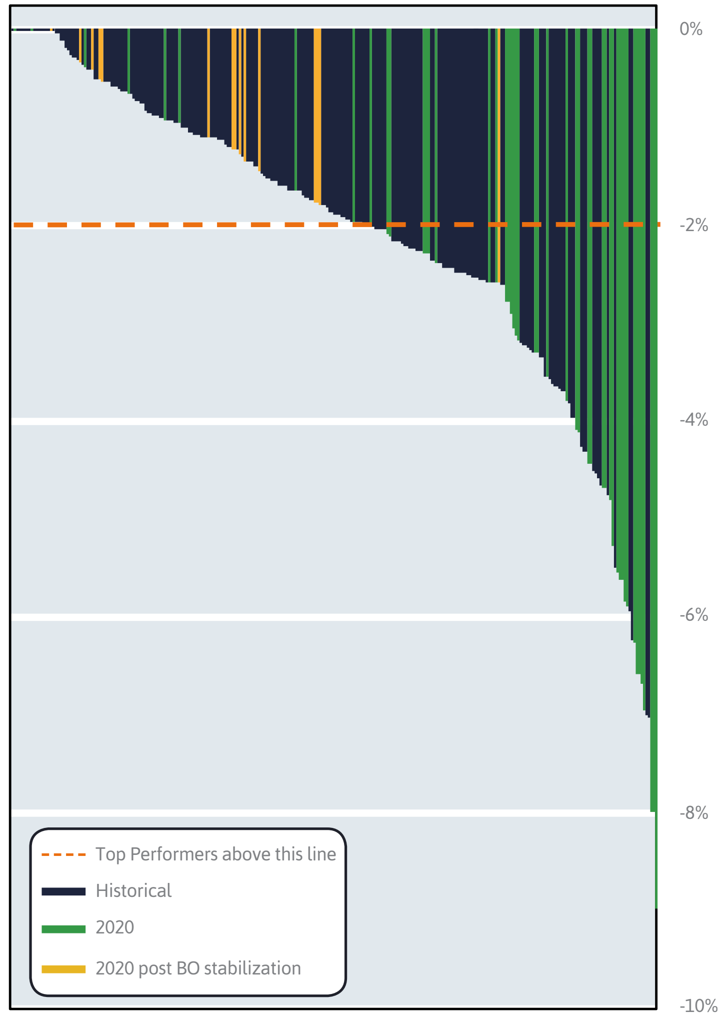
2020 DH TOP PERFORMERS	
Manufacturer	**Module Model**
Astronergy	CHSM72P-HC-xxx / CHSM60P-HC-xxx; CHSM72M-HC-xxx / CHSM60-HC-xxx; CHSM72M (DG)-B-xxx / CHSM60M (DG)-B-xxx
Canadian Solar	CS1H-MS*
First Solar	FS-6xxxA
GCL	GCL-M6/72H / GCL-M6/60H
Hanwha Q CELLS	Q.PLUS DUO L-G5.2*; Q.PEAK DUO G6*; Q.PEAK DUO G7*
Heliene	72M-xxx* / 60MBLK HOME PV*
HT-SAAE	HT72-156M (V)* / HT60-156M (V)*; HT72-156M (PDV)-BF* / HT60-156M (PDV)-BF*
Jinko	JKMxxxM-72HL-V* / JKMxxxM-60HL-V*
LONGi	LR6-60HPB-xxxM; LR6-72PH-xxxM
REC Group	RECxxxTP2M*
Silfab	SLGxxxM* / SLAxxxM*
Sunergy California	CSUNxxx-72MH5* / CSUNxxx-60MH5*
Vikram	Eldora VSP.72.AAA.05 / VSP.60.AAA.05; Somera VSM.72.AAA.05 / VSM.60.AAA.05

**Top performing result achieved following BO stabilization.*

Power Degradation from DH Test Sequence for Each Module Model



Results in Context: Key Takeaways

Damp heat is a critical test to identify underperforming modules susceptible to moisture ingress and corrosion. This can be seen in the example EL images, where the module performed well to the 1000-hour IEC 61215 duration. The performance difference after 2000 hours is stark: corrosion is seen along the bus bars and edges of the cells, and power degradation surpasses 9%.

The graph above shows power degradation results for both pre- and post- BO stabilization. In the most extreme example, PVEL measured 8.4% degradation in a post-DH2000 module that recovered to 1.3% degradation following BO stabilization. While some industry research has shown that BO destabilization is a test artifact that occurs during periods of high heat and no current (conditions which do not occur in the field[1]), more research is required to determine if destabilization will occur in the 25+ year lifetime of a module. It is worth noting this phenomenon only affects some PERC modules.

Bifacial considerations

It is well-documented that glass-glass modules have performed poorly in damp heat testing in the past. However, newer bifacial glass-glass and glass-backsheet combinations have shown similar performance in PVEL's PQP testing thus far. This is likely due to the move from EVA to POE in glass-glass modules.

[1] *F. Kersten et al., "Stability investigations of Cz-PERC modules during damp heat testing and transport: the impact of the boron-oxygen defect", AIP Conference Proceedings 2147, 090001 (2019); https://doi.org/10.1063/1.5123869*

Dynamic Mechanical Load Sequence: Overview and Results

Background

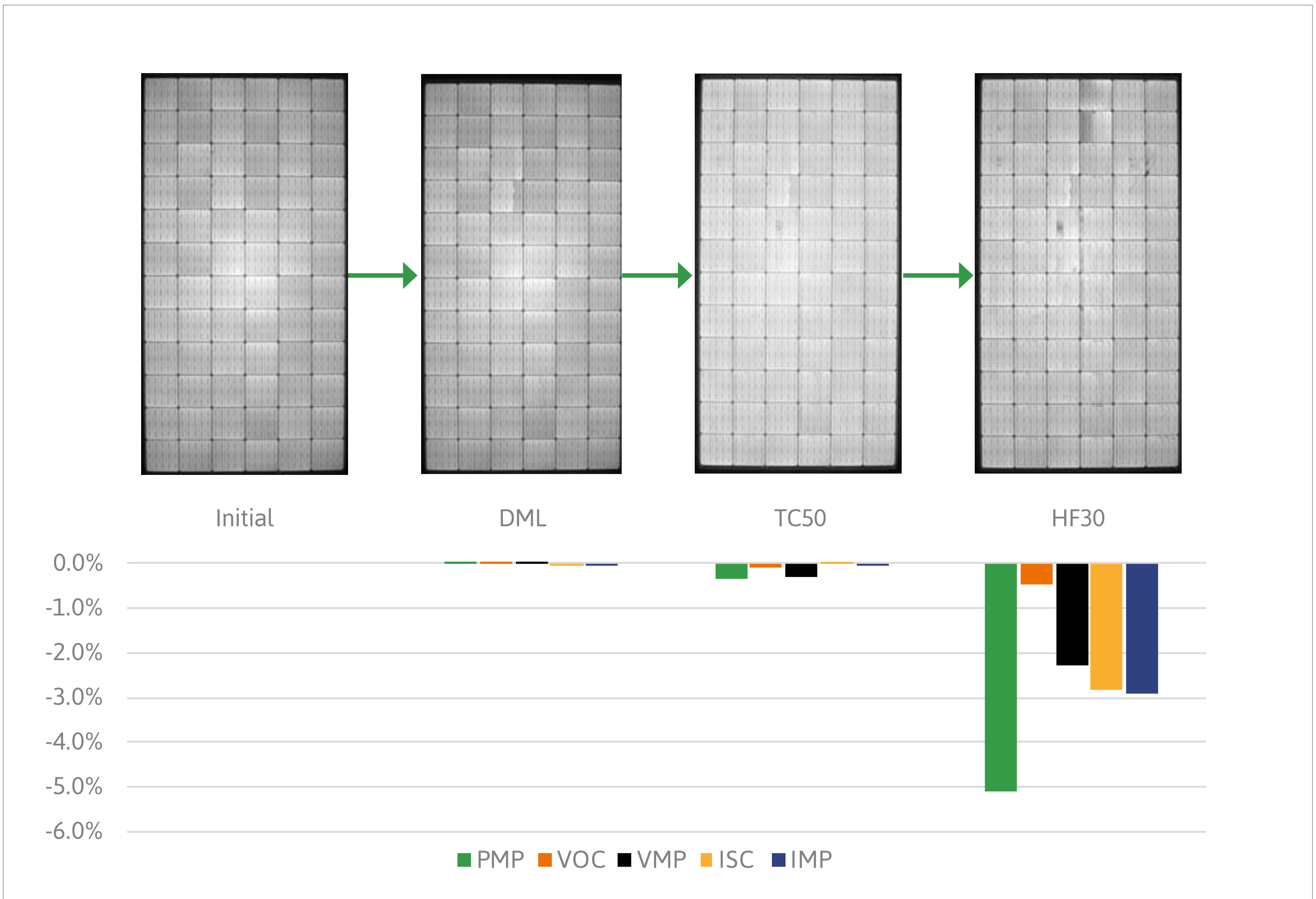
One of the most rigorous PQP test sequences, the dynamic mechanical load (DML) sequence, combines DML, thermal cycling and humidity freeze tests. When PV modules are subjected to mechanical loads like heavy snow or forces like high winds or hail, components become stressed and can break. When this happens, a range of performance degradation-inducing issues can result, such as moisture ingress, cell crack development and propagation, solder joint fatigue and cell corrosion. These issues often lead to reduced energy yield and even module and system field failures.

Why the test matters

Wind and snow subject modules to stress from dynamic loads, which are forces applied in different directions and speeds. Dynamic loading can also take place before the system is built. Improper packaging or handling can result in damage during the transportation, delivery and installation of modules. The DML test helps predict if PV modules can withstand these common loading conditions.

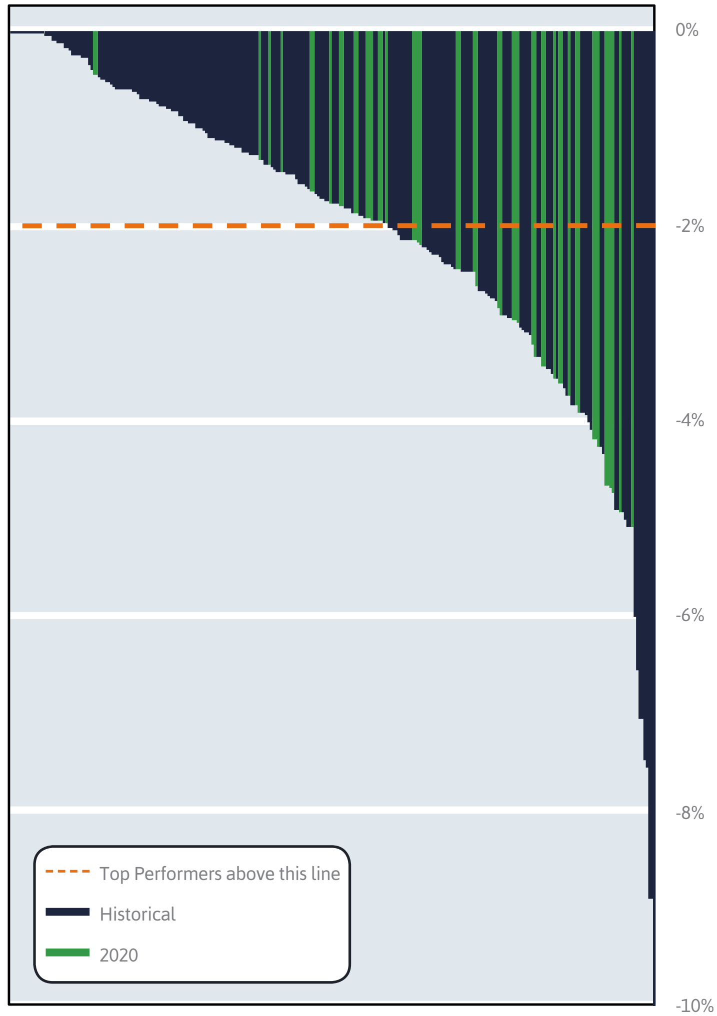
Dynamic mechanical load sequence procedure

First the module is installed according to the manufacturers' recommended mounting configuration. It is then subjected to 1000 cycles of alternating loading at 1000 Pa. Next, the module is placed in an environmental chamber and undergoes 50 thermal cycles (-40°C to 85°C) that can lead to cell crack propagation, followed by three sets of 10 humidity freeze cycles (85°C and 85% relative humidity for 20 hours followed by a rapid decrease to -40°C) to stimulate potential corrosion and further cell cracks. After each step in the sequence the module is characterized and visually inspected for any signs of component failure.



2020 DML TOP PERFORMERS	
Manufacturer	**Module Model**
Adani/Mundra	ASP-7-AAA / ASP-6-AAA
Astronergy	CHSM72P-HC-xxx / CHSM60P-HC-xxx; CHSM72M (DG)-B-xxx / CHSM60M (DG)-B-xxx
Canadian Solar	CS1H-MS
LONGi	LR6-72HPH-xxxM / LR6-60HPH-xxxM; LR4-60HPB-xxxM; LR6-60HPB-xxxM; LR6-72PH-xxxM
REC Group	RECxxxTP2M
Silfab	SLGxxxM / SLAxxxM
Vikram	Eldora VSP.72.AAA.05 / VSP.60.AAA.05
ZNShine	ZXP6-72-xxx/P / ZXP6-60-xxx/P

Power Degradation from DML Test Sequence for Each Module Model



Note: approximately 80% of the historical data includes only 10 humidity freeze cycles, which reflects past PQP test durations.

Results in Context: Key Takeaways

The DML sequence produced a wide range of degradation results, continuing last year's trend. A potential cause for these results is that BO destabilization may occur as a result of the damp heat conditions during humidity freeze testing. However, there are some module types that experienced BO destabilization following DH2000 but are DML Top Performers.

Another reason for the range of DML performance is susceptibility to power loss caused by cell cracking and rapid temperature changes. This can be seen in the provided example where the module suffered over 5% power loss after HF30 due to increased series resistance from metallization defects, cell cracks and loss of active area.

As seen in the updated PQP chart (see Pg. 14), the DML+TC50+HF30 test has been replaced by the new mechanical stress sequence ("MSS"). Early results indicate that the range of performance will continue with MSS testing. PVEL plans to release a separate publication featuring MSS results in the coming months.

Bifacial considerations

To date, glass-glass and glass-backsheet bifacial modules show similar performance results following the DML sequence, with fairly aligned front-side and rear-side degradation. Over 20 bifacial BOMs are queued for the new MSS test and PVEL is eager to share those results with the industry when available.

Potential-induced Degradation: Overview and Results

Background

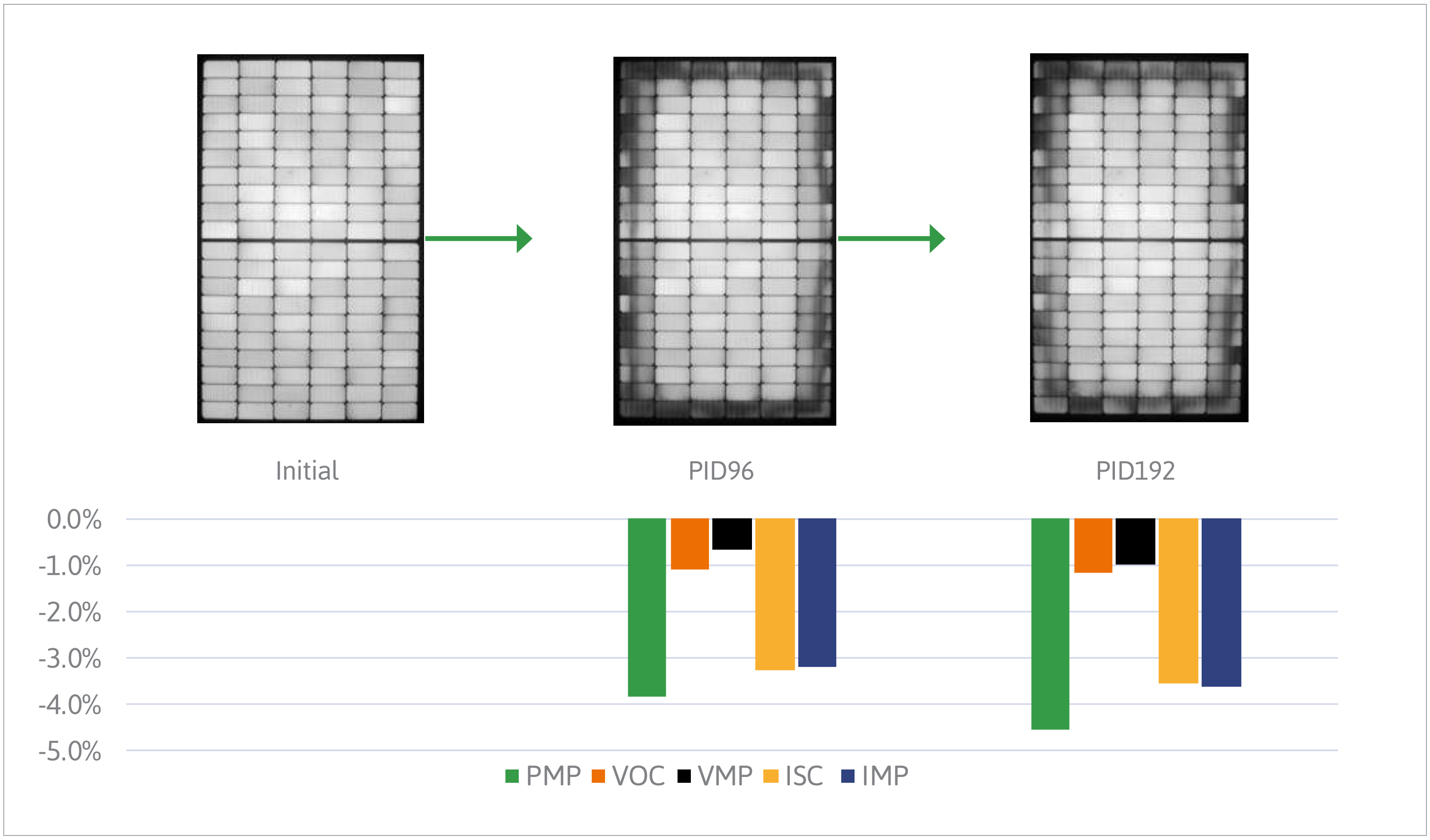
The phenomenon of potential-induced degradation (PID) has emerged over the past 10 years with the development of higher system voltages and ungrounded systems. PID can occur within weeks or even days of commissioning. It generally occurs when the internal PV electrical circuit is biased negatively in relation to ground. The voltage between the frame and the cells can cause sodium ions from the glass to drift toward the cell surface which typically has a silicon nitride (SiN) antireflective coating. If pinholes in this coating are large enough to allow sodium ions to enter the cell, then performance can be irreparably damaged. Additionally, this voltage can cause a buildup of static charge which can also reduce performance, although this effect is typically reversible.

Why the test matters

While not a concern for utility-scale sites employing central inverters equipped with negative system grounding, PID can significantly diminish module performance at sites with transformerless inverters, which are electrically ungrounded. While certain PID mechanisms are reversible in the early stages of degradation, some are irreversible and can lead to chronic underperformance. One solution to PID is through system design, including the use of specific grounding configurations or distributed electronics. PVEL recommends that developers and EPCs evaluate these alternative solutions if PID-resistant modules are not being procured for a project.

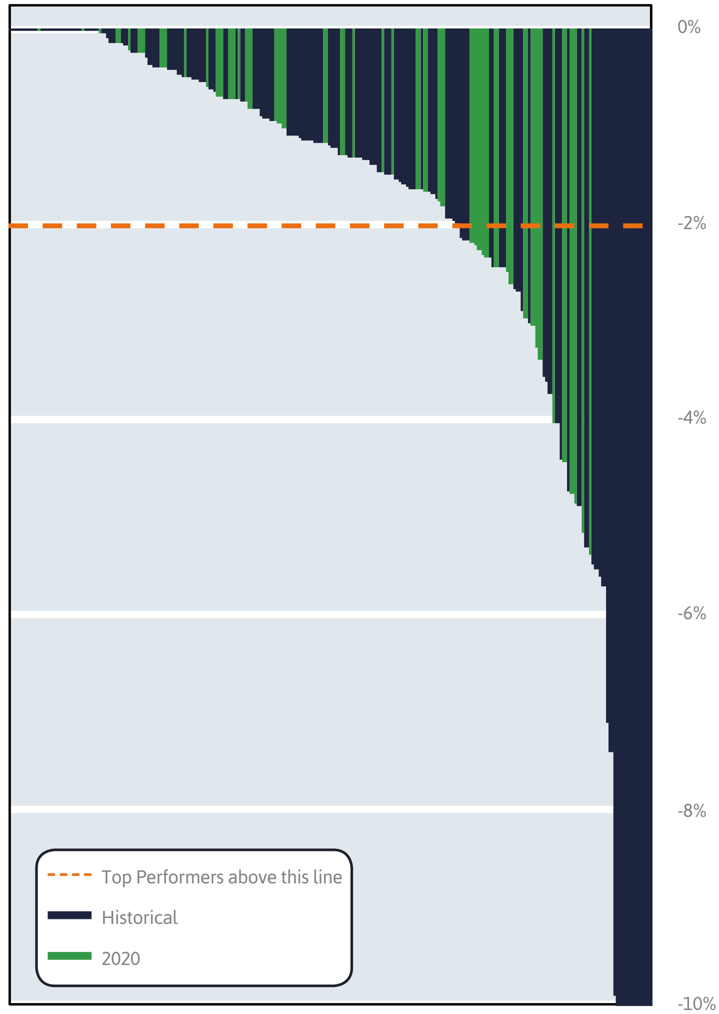
PID procedure

Once the module is placed in an environmental chamber, the voltage bias equal to the maximum system voltage (MSV) rating of the module (-1000V or -1500V) is applied with 85°C and 85% relative humidity for two cycles of 96 hours. These temperature, moisture, and voltage bias conditions help PVEL evaluate possible degradation and failure mechanisms related to increased leakage currents.



2020 PID TOP PERFORMERS	
Manufacturer	**Module Model**
Adani/Mundra	ASP-7-AAA / ASP-6-AAA
Astronergy	CHSM72P-HC-xxx / CHSM60P-HC-xxx; CHSM72M-HC-xxx / CHSM60-HC-xxx; CHSM72M (DG)-B-xxx / CHSM60M (DG)-B-xxx
Boviet	BVM6612M-xxx-H / BVM6610M-xxx-H
Canadian Solar	CS1H-MS
First Solar	FS-6xxxA
GCL	GCL-M6/72H / GCL-M6/60H
Hanwha Q CELLS	Q.PLUS DUO L-G5.2; Q.PEAK DUO G6; Q.PEAK DUO G7
HT-SAAE	HT72-156M (V) / HT60-156M (V)
JA Solar	JAM72S09-xxx/PR / JAM60S09-xxx/PR
Jinko	JKMxxxM-72HL-V / JKMxxxM-60HL-V; JKMxxxM-72H-TV / JKMxxxM-72HL-TV
LONGi	LR6-72PH-xxxM; LR4-72HIBD-xxxM / LR4-60HIBD-xxxM
Panasonic	VBHNxxxSA17
REC Group	RECxxxTP2M
Seraphim	SRP-xxx-6MA-HV / SRP-xxx-6MB-HV
Silfab	SIL-xxxBL; SLGxxxM / SLAxxxM
SunPower	SPR-Axxx-G-AC
Suntech	STPxxxS-24/Vfh / STPxxxS-20/Wfh
Trina Solar	TSM-xxxPE14H / TSM-xxxPE05H; TSM-xxxPE14A / TSM-xxxPE05A; TSM-xxxDE14A(II) / TSM-xxxDE05A(II)
Vikram	Somera VSM.72.AAA.05 / VSM.60.AAA.05
ZNShine	ZXP6-72-xxx/P / ZXP6-60-xxx/P

Power Degradation from PID Test Sequence for Each Module Model



Results in Context: Key Takeaways

There are many Top Performers listed here for their excellent PID results, yet susceptibility to this degradation mode remains a concern. PVEL's median PID degradation result was higher for testing conducted for the 2020 Scorecard than at any time in PVEL's history. When PVEL's testing uncovered PID issues the module manufacturers typically responded with surprise, having thought their modules to be PID-resistant.

Clearly more work needs to be done to ensure all modules are PID-resistant, and the PQP remains a key tool to uncover defects such as PID that can lead to significant financial losses in the field.

Bifacial considerations

PID testing of bifacial modules produced a wide range of front-side degradation and an even wider range of rear-side degradation, with a rear-side power loss of over 30% in one case. It is possible that some rear side degradation is due to a reversible polarization effect that can occur in bifacial modules during PID testing, but not all p-type bifacial modules are susceptible to this phenomenon.

PAN Performance: Overview and Results

Background

PVsyst is the industry's standard modeling software used to predict the performance of PV sites. A PAN file is used by PVsyst to model the irradiance- and temperature-dependent behavior of a PV module. PVsyst default PAN files are typically created from the specifications listed on a module's datasheet, which may not define all module performance parameters sufficiently. While the resulting PAN file is functional, it usually does not model the behavior of a PV module accurately for the entire range of potential irradiance and temperature conditions.

Why the test matters

Energy yield predictions factor heavily in procurement decisions, cost of capital calculations and risk assessments. A custom PAN file provided by PVEL that is based on laboratory-measured irradiance- and temperature-dependent behavior of the PV module will result in more accurate energy models. To better illustrate performance from optimized PAN files, each PAN report includes two site simulation results: a 1 MW site in a temperate climate at a 0° tilt (in Boston, USA), and a 1 MW site in a desert climate at 20° tilt (in Las Vegas, USA).

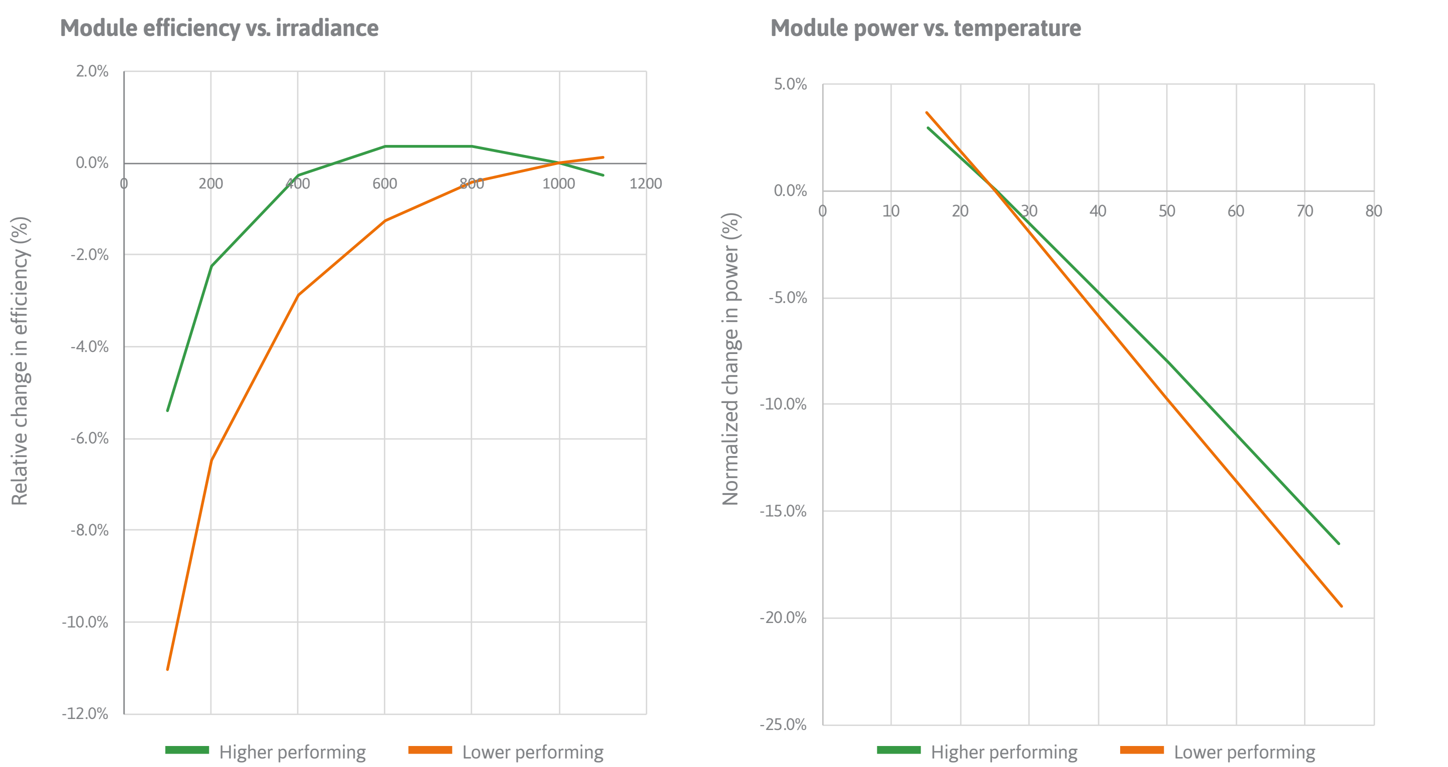
PAN test procedure

Three identical PV modules are tested across a matrix of operating conditions per IEC 61853-1, ranging in irradiance from 100 W/m² to 1100 W/m² and ranging in temperature from 15°C to 75°C. A custom PAN file is then created with PVsyst's model parameters optimized for close agreement between PVsyst's modeled results and PVEL's measurements across all conditions.

PAN performance differences

The graph on the left shows relative change in module efficiency versus irradiance. The lower performing module shows greater efficiency losses at lower irradiance. Although this difference affects performance at low insolation locations, such as the simulated Boston site, it is also impactful for high insolation locations due to the low irradiance experienced at different times of the day and year.

The graph on the right shows relative change in module efficiency versus temperature. Here, the lower performing module exhibits greater efficiency losses at high temperatures. This difference would be most significant in high temperature environments.



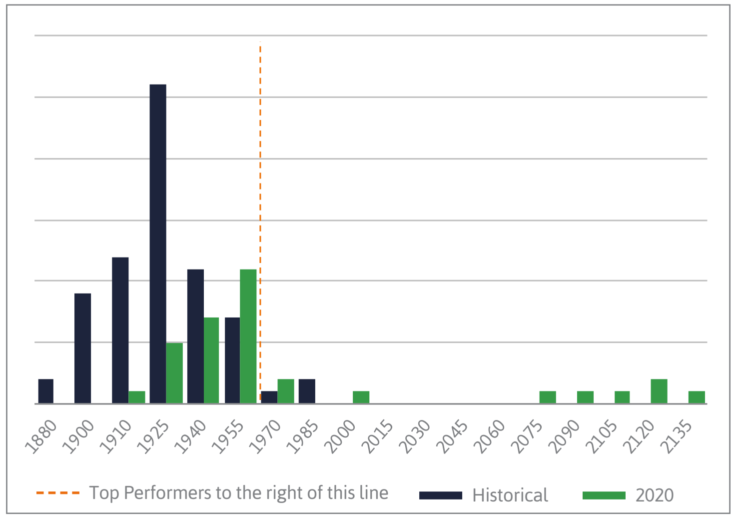
All modules shown here are p-type monofacial crystalline from the 2020 Scorecard dataset.

2020 PAN TOP PERFORMERS	
Manufacturer	**Module Model**
Astronergy	CHSM72M (DG)-B-xxx; CHSM60M (DG)-B-xxx
GCL	GCL-M3/72GDF; GCL-M6/72GDF
HT-SAAE	HT72-156M (PDV)-BF
JA Solar	JAM72S09-xxx/PR
Jinko	JKMxxxM-72H-TV / JKMxxxM-72HL-TV
Panasonic	VBHNxxxSA17
Trina Solar	TSM-xxxDE14A(II)

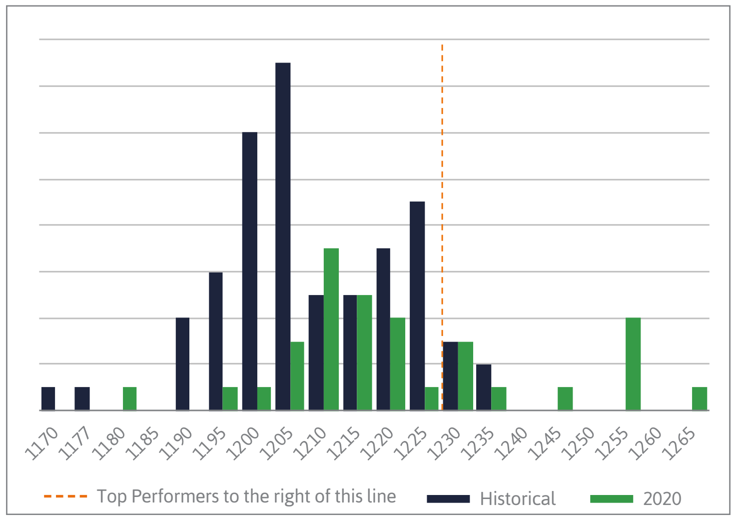
Top Performer Criteria

The Top Performers listed are module types whose PVsyst simulations for the Las Vegas or Boston site resulted in a kWh/kWp energy yield within the top quartile of all eligible results. The data presented here is only from PVEL's PAN testing as part of a PQP where the samples are factory witnessed.

kWh/kWp for 1 MW project in Las Vegas, USA



kWh/kWp for 1 MW project in Boston, USA



Results in Context: Key Takeaways

The presented historical data provides context for the performance improvements seen in the 2020 Scorecard PAN dataset. Module energy yield is clearly increasing with improved module designs. Of PVEL's historical data from all PQPs since 2016, only 4% of modules tested would receive a 2020 Scorecard Top Performer designation.

Bifacial modules are strongly represented in the Top Performers in this category. There is also a heterojunction module, which offers inherent high temperature performance gains. Two full-cell monofacial p-type PERC modules are also represented. A full-cell module's low light performance will be higher at the same nameplate rating than that of an identical half-cut module, which can result in higher annual energy yield. In one case, a full-cell BOM had a modeled energy generation for the Boston site that was 1.5% higher than an identical half-cut BOM. However, half-cut modules offer the benefit of higher power classes for the same cell efficiency. Module performance involves more than the datasheet values alone; PVEL's custom PAN files allow project stakeholders to model energy yield performance and determine which module choice is best for their site.

Bifacial considerations

The results show that bifacial modules represent a step-function performance improvement as two thirds of the Top Performers are bifacial modules. With no inverter clipping, the median energy yield of all the Las Vegas sites with bifacial modules was 7.7% higher than that of monofacial sites. At the horizontal tilt site in Boston the median bifacial energy yield was 3.3% higher than the monofacial median.