

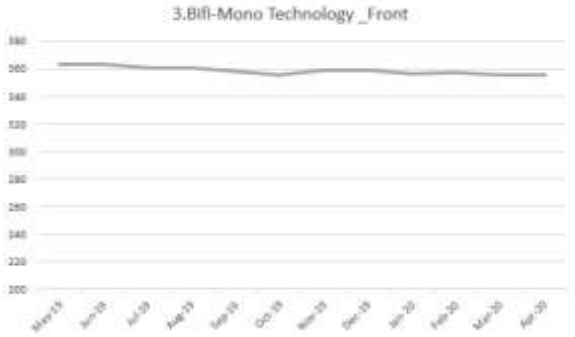
1. Monthly indoor test was performed according to MQT 06.1 in IEC 61215-2
2. Modules have been cleaned

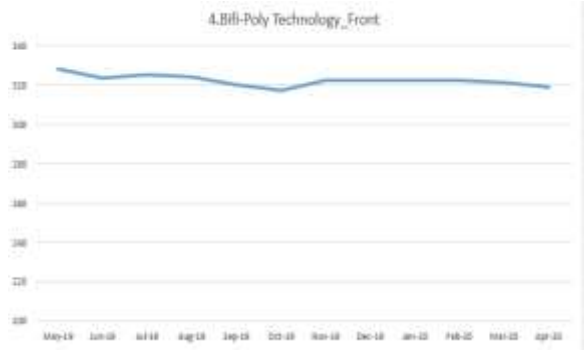


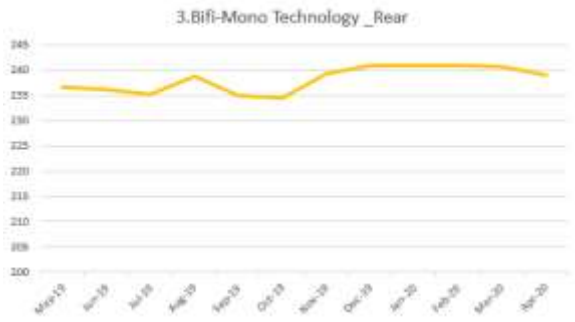


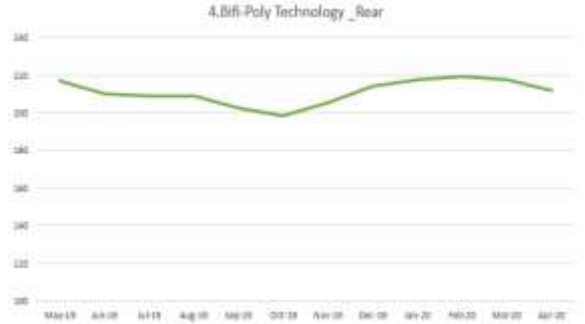
Results

I-V measurement at STC









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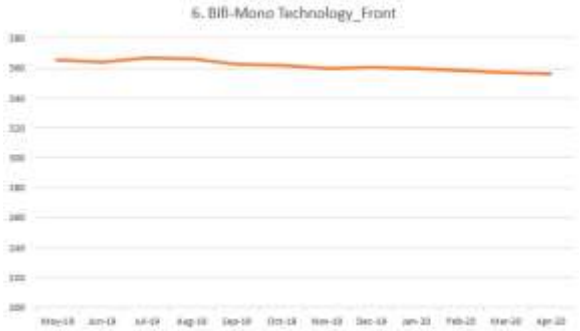
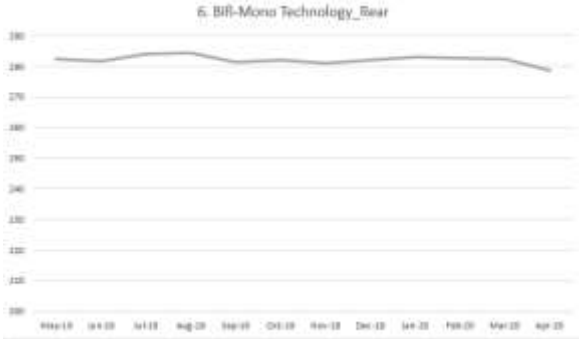
Results

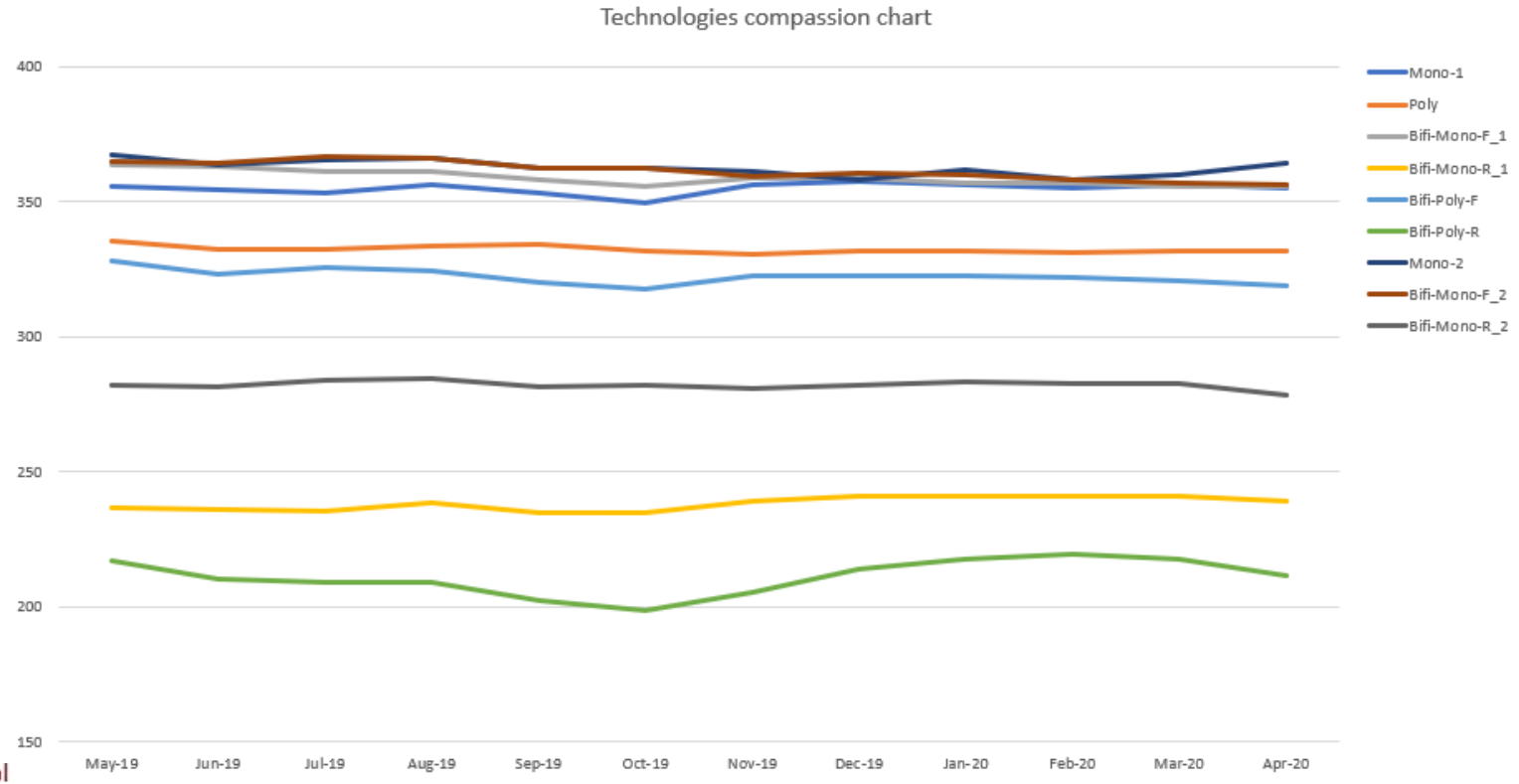
I-V measurement at STC





Results

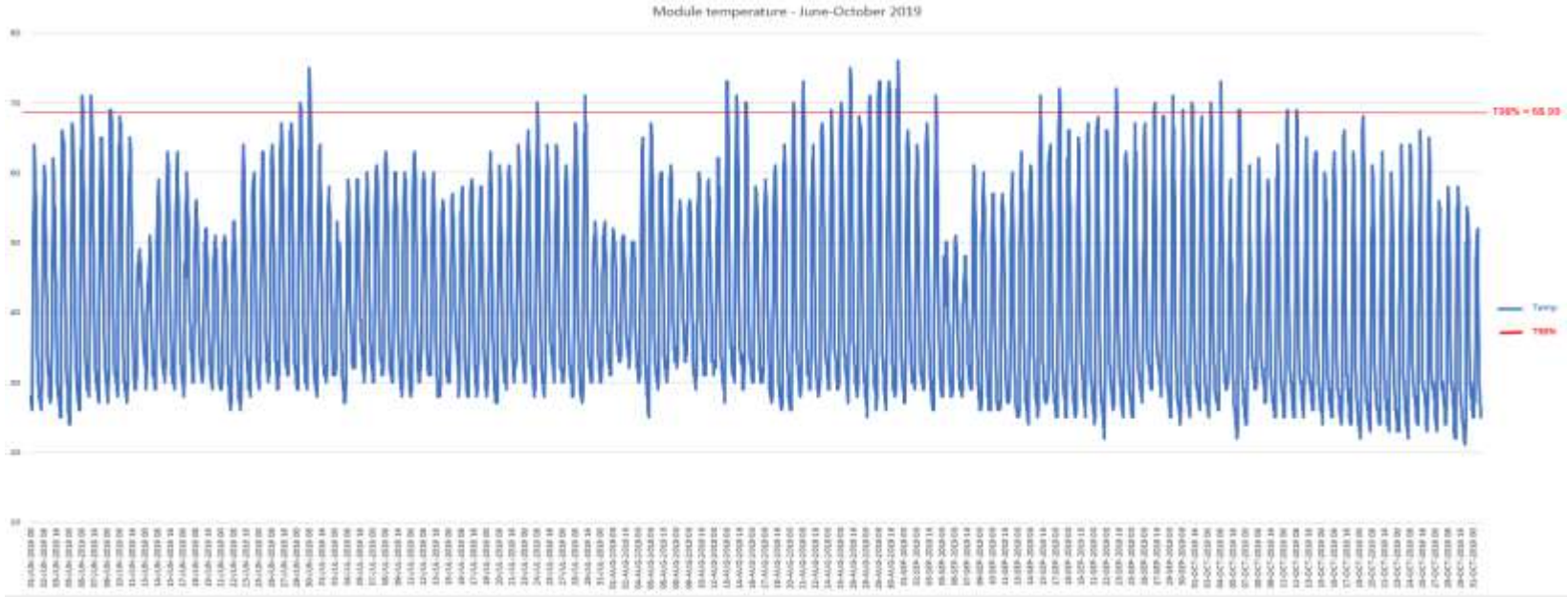
I-V measurement at STC



Results

Module Temperature

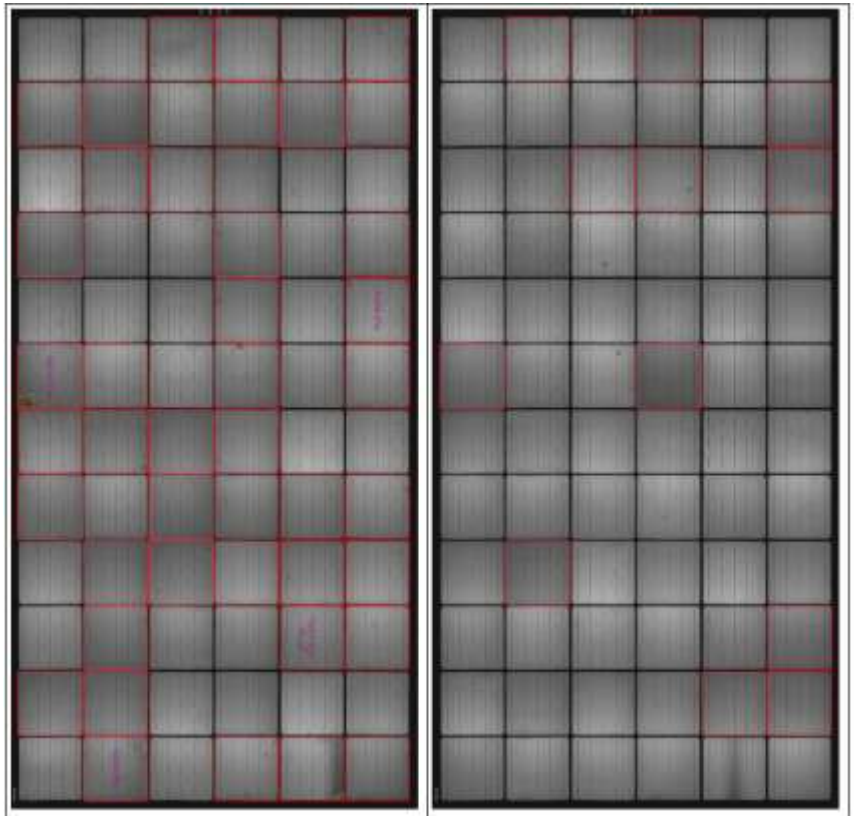
The Data Analysis was done based on hourly average values taken over the whole time period of measurement. 2% of the highest values were removed to get TR98%R values as indicated below.



Results

Electroluminescence Test

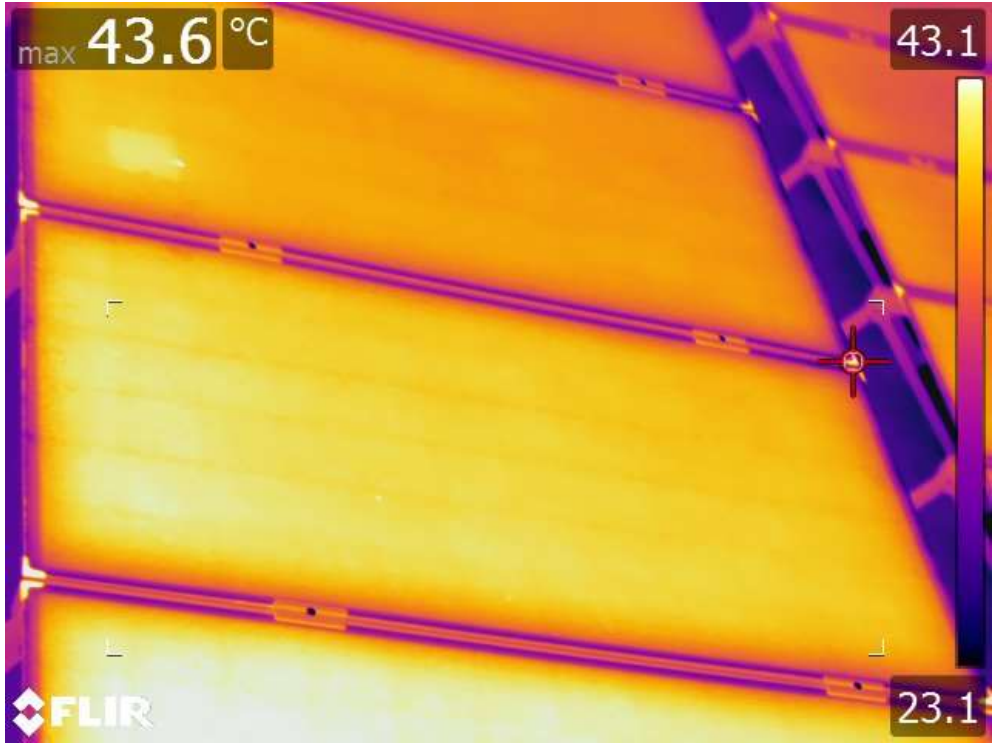
Due to many reasons such as (transportation, installation, sandstorms or and wind load vibration) invisible micro cracks have been found on many modules through electroluminescence (EL) testing. To detect degradation of power performance in PV modules, we recommended to do annual inspections and testing of the modules including (I-V measurements, EL and IR) tests, especially for utility scale PV systems with significant wind loads.



Results

Infrared Test (IR)

IR surveys have been conducted for all modules after 4 months and at the end of project to check for hotspots during the project period.



Recommendations

- Module temperatures of approximately 70°C or less, the existing test and certification standards issued by the IEC are sufficient in their present form and testing requirement.
- Center areas in a large open-rack-style PV arrays may have higher temperature and Level 1 80°C or less testing may be a reasonable consideration for these situations, however, these effects are minimized by providing thermal breaks between modules (2.5 cm) and higher temperature was observed on stacking three modules in landscape orientation or two in portrait orientation.

Recommendations

Soiling can affect module temperature, often decreasing it due to the blocked irradiance to the cells and is worth further investigation.

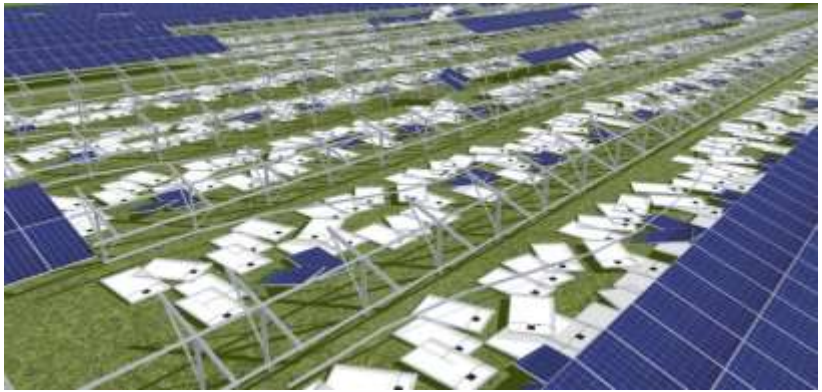
Recommendations

Due to sand movement, contamination to connectors may occur and to avoid such issue we recommend using connector cap during shipping and installation.

Recommendations

Due to expansion/contraction of the metal structure, crack of module glass may occur for frameless module design and to avoid such damage module should be given enough space while installation for stretching and shrinking of structure material.

Manifestations of material durability…



UL Standards Development Addressing PV Market Needs

North American Leader

1986 – UL1703 PV Modules and Panels
1999 – UL1741 Inverters and Converters
1999 – SU 1279 Solar Collectors

2005 – UL 4703 PV Wire
2007 – SU 2579 Low Voltage Fuse Holders
2007 – SU 5703 Max Operating Temp
2008 – SU 8703 Concentrator PV Modules
2010 – UL 2703 Mounting Systems
2010 – SU 4248-18 Fuse Holders
2010 – UL 489B Circuit Breakers
2010 – UL 6703/A Connectors
2010 – SU 98B Dead-Front Switches

2011 – SU 1699B Arc Fault Protection
2011 – UL 3703 Solar Trackers
2011 – UL 3730 Junction Boxes
2011 – SU 508i Disconnect Switches
2011 – SU 9703 Wiring Harnesses
2012 – UL 4730 Name Plate Rating
2014 – UL 62109-1 Power Converters
2016 – UL 61215 Terrestrial PV Modules – series
2016 – UL 1741SA Advanced Inverter Testing
2016 – UL 9540 Energy Storage Systems and Equipment
2017 – UL 61730 PV Module Safety (harmonized)
2018 – UL 9540a Thermal Runaway Fire in BESS
2018 – SU 3741 PV Hazard Control

2000 > 2010 > 2020

International Collaborator

IEC 61215 Module Type Qualification - Series
IEC 61724 System performance monitoring
IEC 61730-1/2 Module safety
IEC 61853-1/2 Module performance
IEC 62093 BOS design Qualification
IEC 62109-1/2/3/4 Safety of Power Converters
IEC 62446 System commissioning and Inspection
IEC 62509 Battery charge controller performance
IEC 62548 PV array design requirements
IEC 62738 PV plant guidelines
IEC 62804 System voltage durability for modules
IEC 62938 Snow load testing
IEC 62947 Energy performance
IEC TS 60904-1-2 Measurement for Bifacial Modules

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PV Module Testing Services Required for PV Projects

Safety

- Demonstrate non-hazardous failure conditions

Compliance to Standards

- UL/IEC 61730
- CSA 61730
- *UL1703/ORD-1703**
- Other market access (CB scheme)

* sunsetting

Quality

- Consistency in production

Compliance to Standards

- Factory Inspection according to IECRE OD-405 and IEC TS 62941.

Performance

- Maintain electrical ratings after stress tests

Compliance to Standards

- UL/IEC 61215 series
- PAN File
- IAM
- LID/LeTID
- PID
- DML
- Corrosion
- Abrasion/dust

Durability

- Performance after exposure to extended duration stress

Standards Based **

- Temperature Cycle (TC)
- Humidity-Freeze (HF)
- Damp Heat (DH)
- Dynamic Mech Load (DML)
- Ultra-Violet (UV)

** per IEC TS 63209

Reliability

- Lifetime performance as expected

Best Practice

1. Qualification Test
   - Safety
   - Performance
   - Durability
2. Factory Inspection
3. Batch Testing
4. On-site Evaluation
5. *Plant Inspection **
6. *Operational Performance **

** System level assessment*

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“Typical Environments” Assumed in PV Standards

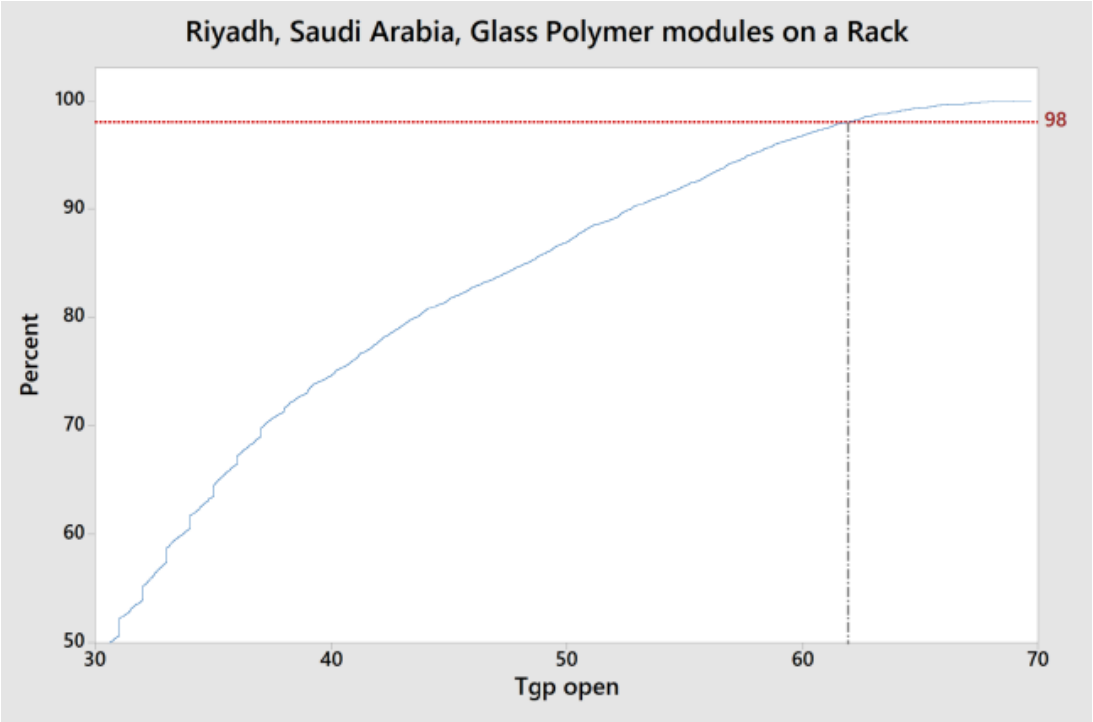
Factor	Standards Assumption
Air temperature	-40ºC to +40ºC
Module temperature	-40ºC to +70ºC (T_{98th})
Wind load	2400 Pa (minimum static test load) 1000 cycles x 1000 Pa dynamic mechanical load
Snow load	2400 Pa (minimum static test load)
Corrosivity	Mild to moderate
Abrasion resistance	Not typically addressed
Hail	Minimum: 25 mm hail, 7.53 m/s (typical) Optional: up to 75 mm hail, 39.5 m/s (rare)
Mounting	Fixed roof-mount, fixed or tracking ground-mount

98th Percentile Temperature (T_{98th})

T_{98th} Definition:

- When temperature data from a varying temperature process are placed into rank order, the 98th percentile temperature represents a temperature that is larger than 98 percent of remaining temperatures and is exactly met or exceeded only 2% of the time.
- The temperature that a module would be expected to equal or exceed for 175.2 hours per year.

- PV standards assume T_{98th} is 70°C or less; examples:



98th Percentile Temperature (T_{98th}) > 70°C – IEC TS 63126

Provides guidance for modifying standard tests:

- IEC 61215, Module performance
- IEC 61730, Module safety
- IEC 62790, Module jboxes
- IEC 62852, Module connectors
- ~~IEC 62930, Module cables~~
- ~~IEC 62979 Bypass Diode - Thermal Runaway Test~~
- *IEC TS 62788-1-7, Optical durability of transparent materials (new)*
- *IEC TS 62788-2, Polymeric frontsheets and backsheets (new)*

To take into account modules operating at high temperatures due to:

- Ambient air temperatures in excess of 40°C
- Mounting systems that restrict cooling.

By modifying individual tests contained in those standards through

- Increasing testing temperatures, or
- Increasing testing duration, or
- Modifying test parameters, such as current injection.

Quantifying the 98th Percentile Temperature (T_{98th})

Basic Form of Equation

$$T_{module} = Irradiance \times e^{(a+b\times WindSpeed)} + T_{ambient}$$

Empirically determined

Module to Cell Temperature

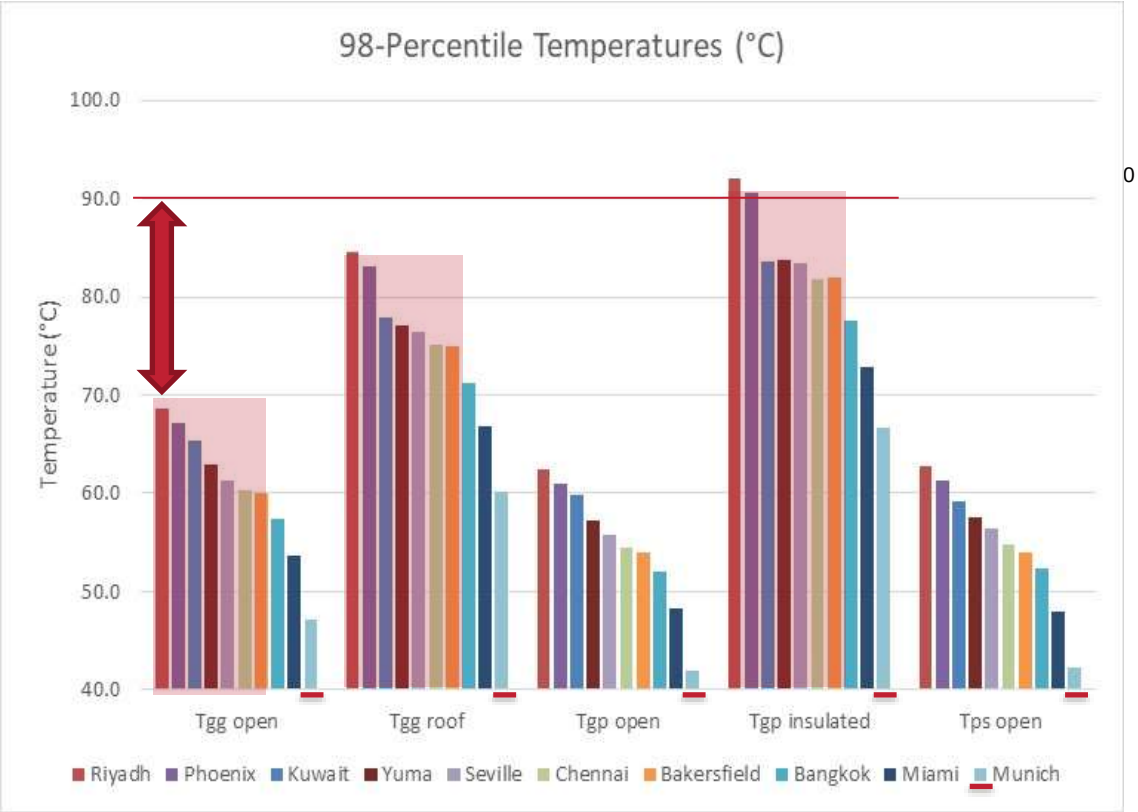
$$T_{cell} = T_{Module} + \frac{G}{1000W/m^2}\Delta T$$

Module Type	Mount	a	b	ΔT (°C)	
Glass/cell/glass	Open rack	-3.47	-.0594	3	→ Tgg open
Glass/cell/glass	Close roof mount	-2.98	-.0471	1	→ Tgg roof
Glass/cell/polymer sheet	Open rack	-3.56	-.0750	3	→ Tgp open
Glass/cell/polymer sheet	Insulated back	-2.81	-.0455	0	→ Tgp insulated
Polymer/thin-film/steel	Open rack	-3.58	-.113	3	→ Tps open

SAND2004-3535
Unlimited Release
Printed August 2004

98th Percentile Temperature (T_{98th})

- Modules in an open-rack" installation ~ 70ºC (T_{98th}) – standard tests apply in most climates
- Modules in close roof / insulated back installations may have T_{98th} > 70ºC
  - New 63126 Classifications
  - T_{98th} </= 80ºC: "Level 1"
  - T_{98th} </= 90ºC: "Level 2"



How do we apply Level 1 and Level 2?

Extreme Environments: High PV Temperatures

IEC TS 63126

Standard	Test Ref	Test Name	Original Requirement $T_{98\%}$ = 70 °C or less	Proposal - Level 1 $T_{98\%}$ > 70 °C to ≤ 80 °C	Proposal - Level 2 $T_{98\%}$ > 80 °C to ≤ 90 °C
module level tests					
IEC 61215	MQT 09	Hot-spot endurance test	(50 ± 10) °C	+10 °C, (60 ± 10) °C	+20 °C, (70 ± 10) °C
	MQT 10	UV preconditioning	(60 ± 5) °C	+10 °C, (70 ± 5) °C	+20 °C, (80 ± 5) °C
	MQT 11	Thermal cycling test	(85 ± 2) °C	+10 °C, (95 ± 2) °C	+20 °C, (105 ± 2) °C
	MQT 18	Bypass diode testing chamber Part 1 Part 2	(75 ± 2) °C I_{SC} 1.25 * I_{SC}	+15 °C, (90 ± 2) °C 1.15 * I_{SC} for diode T 1.4 * I_{SC} for stress	+25 °C, (100 ± 2) °C 1.15 * I_{SC} for diode T 1.4 * I_{SC} for stress
IEC 61730	5.5.2.3.3	RTI/RTE/TI	min RTI 90 °C	min RTI 100°C	min RTI 110 °C
	MST 22	Hot spot endurance	(50 ± 10) °C	+10 °C, (60 ± 10) °C	+20 °C, (70 ± 10) °C
	MST 37	Material creep test	105 °C	no change	110 °C
	MST 51	Thermal cycle	(85 ± 2) °C	+10 °C, (95 ± 2) °C	+20 °C, (105 ± 2) °C
	MST 54	UV test	(60 ± 5) °C	+10 °C, (70 ± 5) °C	+20 °C, (80 ± 5) °C
	MST 56	Dry heat conditioning	105 °C	no change	110 °C
component level tests					
IEC 62788-1-7 (encapsulant, performance)	8	Optical durability encapsulants	IEC TS 62788-7-2 (A3 cond.)	IEC TS 62788-7-2 (A4 cond.)	IEC TS 62788-7-2 (A5 cond.)
IEC TS 62788-2* (backsheet and frontsheet safety)	BST 9	Weathering (UV) ageing test	IEC TS 62788-7-2 (A3 cond.)	IEC TS 62788-7-2 (A4 cond.)	IEC TS 62788-7-2 (A5 cond.)
IEC 62852	5.2.1 h)	Marking, Upper Limit Temperature (ULT)	no requirement	95 °C	105 °C
IEC 62790	4.2.1 i)	Range of temperature (upper ambient temperature)	no requirement	95 °C	105 °C

* - Following publication of IEC 62788-2-1, pass/fail requirements from this document shall be followed.

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Extreme Environments: Wind Load

What governs wind load? Predominantly, three things:

- The site
- The system design (row spacing)
- The mounting system (tilt, height above ground, # modules per row)
- For standard PV modules – the PV is not a governing factor
- Mounting system standards:
  - UL 2703 (fixed), 3703 (trackers) – static/uniform mechanical load tests, bonding tests
  - IEC 63104 – tracker safety, early stages of development
  - IEC Working Group 9 – new group working on PV/structure interface

Extreme Environments: Wind Load

Standards updates under consideration for mounting systems (2703, 3703, WG9) - verify manufacturer's specifications

- Deflections under maximum rated load / torques
- Static pressure coefficients and/or load ratings
- Dynamic response
  - Address instabilities
  - Natural frequencies, damping ratios for all modes < ~10 Hz
  - Dynamic amplification factors

PV modules

- Non-uniform wind-load test (under consideration in WG2 and WG7)
- Verify allowable deflections and loads – designers then verify compatibility with mounting system

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Extreme Environments: Severe Corrosivity

IEC 61701 Salt mist corrosion testing

Corrosivity Classification of module location	Location Characteristics		One-year Mass loss range (g/m^2) of bare steel coupons	60068-2-52 Test Method achieving similar one-year corrosivity
	Distance from Saltwater (km)	Percentage Time of Wetness (ToW)		
C1 (testing per this document not necessary)	--	--	<10	none
C2 (testing per this document not necessary)	≥ 10	<25%	10-200	2, 3
C3	≥ 10 2 to 10	≥ 25% <25%	200-400	4 (14 days)
C4	2 to 10 < 2	≥ 25% <25%	400-650	1 (28 days) 5 (28 days)
C5	< 2	≥ 25%	650-1500	6 (56 days)
CX	offshore	--	1500-5500	7 (90 days) 8 (70 days)

Percentage time of wetness (ToW) is defined as the number of hours during the year at which the RH is at 80% or higher and the temperature is greater than 0°C, divided by the total hours in a year. This is defined in ISO 9223, but the tool uses a more complex model based on hourly RH measurements in the climate database.

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PV Module – Performance (Dust and Abrasion)

Description	Standard	Test Elements	Pass/Fail Criteria
Dust and Abrasion	ASTM D968-17	Standard Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive	Informative Report
	IEC 60068-2-68 :1994	Environmental testing - Part 2: Tests - Test L: Dust and sand Note: more appropriate for sealed enclosures	Informative Report
	DIN EN 1096-2 :2012	Glass in building – Coated glass – Part 2: Requirements and test methods for class A, B and S coatings	Informative Report
	IEC 62788-7-3 under development	• Measurement procedures for materials used in photovoltaic modules • Part 7-3 Materials and coatings for photovoltaic modules or similar solar devices: Abrasion test methods for environment facing surfaces	TBD

Extreme Environments: Hail

- Module manufacturer specifies desired hail test conditions (Table 3, IEC 61215)
- UL verifies compliance
- Designer assess site-specific risk of exceeding test conditions (AHJ, insurance provider, other stakeholders may require specific level of hail resistance
- Testing in excess of standard requirements can be done, if desired

Table 3 – Ice-ball masses and test velocities

Diameter	Mass	Test velocity	Diameter	Mass	Test velocity
mm	g	m/s	mm	g	m/s
25	7,53	23,0	55	80,2	33,9
35	20,7	27,2	65	132,0	36,7
45	43,9	30,7	75	203,0	39,5

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Extreme Environments – “New” Applications

PV pavers – sidewalk applications
- Immersion risk, impact on reliability, safety
- Slip risk
- Cyclic compressive loads (high heels)
- Maintenance – shoveling, salt/sand

PV thermal hybrid
- Thermal shock
- Thermal cycling
- Extreme temperatures
- PV integration – mechanical securement, chemical compatibility, grounding
- Failsafe design in prolonged leak
- Industry demand for field retrofits based on limited or testing for adding new modules to certifications

Summary - Standards Considerations for Extreme

Factor	Extreme Environment Adjustment
Air temperature	Increase temperature per IEC TS 63126
Module temperature	Increase temperature per IEC TS 63126
Wind load	***Updates needed:*** • Assess impact of mounting system (deflections, dynamic amplification) • Non-uniform load
Corrosivity	IEC 61701
Abrasion	Reference IEC 62788-7-3 (draft); DIN EN 1096-2-2012; ASTM D968-17
Hail	Verify compliance with site requirements or get insurance / modify test
Mounting	Custom hazard-based assessment needed to determine requirements.

Questions?

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Thank you