PV Lifetime Project – 2024 NREL Annual Report

Chris Deline, Dirk Jordan, Bill Sekulic, Josh Parker, Byron McDanold, and Allan Anderberg

National Renewable Energy Laboratory

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Technical Report
NREL/TP-5K00-90651
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Acknowledgments

We acknowledge the work of the PV module measurement group at NREL in recording these indoor IV measurements, and our PV Lifetime counterparts at Sandia, particularly Josh Stein, Bruce King and Marios Theristis. This work was authored by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 38535. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Executive Summary

DOE's PV Lifetime project was initiated in 2016 with the goal of accurately characterizing the early-life evolution of photovoltaic (PV) field performance. Different PV cell and module technologies result in different initial degradation rates due to effects like light-induced degradation (LID) and light & elevated temperature-induced degradation (LeTID). To accurately characterize the initial field degradation of maximum power (Pmp) requires the use of high-accuracy indoor IV curve measurements at standard test conditions. Therefore, PV modules involved in this study are removed from the field once or twice per year and brought indoors for measurement under constant temperature and irradiance conditions.

Current samples deployed and monitored in this way include Jinko Solar (2016), Trina Solar (2016), Hanwha Q-Cells (2017), Panasonic (2018), LG (2018), Canadian Solar (2018), Mission Solar (2019). Modules from Sunpreme (2019), and LONGi (2020) have been deployed and were first reported on in the 2022 report. For this report, initial baseline measurements for two additional partners are included: REC (2023) and Solaria (2023).

Overall annual degradation rates are as follows: our first modules to be deployed (Jinko and Trina) have annual median degradation rate between −0.35%/yr and −0.55%/yr, mainly concentrated in the first year. The QCells mono-PERC and multi-PERC modules have an annual degradation rate of −0.4%/yr and −0.3%/yr respectively, also concentrated in the first year of operation.

Mission Solar, LG and LONGi modules are all displaying modest degradation, better than −0.25% / year. Indeed, Mission Solar fielded modules degraded less than their control modules which remain indoors and un-exposed. By comparison, the Sunpreme n-HIT bifacial modules are showing a rapid loss rate around −2%/yr, or almost −8% total to date. This is largely attributed to loss in front-side Isc, and this rapid loss has been corroborated by comparing against RdTools degradation analysis, using real-time field performance data.

Several module types exhibit strong seasonal performance change, consistent with LeTID susceptibility. This is characterized by lower indoor IV measurement after prolonged high-temperature exposure, and a recovery during cooler temperatures. This can result in a sawtooth-type response when sequential indoor measurements are taken in the spring and again in the fall. These types of profiles are visible in Jinko, Trina and Mission Solar module types. It is possible that Canadian Solar multi-PERC also follows this trend, but the measurement timing has not lined up to confirm this possibility.

An analysis was conducted on the initial module performance relative to their nameplate rating. Most module types had initial performance right at nameplate rating, or within 1%: Jinko, Trina, LONGi, Panasonic, QCells and REC N-peak (TOPCon). Other module types came in 2% − 3% below nameplate: Mission Solar and Solaria. The REC 405 Pure Alpha came 3%-4% below nameplate, which is outside of its stated accuracy bounds. It wasn't all bad news - LG modules were measured at 2% above nameplate. Finally, the Sunpreme heterojunction modules had inconsistent measurements which made it difficult to make any statements on their nameplate accuracy.

Three related publications published in 2022 have made use of the PV Lifetime data included in this report, and can help provide greater context and additional information. M. Theristis et al., "Onymous early-life performance degradation analysis of recent photovoltaic module technologies" (http://doi.org/10.1002/pip.3615) provides additional analysis and measurements from New Mexico and Florida test sites for comparable module samples. An international round-robin test on LeTID stabilization processes was published by Karas et al., "Results from an international interlaboratory study on light- and elevated temperature-induced degradation in solar modules" (DOI: 10.1002/pip.3573). Finally, a detailed discussion of LeTID kinetics and how this affects field performance and LCOE is provided in the MRS Bulletin, I. Repins et al., "Long-Term Impact of Light and Elevated Temperature Induced Degradation on Photovoltaic Arrays". (DOI: 10.1557/s43577-022-00438-8)

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1 Introduction

In 2016, the US Department of Energy initiated the PV Lifetime project – an effort to procure, deploy and accurately characterize the initial performance degradation of commercial PV module samples. In the process of this project, NREL and Sandia national laboratories have collaborated to deploy and publish on the initial performance of over 950 different samples from 12 different manufacturers to date. This report represents a cumulative snapshot of field results for the PV modules deployed at NREL.

Figure 1. Overview of the NREL PV Lifetime field samples ca 2018

As of 2024, the following module types have been deployed at each of the PV Lifetime locations:

Table 1. PV Lifetime Modules under test in Albuquerque, NM, Golden, CO and Cocoa, FL.

Company	Model	Type	Number in NM	Number in CO	Number in FL
Jinko Solar	JKM260P 260W	Multi	28	28	56
Jinko Solar	JKM265P 265W	Multi	28	28	-
Trina Solar	TSM-PD05.05 255W	Multi	-	28	-
Trina Solar	TSM-PD05.08 260W	Multi	56	28	56
Canadian Solar	CS6K-270P 270W	Multi	48	-	-
Canadian Solar	CS6K-275M 275W	Mono	48	-	-
Canadian Solar	CS6K-300MS 300W	PERC	-	28	-
Hanwha Q-Cells	Q.Plus BFR-G4.1 280	PERC	48	28	-
Hanwha Q-Cells	Q.Peak BLK G4.1 290	Mono-PERC	48	28	-
Solar World	SW 245W Mono	Mono	21	-	-
LG	LG320N1K-A5 320W	N-Si	48	30	-
LG	LG400Q1C-A6	N-IBC	30	-	-
Panasonic	VBHN330 330W	N-HIT	48	28	-
Mission Solar	MSE360SQ65 300W	Mono-PERC	48	20	-
Sunpreme	HxB-400	Bifacial HIT	-	20	-
LONGi	LR6-72BP-360M	Bifacial PERC	-	20	-
LONGi	LR6-72PH-365M	Monofacial	-	20	-
REC	REC405AA Pure Black	N-type HIT	28	10	-
REC	REC360NP2	N-type TOPCon	-	12	-
Solaria	PowerX-400R	Mono, shingled	28	14	
Program Total			**>950 modules**		

The objective of the PV Lifetime Project is to determine and communicate module degradation profiles over time, including the uncertainty and any differentiation between module types. This will be done by:

- Annual flash testing of PV modules operated in the field in a variety of locations and climates.
- Analysis of periodic data to detect system degradation rates and causes.
- Sharing of reviewed results and data publicly.

For additional information on the PV Lifetime project background and initial module performance, see the WCPEC conference publication for additional details: J. Stein et al. PV Lifetime Project: Measuring PV Module Performance Degradation: 2018 Indoor Flash Testing Results, WCPEC-7 (2018).

1.1 PV system descriptions and initial LID performance

The PV Lifetime systems currently deployed at NREL are described below. Where initial LID performance is stated, it is based on repeated indoor flashing of modules following small increments of outdoor light soak exposure in the range of 5 – 20 kWh/m^2.

Figure 2. NREL PV Lifetime installations. Jinko Solar (left) and Trina Solar (right)

Jinko Solar. PV systems composed of 28 modules each of Jinko JKM260P-60 and Jinko JKM265P-60 modules were deployed outdoors in October 2016 following initial baseline PV measurements in September 2016. The systems are grid-tied through an ABB TRIO 20.0 inverter, in two strings of 14 modules apiece. Due to a delay in system electrical configuration, the PV system was not grid-tied until April 2017. An initial light-induced degradation of up to 1.5% was detected following 10+ kWh/m^2 of light exposure of the control modules.

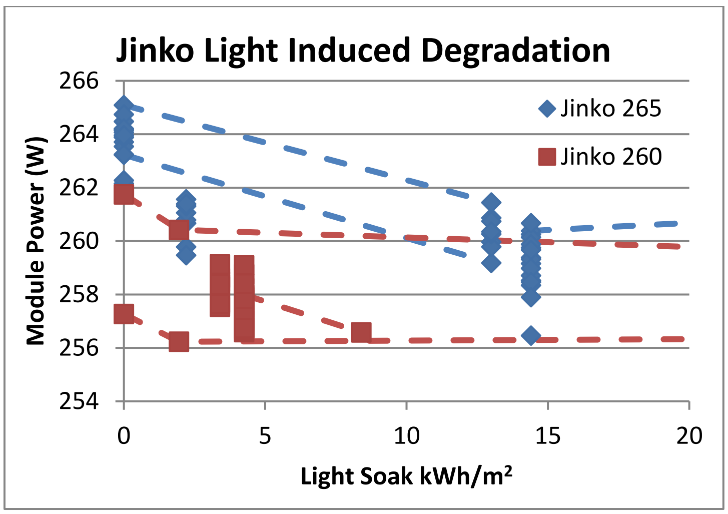

Figure 3. Jinko Solar initial LID data showing 0.5% LID loss for JKM260 and 1.5% LID loss for JKM265 modules. Data from repeated indoor IV measurements. Dashed lines shown for select modules.

This system was offline (open circuit) in 2023 due to failure of the ABB TRIO inverter (7 years of field operation). The system was offline from April – August 2023 and was replaced with a Fronius SYMO 20.0-3 480 inverter. During this time period the system size was reduced from 28 modules to 14 modules per type to make room for additional new partners.

Trina Solar. PV systems composed of 28 modules each of Trina TSM-PD05.08 260W and Trina TSM-PD05.05 255W (Black backsheet) modules were deployed in October, 2016. The systems are grid-tied through an ABB TRIO 20.0 inverter, in two strings of 14 modules apiece. The PV system was grid-tied in April, 2017. An initial light-induced degradation of ~0.4% was detected following 10 kWh/m^2 of light exposure of the control modules.

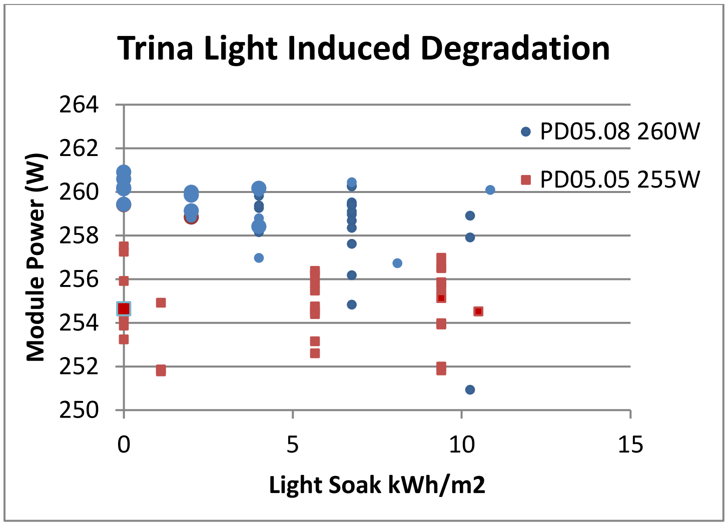

Figure 4. Trina Solar initial LID data showing 0.4% LID loss for both module types. (Data from repeated indoor IV measurements)

This system was offline (open circuit) in 2023 due to failure of the ABB TRIO inverter (7 years of field operation) which was in common with the Jinko system. The system was offline from April – August 2023 and was replaced with a Fronius SYMO 20.0-3 480 inverter. During this time period the system size was reduced from 28 modules to 14 modules per type to make room for additional new partners.

Figure 5. NREL PV Lifetime installations. QCells (left) and Panasonic (right)

QCells. PV systems composed of 28 modules each of QCells Q.Plus BFR-G4.1 280 (multi-PERC) and Q.Peak BLK-G4.1 290 (mono-PERC, black backsheet) modules were deployed in October, 2017 following baseline measurements in July 2017. The systems are grid-tied through an ABB TRIO 20.0 inverter, in two strings of 14 modules apiece. An initial light-induced degradation of around 1% was detected following 10 kWh/m^2 of light exposure.

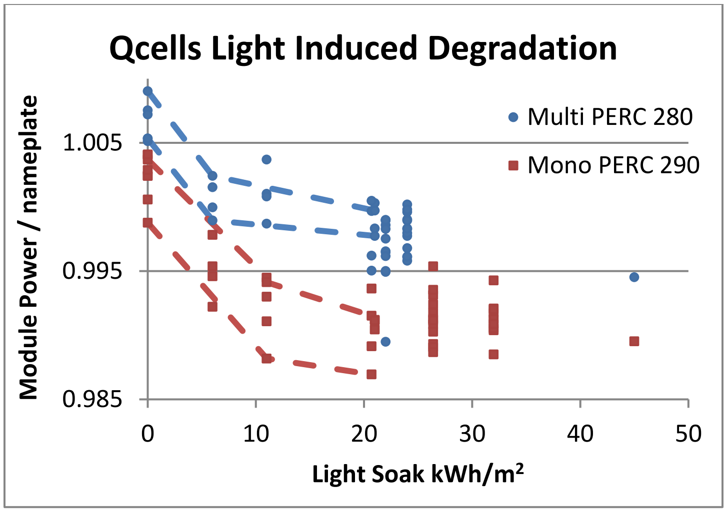

Figure 6. QCells initial LID data showing 0.9% LID loss for Qplus (multi PERC) 280W and 1.2% LID loss for QPeak (monoPERC) 290W. Data from repeated indoor IV measurements. Dashed lines shown for select modules.

Panasonic, Canadian Solar, LG. Three separate PV systems were deployed in 2018 composed of 30 modules of Panasonic VBHN3305A16 (Heterojunction "HIT"), 28 modules of Canadian Solar CS6K-300MS (Mono-PERC) and 28 modules of LG LG320N1K-A5 (N-Type Mono-Si "NeON2"). The systems are grid-tied through HiQ ProHarvest inverters, in either two-string (Canadian, LG) or three-string (Panasonic) configurations. PV module baseline data were taken in June 2018, with modules installed June − October 2018. Initial LID performance changes following 20 kWh/m^2 of light exposure depended on product technology: Canadian Solar: −0.5%. LG: 0%. Panasonic: +0.6% improvement.

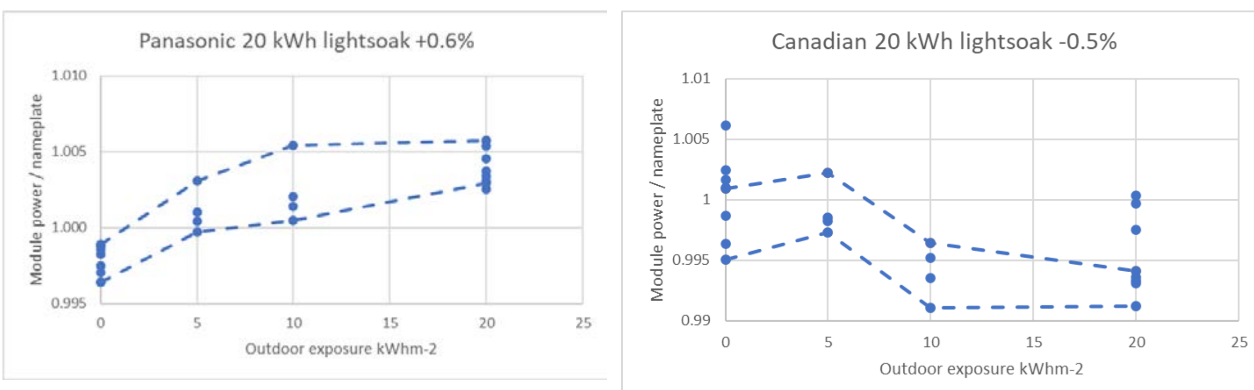

Figure 7. Panasonic initial light-soak data showing +0.6% performance gain and Canadian CS6K-300MS showing −0.5% decline. Data from repeated indoor IV measurements. Dashed lines shown for select modules.

Mission Solar, Supreme, LONGi Bifacial tracker. A 10-row single-axis tracked system was installed at NREL in 2018−2020. The site supports three PV Lifetime systems: 20 modules each of Mission Solar MSE360SQ6S (Mono-PERC), Sunpreme Maxima HxB 400 (bifacial HJT) and LONGi (bifacial and monofacial mono-PERC). The systems are grid-tied through SolarEdge SE20k inverters, and utilize module-level power optimization to identify module-level mismatch throughout the system. The other rows in the system are part of a separate research program on bifacial PV energy gain and field durability. A detailed study of LID loss in the first 10−20 $kWhm^{-2}$ light exposure was not conducted for these modules.

Figure 8. NREL 75-kW tracking PV system supporting PV Lifetime performance data

REC 360NP2 (TOPCon), REC 405AA Pure Black (HIT), Solaria PowerX-400R. These next module types have undergone initial characterization and were deployed in late 2023. These module technologies include n-type silicon heterojunction (HIT) and TOPCon technology from REC, as well as shingled p-type PERC solar cells from Solaria. All three module types utilize half-cut solar cells, and feature all-black module frame and backsheet. A total of 10-14 modules of each type was deployed.

Figure 9. REC 360NP2 (left), 405AA Pure Black (middle) and Solaria PowerX-400R (right)

1.2 Program measurement methodology

Rather than focusing on in-situ performance monitoring under prevailing meteorological conditions, the PV Lifetime project instead takes periodic indoor IV curve measurement at 25 ºC and 1000 W/m^2. On a regular schedule of 1−2 times per year, a subset of fielded PV modules are brought indoors for high accuracy STC flash test measurement. In between measurements, the modules are returned outdoors and put back under grid-tied conditions.

Un-exposed indoor control modules are also maintained for each module type to distinguish between field-induced changes and other factors. These can include simulator setting changes or sample instability. Since we are measuring the inherent performance of the PV module as it changes in time, we use the term 'degradation rate' in reporting on module STC loss over time. The wider term 'performance loss rate' refers to system-level AC performance of a fielded system as it changes with time. The DC degradation rate is a subset of all system-level performance losses, which also include items like module soiling, tracker pointing errors or AC availability, which are not considered here.

1.2.1 Initial simulator measurement (Spire 5600)

Indoor IV curve measurements at NREL are conducted on multiple test platforms with various stability and accuracy specifications. The highest accuracy measurement is the Module Self-Reference (MSR) methodology, with a stated accuracy of 1.1% (Levi et al, 2017; Ndione et al, 2020). This is a time-consuming method that is only conducted once per module type at the beginning of the experiment. The faster approach is to take flash measurements on a Spire simulator. The flash simulator can result in offset errors due to illumination level setting, but is relatively stable over time. It is therefore useful in identifying relative levels of change.

To judge the overall accuracy of the Spire 5600 simulator, in Figure 10 and 11 we plot the high accuracy MSR measurements taken for all module types against comparable Spire 5600 measurement. The Spire 5600 flash platform is generally below the dashed black 1:1 line, indicating that it is measuring a lower Pmp value than the MSR platform. For the Panasonic, Jinko, Trina, LONGi and Mission Solar modules, the Spire measurement is within 1% of the true value, but for Canadian, REC, Solaria and QCells the Spire values are 2% −3% low, and for LG modules the Spire values are measuring 4.4% below the true value. A tremendous difference in the two platforms of 6% − 8% was found for the Sunpreme HJT modules, which should be investigated further. The difference in measurement platforms should be considered when looking at the figures in the remainder of this report, all of which were measured with the Spire 5600 flasher. These values may be adjusted by the offset shown in Figure 10 and 11 to arrive at a more accurate absolute power value..

Figure 10 and 11 also provide a comparison between a module's nameplate rating and its actual measured value. In the figure, nameplate values are represented by vertical dashed lines with color corresponding to the given module type. In the case of Canadian, Jinko, Trina, LONGi, Panasonic and REC TOPCon, initial baseline measurements are right at expected nameplate rating. LG was measured at 2% above nameplate. QCells was within 1% but consistently low, and Mission Solar and Solaria were 3% below nameplate. The two REC 405Pure AA modules were at 2% and 4% below nameplate rating, which somewhat falls outside of its stated nameplate accuracy of 3%. The Sunpreme HxB heterojunction modules had a lot of variability in their initial measurement, with the Spire 5600 showing initial performance 3% − 4% below nameplate, but the higher accuracy MSR measurement showing performance at 2% − 6% above nameplate. The cause of this discrepancy is under investigation.

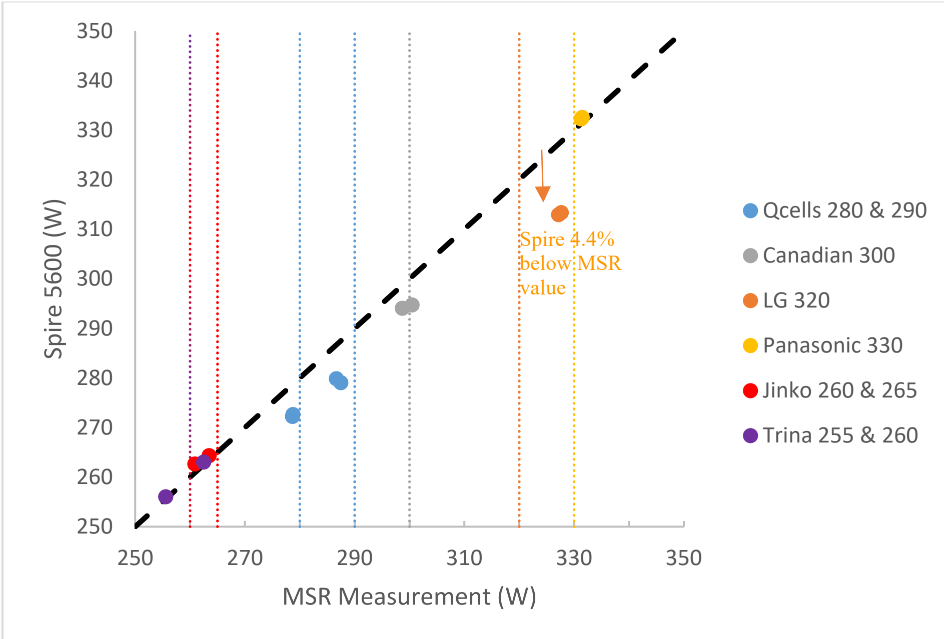

Figure 10. Initial baseline characterization of the first half PV Lifetime modules. MSR measurement (1.1% absolute accuracy) compared with Spire 5600 measurement (lower accuracy). Vertical lines represent nameplate rating of each module type.

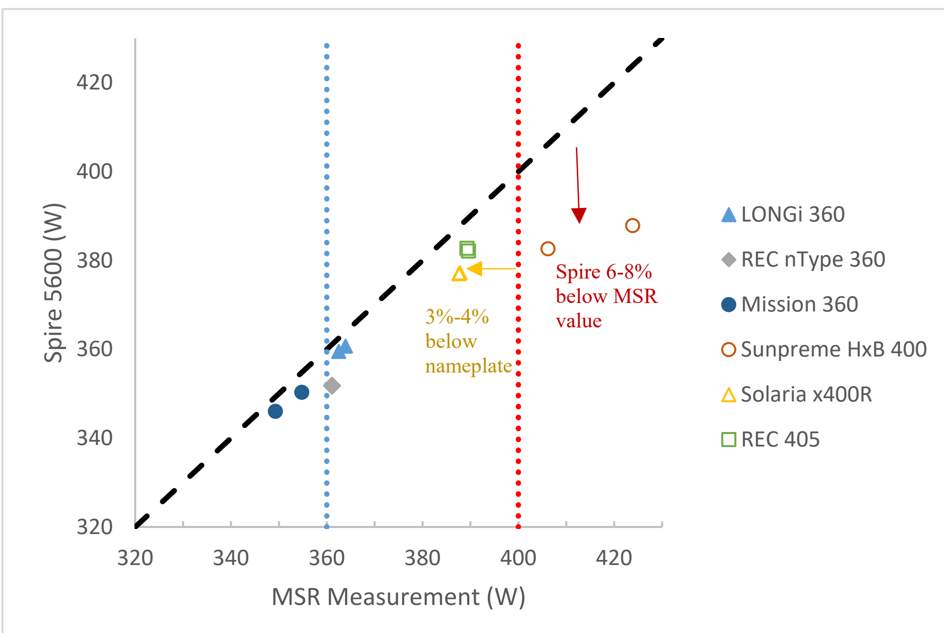

Figure 11. Initial baseline characterization of the second half PV Lifetime modules. MSR measurement (1.1% absolute accuracy) compared with Spire 5600 measurement (lower accuracy). Vertical lines represent nameplate rating of each module type, either 360 W (closed symbols) or 400-405 W (open symbols).

1.2.2 Recent Spire 4600 measurements (2022)

For a brief period in 2021−2022 the PV Lifetime project switched to taking measurements on even another flash simulator platform. The Spire 4600 flash simulator user facility at the NREL VTIF building has lower absolute accuracy than the Spire 5600 instrument described above, but has much more time availability. For one example of reduced accuracy, building temperature is only controlled within +/− 5 C vs 0.1 C, leading to a requirement for temperature correction of these measurements. Furthermore, simulator uniformity, spectral match and aperture area is worse, leading to systematic offsets in measurements. To allow recent Spire 4600 measurements to be compared directly with earlier Spire 5600 measurements, control modules of each module type were measured on both platforms, allowing a correction factor to be developed (Figure 12). For some module types (Jinko, Trina) the Pmp error is small, < 1W. For the largest discrepancy (QCells) the measurement difference is on the order of 5−6W.

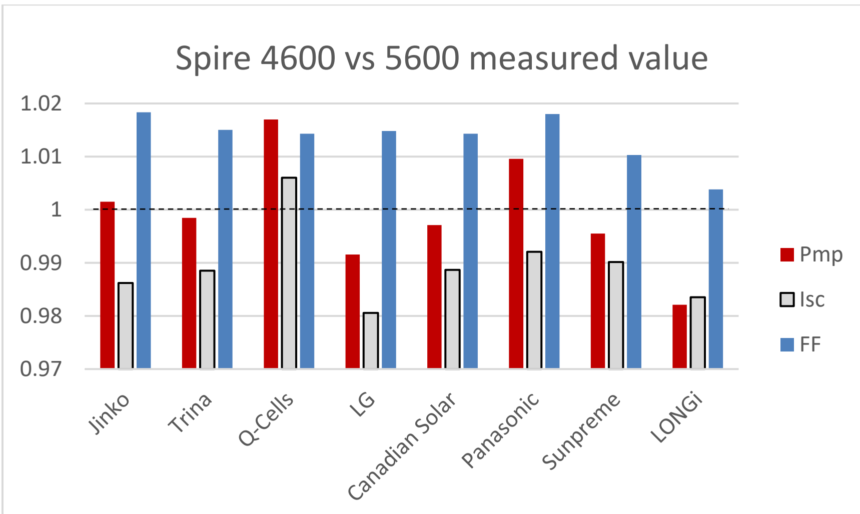

Figure 12. Comparison of Spire 4600 vs Spire 5600 control module measurements. Fill Factor was measured higher on all modules. I_{sc} was either higher or lower based on module type, leading to variability in P_{mp} offset. The largest power offset was for QCells leading to a 5-6W measurement difference. Data taken on this platform is corrected to remove this simulator offset.

For data plotted in this report, measurements taken on the Spire 4600 will be indicated with square markers, post-correction. Stability of this correction factor will be monitored over time by comparisons between Spire 4600 and 5600 each subsequent measurement period. Because of reduced accuracy of these measurements, we returned to measurement on the Spire 5600 in 2023−2024.

2 Field measurement results

Each module type when received by NREL underwent initial light-soak stabilization of 10 – 20 kWh/m^2 to remove initial LID effects before our first 'true' baseline measurement is taken. For some module types, we monitored the fast change in performance over this initial light soak – for others we did not. For all module types, we are using our first post- light-soak indoor P_{mp} measurement as the time zero reference point — subsequent changes are stated as a % of this initial measurement.

2.1 Jinko JKM260

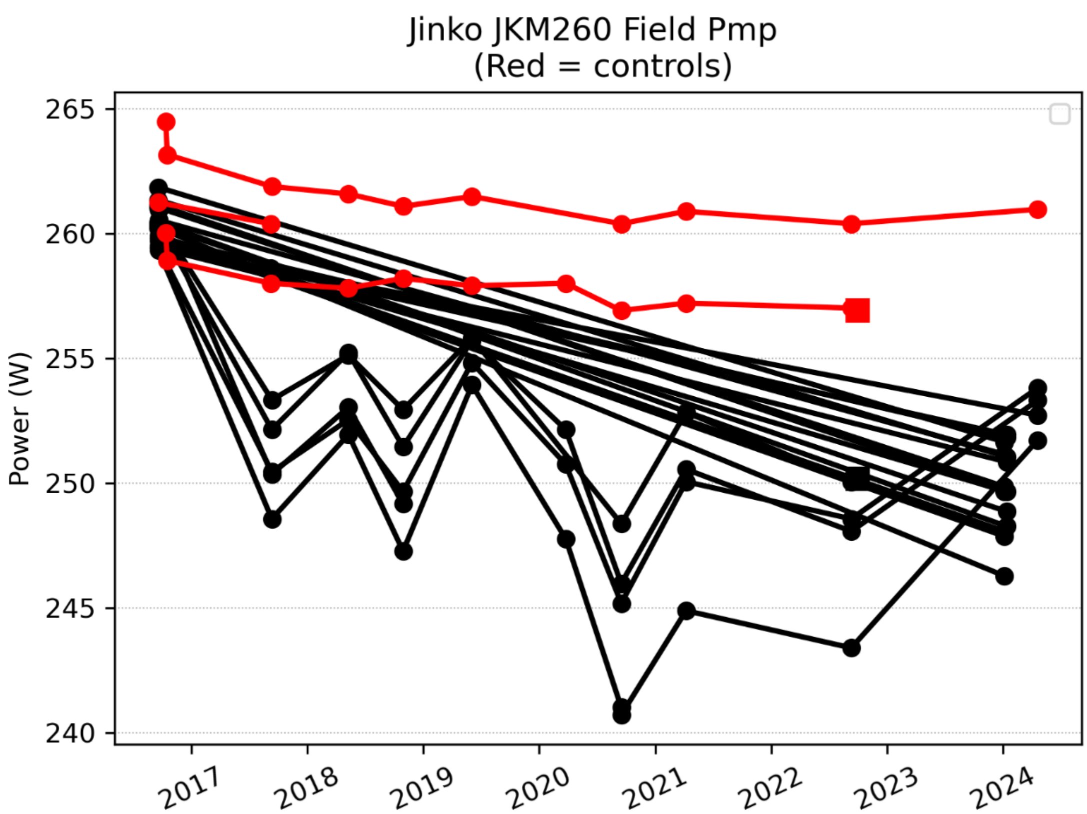

Figure 13. Jinko JKM260 flash measurements. Field modules (black) and indoor controls (red). Square markers indicate Spire4600 measurement (post-correction). Seasonality may still be present, but is not recorded with new annual measurements. A new cohort of 14 modules was measured for the final time when they were de-integrated and removed from further test.

2.1.1 Initial light soak

Jinko JKM260 experienced ~0.5% initial loss due to LID following 22kWhm-2 light exposure

2.1.2 Control module change (post-lightsoak)

Jinko JKM260 control modules showed a modest overall change of −1% over the entire measurement period.

2.1.3 Field module change (post-lightsoak)

The first thing to mention on the plot this cycle is that a large number of additional modules were measured. Because the Jinko JKM260 system was cut down from 2 strings to 1, an additional 14 modules were removed from test and re-measured after 7 years.

Compared with the relatively stable control modules, the fielded modules demonstrate seasonal performance change, related to inherent instability of this module type. For additional information see [Repins, 2020]. In particular, this module type has been tested and found to be LeTID sensitive per the procedure described in Karas, 2022 which is an early draft version of IEC TS 63342.

For the fielded modules (4 of the typically monitored modules plus 14 additional ones), overall median degradation was −3.9%. Based on the few modules measured with more regularity, the majority (-3%) of this loss occurred in Year 1. It's expected that a similar degradation profile applied to the other 14 modules, but no interim data was measured to confirm. The overall annualized Pmp loss works out to −0.5%/yr.

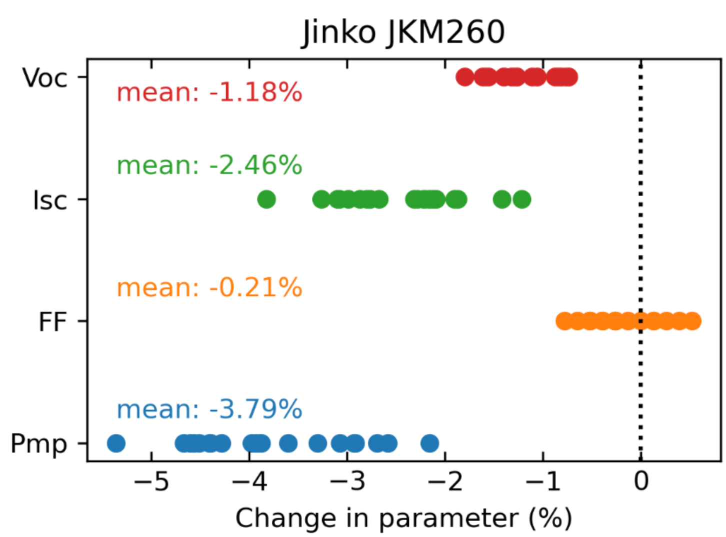

Figure 14. Jinko JKM260 IV curve parameter overall change.

Overall change in performance from 2017 to 2024 for Jinko JKM260 is due to primarily Isc, as well as Voc loss.

It should be noted that all Jinko and Trina modules in this field withstood a large hailstorm that came through the Golden area on May 2017. Although no SLTE modules experienced broken glass, there were a number of cracked cells that showed up in module EL following their de-integration and final characterization. The below image of module M1609-0008 is typical of the type of damage that occurred – a handful of visible cracks and impact centers.

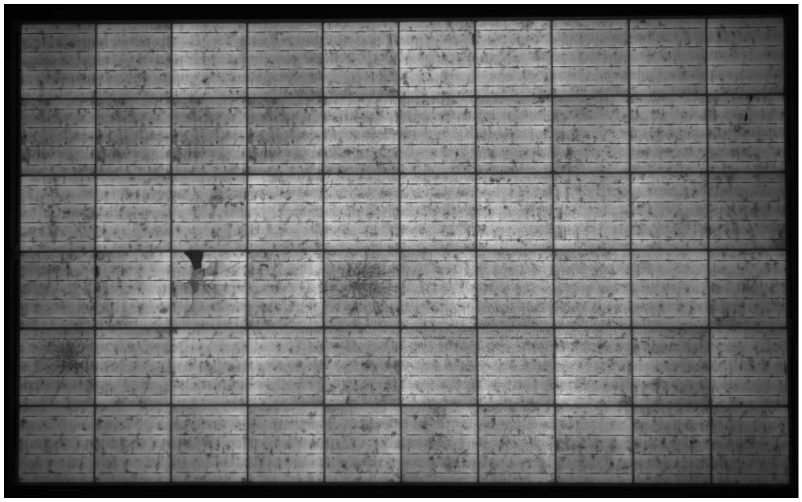

Figure 15. Jinko module EL image at test conclusion in 2024 illustrating 3-4 cracked cells due to hail exposure in 2017. This image is typical of those taken from the field.

2.2 Jinko JKM265

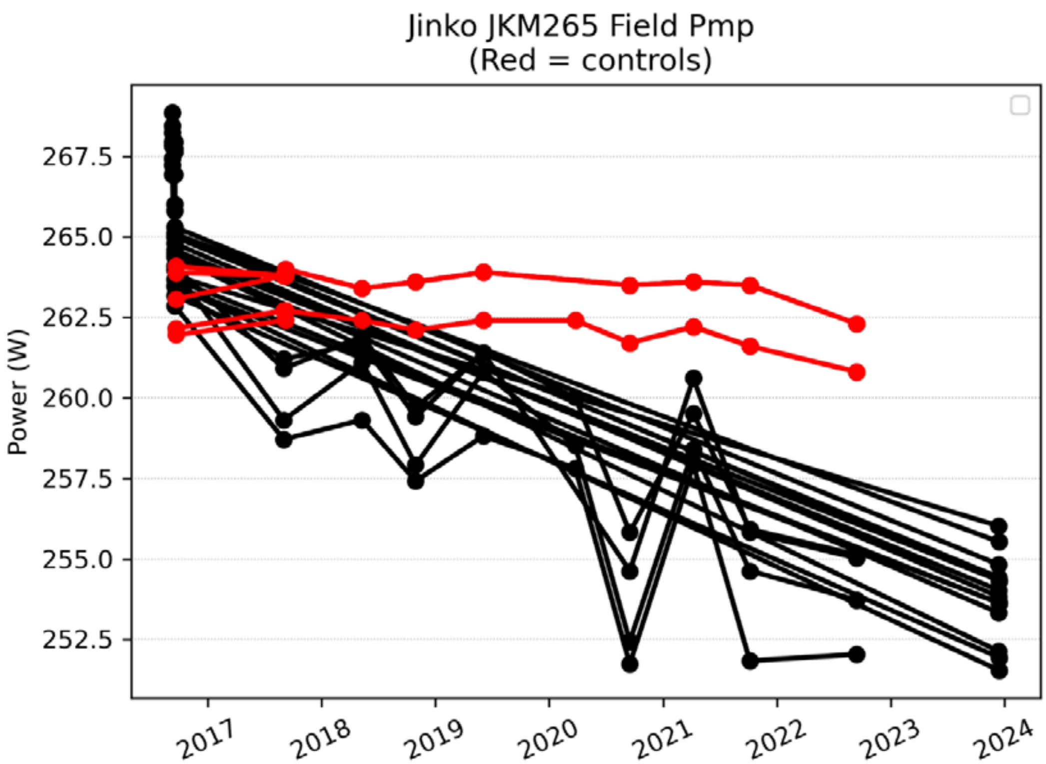

Figure 16. Jinko JKM265 flash measurements. Field modules (black) and indoor controls (red). Starting in 2022, seasonality may still be present, but is not recorded with annual measurement frequency. A new cohort of 14 modules was measured for a final time when they were de-integrated and removed from further test.

2.2.1 Initial light soak

Jinko JKM265 experienced 1.5% initial loss due to LID following 22kWhm-2 light exposure

2.2.2 Control module change (post-lightsoak)

Jinko JKM265 control modules were stable over the measurement period of 2017−2024.

2.2.3 Field module change (post-lightsoak)

Similar to the other Jinko modules, the JKM265 system was reduced from 2 parallel strings of 14 to just one. The 14 modules removed from the system were characterized a final time after 7 years in the field.

Compared with the stable control modules, the JKM265 fielded modules show a relatively high seasonal performance difference depending on the season of measurement. This makes cumulative performance loss difficult to quantify. Based on measurements made in the spring of 2021, post-LID degradation was −1.67%, or −0.37%/yr. However using the more recent (and lower) fall 2022 measurement as an endpoint, degradation was −3.66% or −0.61%/yr. As with the Jinko JKM260 modules, any ongoing seasonality post-2022 was hidden when measurements moved from biannual to annual frequency. Based on the most recent cohort of 14 modules, the overall median degradation was −4.1% or −0.56%/yr.

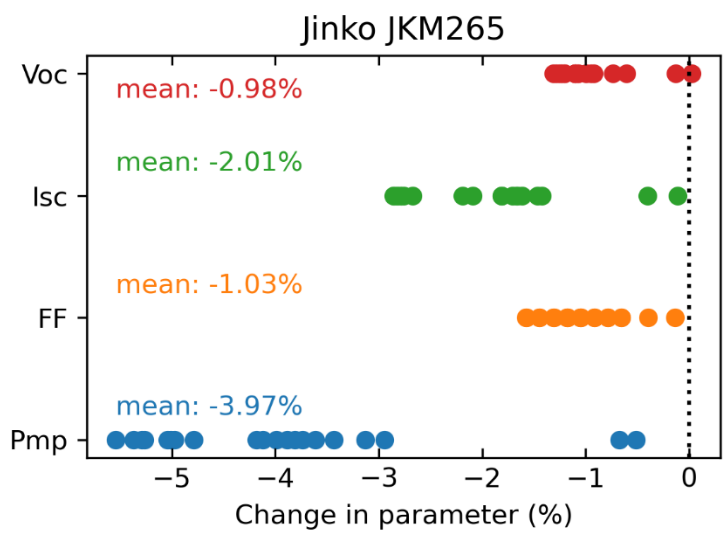

Figure 17. Jinko JKM265 IV curve parameter overall change.

Overall change in performance from 2017 to 2024 for Jinko JKM265 includes contributions from all three parameters - Isc, Voc and Fill Factor.

2.3 Trina TSM255

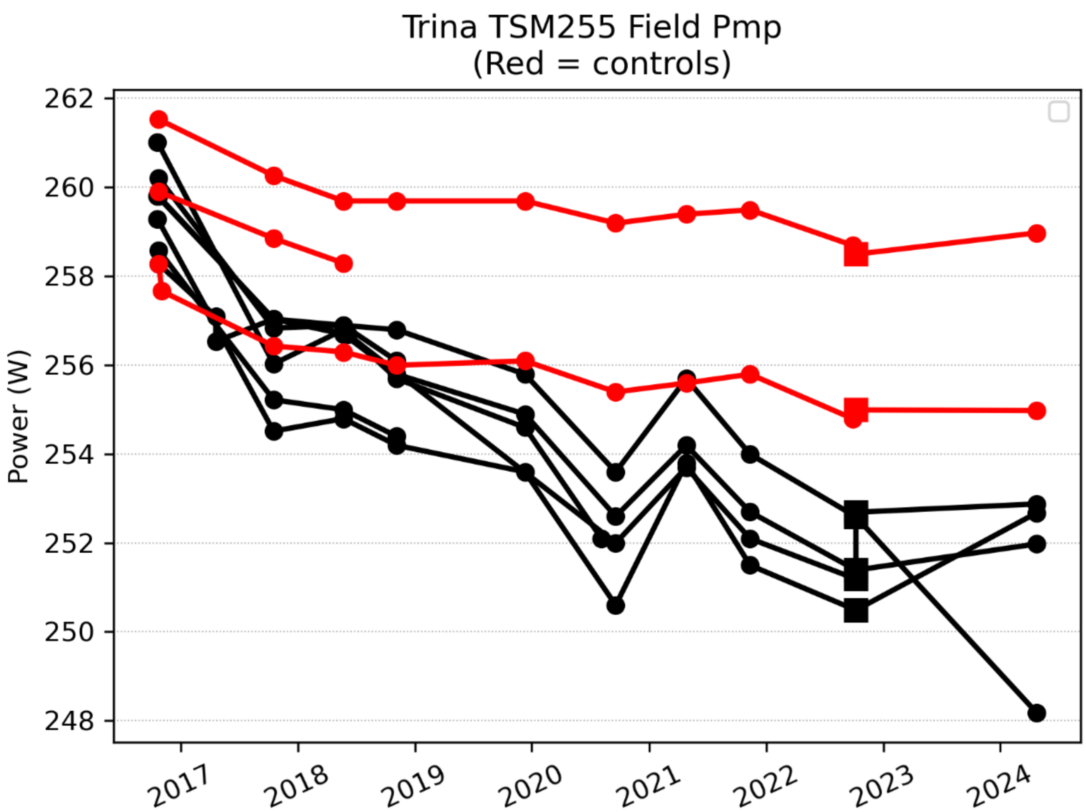

Figure 18. Trina TSM255 flash measurements. Field modules (black) and indoor controls (red). Square markers indicate Spire4600 measurement (post-correction).

2.3.1 Initial light soak

Trina TSM255 experienced 0.4% initial loss due to LID following 10kWhm-2 light exposure

2.3.2 Control module change (post-lightsoak)

Trina TSM255 control modules showed a modest overall change of −1% from 2017-2024.

2.3.3 Field module change (post-lightsoak)

The TM255 fielded modules showed only modest annual performance change and a slight amount of seasonality. Year 1 degradation was roughly −1%. Overall post-LID degradation from 2017 through early 2024 was −2.5%, or −0.34%/yr. Some seasonality in performance may still be happening, but is difficult to determine with the annual measurement frequency.

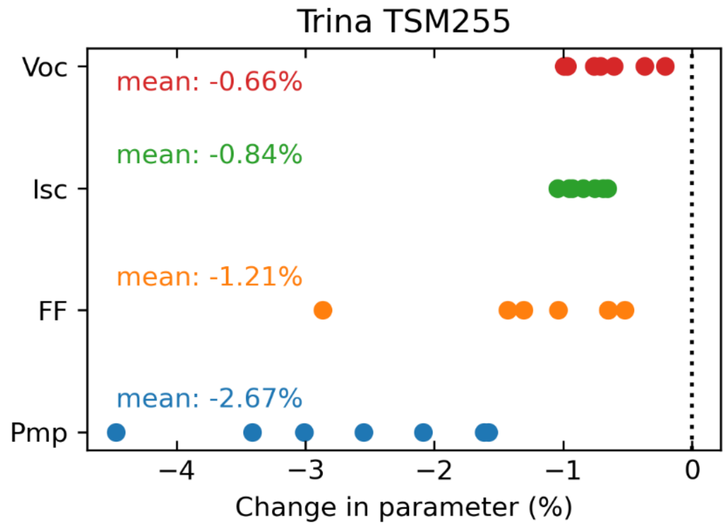

Figure 19. Trina TSM255 IV curve parameter overall change.

Overall change in performance from 2017 to 2024 for Trina TSM255 is split pretty evenly between Isc, Voc and Fill Factor.

2.4 Trina TSM260

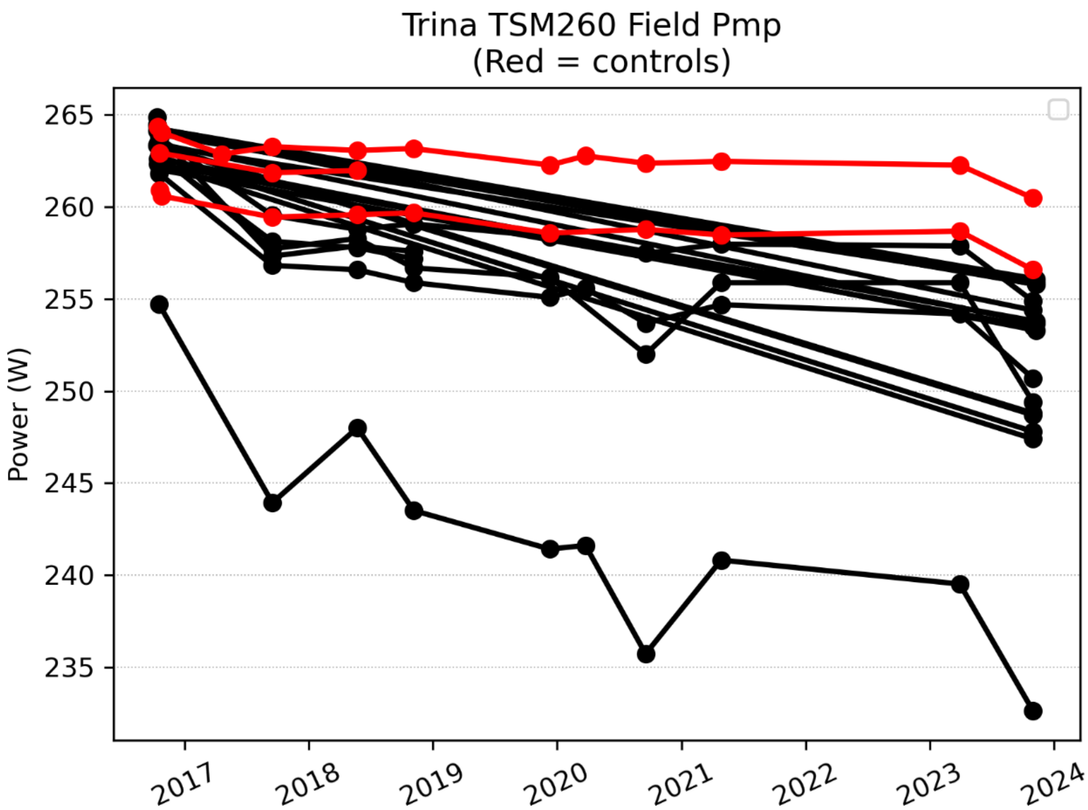

Figure 20. Trina TSM260 flash measurements. Field modules (black) and indoor controls (red)

2.4.1 Initial light soak

Trina TSM260 experienced 0.4% initial loss due to LID following 10kWhm-2 light exposure

2.4.2 Control module change (post-lightsoak)

Trina TSM260 control modules showed a modest overall change of −0.6% from 2017−2021. These modules were not re-measured in 2022.

2.4.3 Field module change (post-lightsoak)

Similar to the Jinko modules, a group of 14 modules was removed from the field to re-configure the Trina TSM260 system into a single string. These modules were measured for the final time, and results were similar to the other (well-behaved) modules in this system.

Year 1 field module degradation was roughly −2% aside from the outlier module M1610-0043 which declined −3.8% in year 1 and continued its low performance. Upon measuring EL, dramatic cell-cracks over 1/3 of the module was visible. It’s difficult to know if these cell cracks pre-date

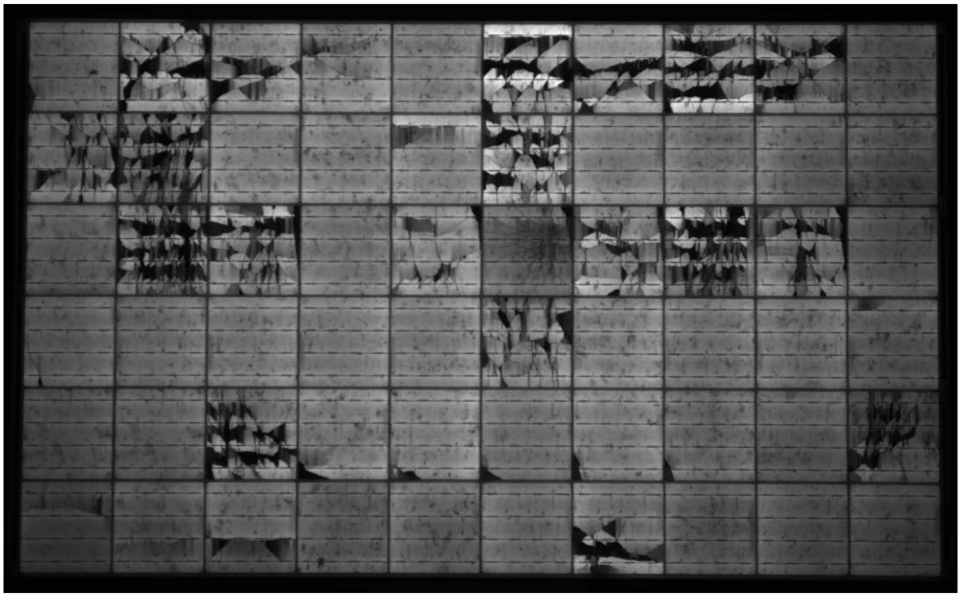

Figure 21. EL image of low performing module M1610-0043 taken in 2023. The nature of the damage (3 parallel tracks across the cell width, centered between busbars) tends to indicate manufacturing damage vs a 'bullseye' crack which would arise from a hail impact. This module's underperformance also predates the May 2017 hail event at NREL.

The TM260 fielded modules (aside from one outlier) showed only modest annual performance change. Overall post-LID degradation from 2017-2024 was −3.2%, or −0.46%/yr.

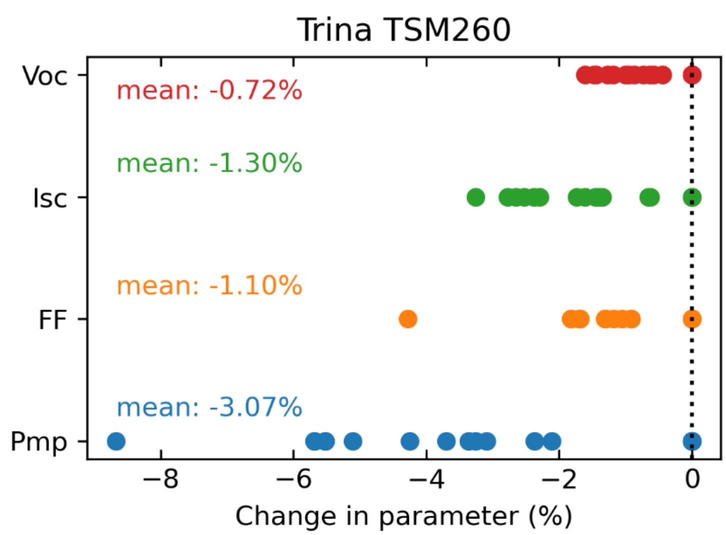

Figure 22. Trina TSM260 IV curve parameter overall change.

Overall change in performance from 2017 to 2024 for Trina TSM260 is due to both Isc, Voc and Fill Factor. The outlier module Module M1610-0043 declined most significantly in FF, which may be indicative of cell-level mismatch within the module.

When removing these 14 extra modules from the field, EL images were captured to assess the damage due to exposure to the May 2017 hail storm. While no glass cracking occurred, internal module damage and cell cracking was evident. The figure below shows an EL image taken from one of the modules that was removed in 2024. The damage to cell corners/edges and visible cracks on 10%-30% of the cells is typical of the hail-damaged modules.

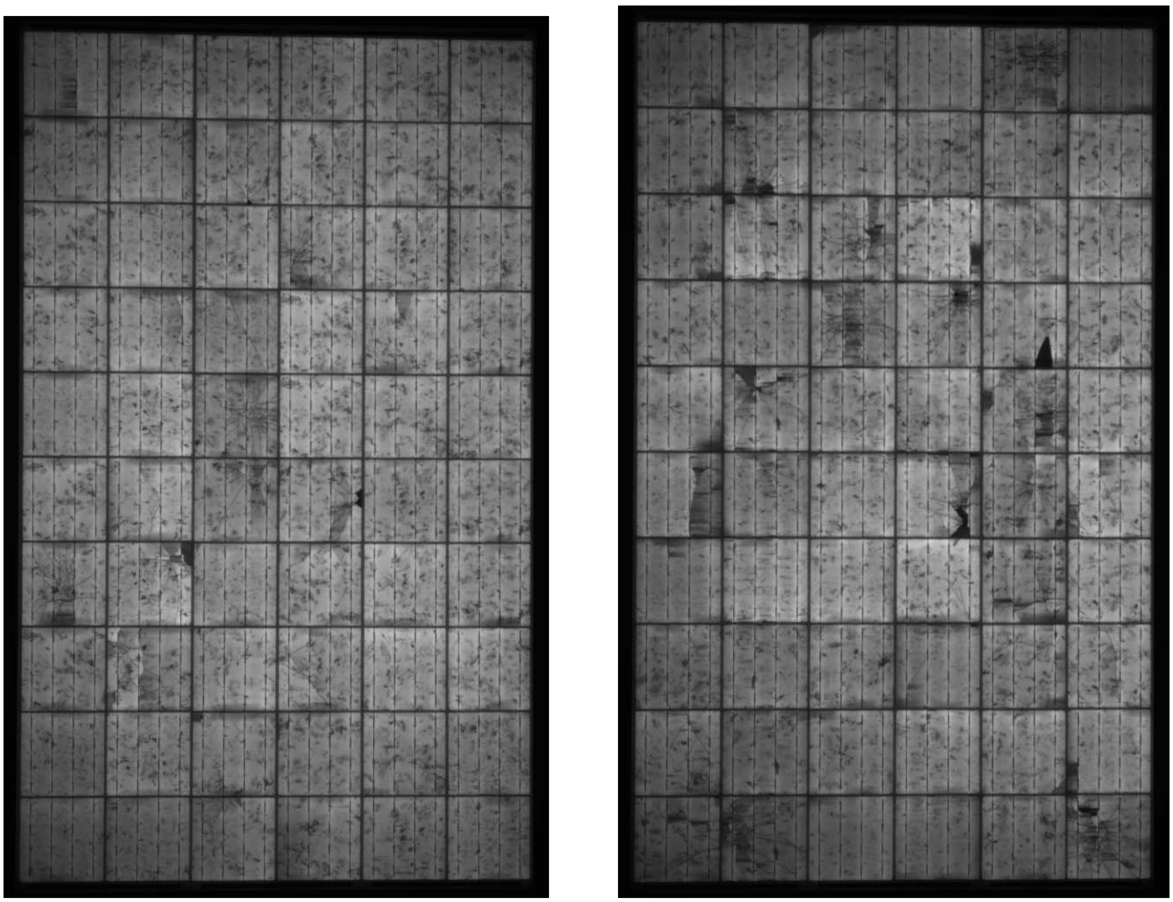

Figure 23. Trina TSM260 cell cracking following 2017 hailstorm. Damage impact and resulting measured power ranged from slight (M1610-0025, left. 255.4W) to moderate (M1610-0042, right. 251.2W).

2.5 QCells Qplus280

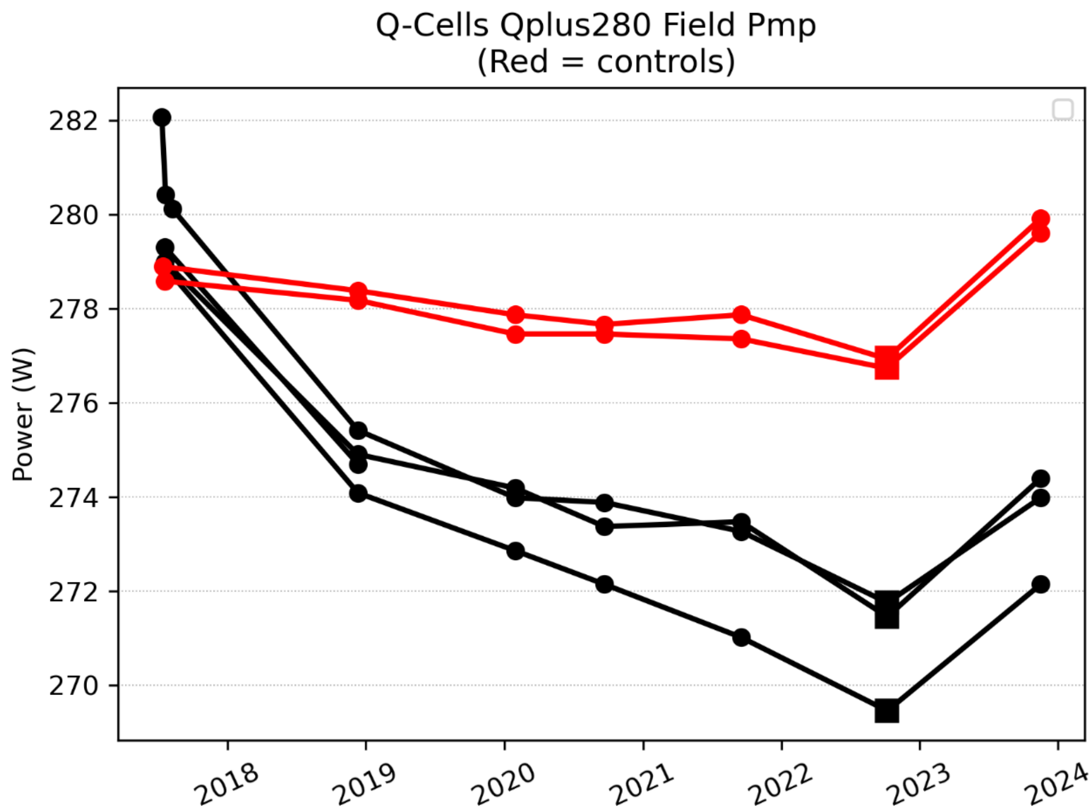

Figure 24. QCells Qplus280 flash measurements. Field modules (black) and indoor controls (red). Square markers indicate Spire4600 measurement (post-correction). In 2024 the flash simulator was changed to a different reference module, resulting in a +0.6% shift in both control and field measurements.

2.5.1 Initial light soak

QCells QPlus280 experienced 0.4% initial loss due to LID following 10kWhm-2 light exposure

2.5.2 Control module change (post-lightsoak)

In 2024 the QCells QPlus280 control modules showed a sharp increase of 1.8 W (+0.6%) compared to its previous measurements. This is an instrumentation shift that has been isolated to a change in the reference module used to set the Spire 5600 light level. This change will show up in field measurements for this module type as well, and mainly affects Isc. Field degradation statistics will not be corrected for this control module shift.

2.5.3 Field module change (post-lightsoak)

Year 1 post-lightsoak field module degradation was roughly −1.5%.

The QPlus280 fielded modules showed overall post-LID degradation from 2017-2022 of −2.9%, or −0.56 %/yr. Including the timespan to 2017-2024 makes the overall median change −2.0% or

−0.3 %/yr. This reflects the relative stability of the field samples, plus a shift in control and field measurements due to a 0.6% change in the indoor flash tester setting.

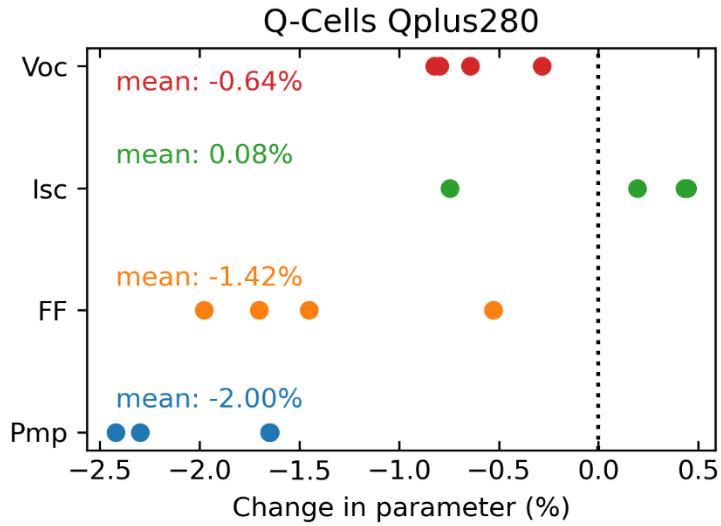

Figure 25. QCells QPlus280 IV curve parameter overall change.

Overall change in performance from 2017 to 2024 for QCells QPlus280 is more modest compared with the 2022 measurements due to a 0.6% positive shift in measured Isc.

2.6 QCells QPeak290

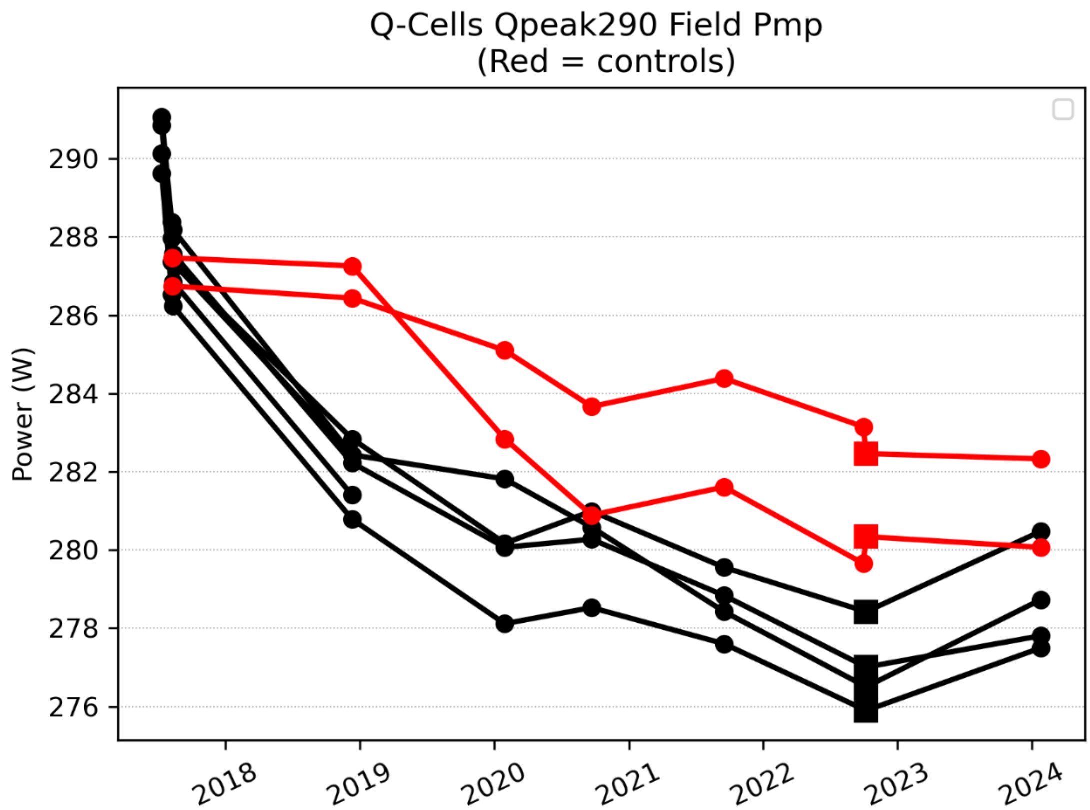

Figure 26. QCells Qpeak290 flash measurements. Field modules (black) and indoor controls (red). Square markers indicate Spire4600 measurement (post-correction).

2.6.1 Initial light soak

QCells QPlus290 experienced 1.2% initial loss due to LID following 10kWhm-2 light exposure

2.6.2 Control module change (post-lightsoak)

QCells QPeak290 control modules showed relatively unstable performance. Overall change in control modules was −2.0% on average from 2017-2024. Unlike with the QPlus280 modules, QPeak290 measurement in 2024 retained the use of the original reference module with the flash simulator. Therefore there is no instrumentation shift in measured control or field modules.

2.6.3 Field module change (post-lightsoak)

The QPeak290 fielded modules showed overall post-LID degradation from 2017-2024 of −2.8%, This is a slight improvement over the 2022 measurement of −3.4% and results in an annual rate of −0.4 %/yr.

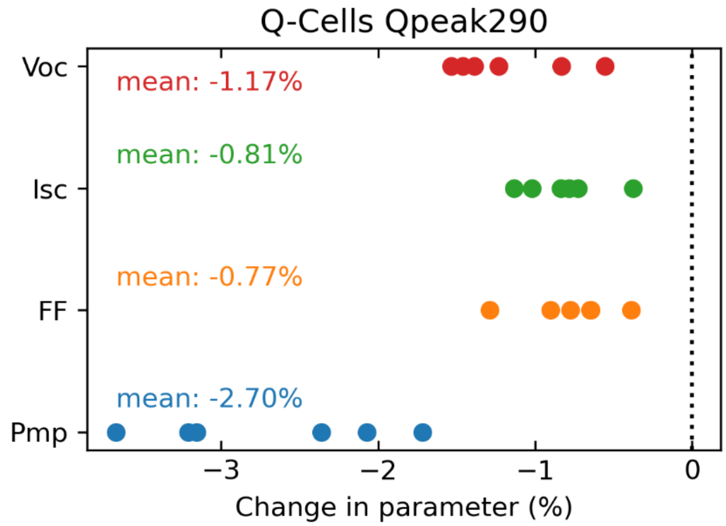

Figure 27. QCells QPeak290 IV curve parameter overall change.

Overall change in performance from 2017 to 2024 for QCells QPeak290 is due to modest changes in Isc, Fill factor and Voc.

2.7 Canadian CS6K-300MS

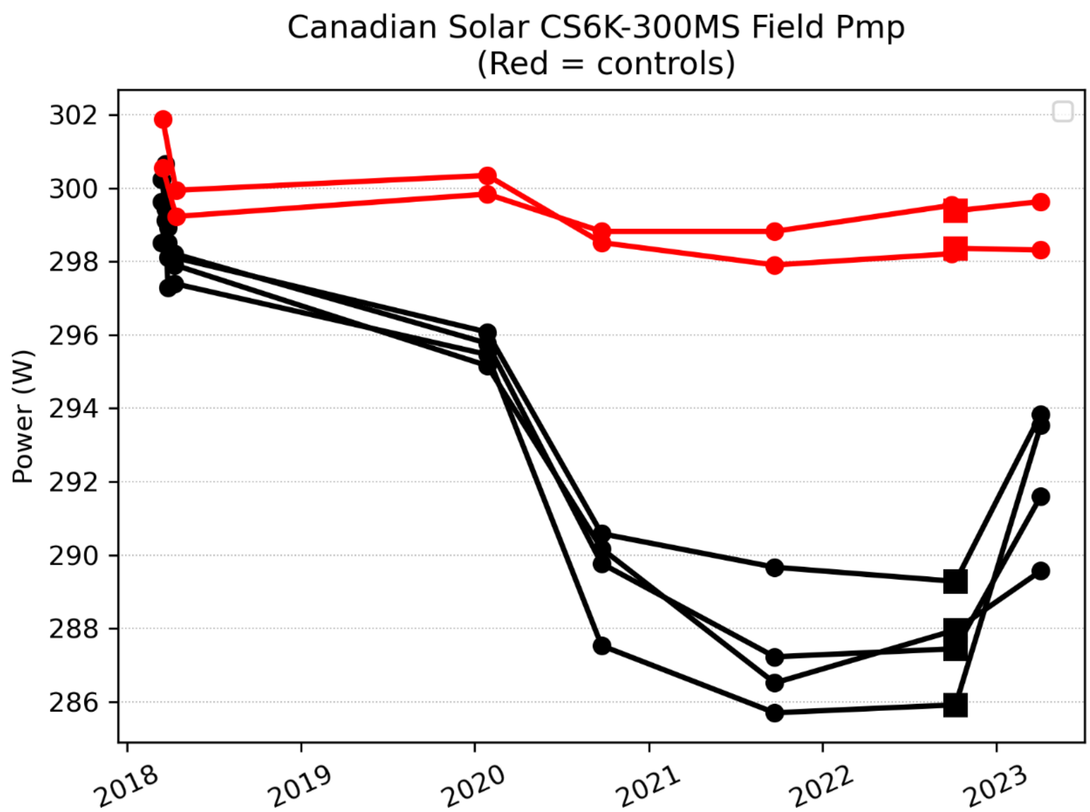

Figure 28. Canadian CS6K flash measurements. Field modules (black) and indoor controls (red). Square markers indicate Spire4600 measurement (post-correction).

2.7.1 Initial light soak

Canadian CS6K-300MS experienced −0.5% initial loss due to LID following 10kWhm-2 light exposure

2.7.2 Control module change (post-lightsoak)

Canadian CS6K-300MS control modules showed relatively stable performance with overall change < 0.25% from 2018−2024.

2.7.3 Field module change (post-lightsoak)

The CS6K-300MS fielded modules had initial stability in year-1 with only −0.4% degradation (post-LID). However, degradation accelerated starting in year-2, then stabilized in the third year. Starting in 2023 there was an apparent partial recovery, possibly as LID or LeTID effects have stabilized and recovered. Overall loss from 2018−2023 was −1.8%, or −0.37 %/yr. One un-explored factor in the Canadian Solar performance may be un-detected seasonality in the performance, similar to Jinko or Trina modules. This is because measurements shifted from springtime in year-1 to fall in years 2 and 3, and back to springtime in year-4. This could be leading to the lower measurements in the fall and higher measurements in the spring. Re-measurement of a subset of these modules in the fall may help isolate this factor.

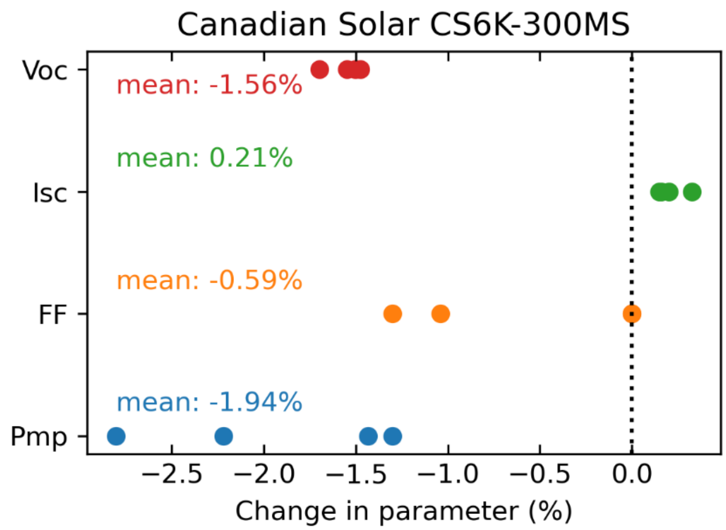

Figure 29. Canadian CS6K-300MS IV curve parameter overall change.

Degradation from 2017 to 2022 for Canadian CS6K-300MS is due primarily to Voc.

2.8 LG 320N1K

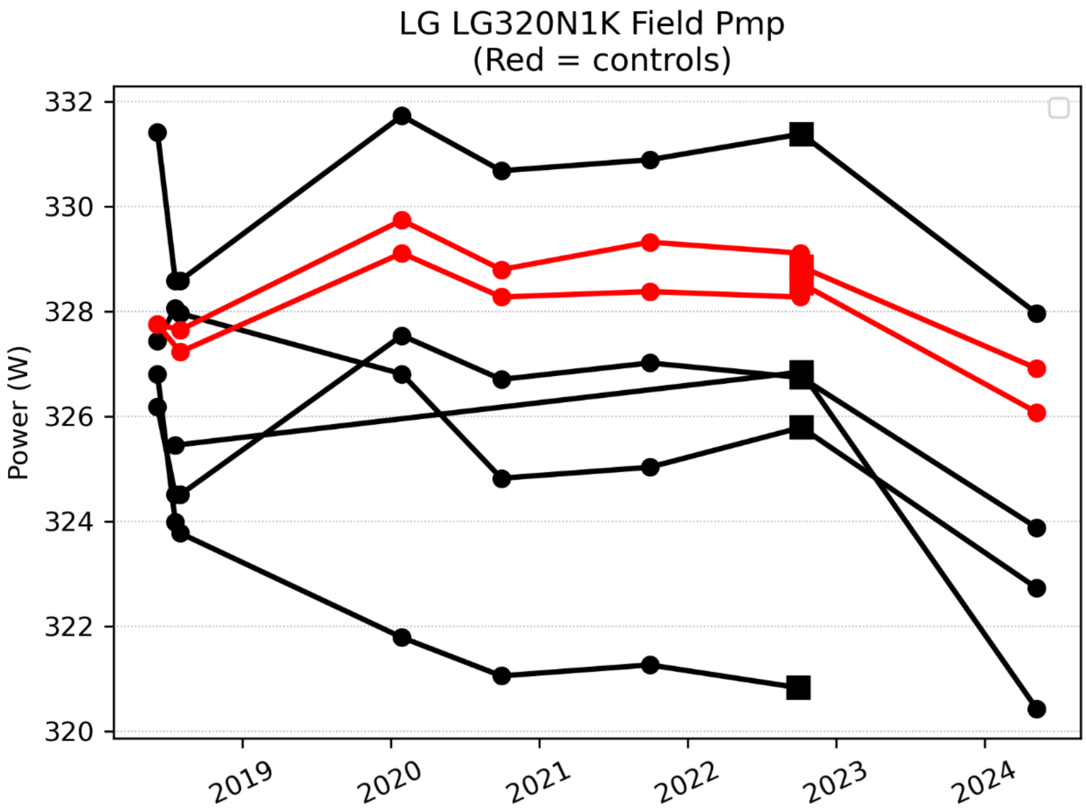

Figure 30. LG 320N1K flash measurements. Field modules (black) and indoor controls (red). Square markers indicate Spire4600 measurement (post-correction).

2.8.1 Initial light soak

LG 320N1K had no change to module performance following outdoor light soaking. This may be due to the N-type silicon technology which is not affected by the standard B-O light induced degradation effect.

2.8.2 Control module change (post-lightsoak)

Following initial light soaking, LG 320N1K control modules showed slight performance changes. Performance initially increased by roughly 0.3%. from 2018−2022, but declined from 2023−2024 for a total change of −0.4%. There was no apparent change in the indoor flash tester configuration during this time, so this may be a physical change in both control and field modules.

2.8.3 Field module change (post-lightsoak)

The LG 320N1K fielded modules showed variable performance with modules increasing in performance for 3−4 years and more recently declining. This leads to overall median post-LID degradation from 2018-2024 of −1.2%, or −0.21%/yr. One module (M1806-0005) was found to have cell cracking which led to low performance and it was removed and will be monitored in a separate cell-crack testbed.

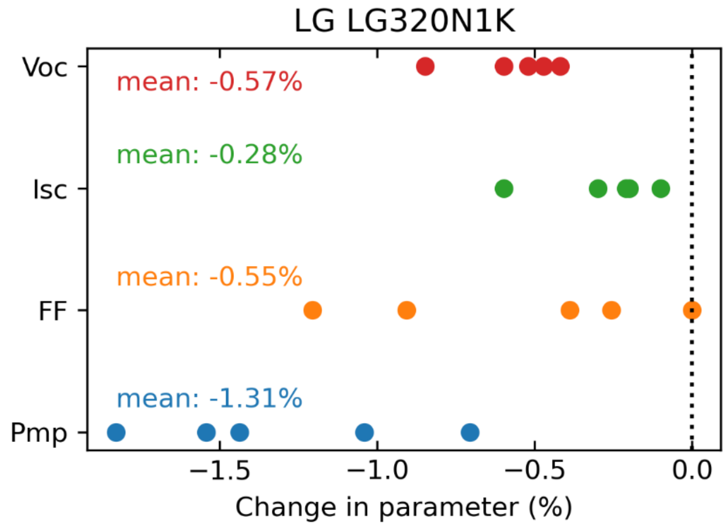

Figure 31. LG 320N1K IV curve parameter overall change.

Overall change in performance from 2018 to 2024 for LG 320N1K is stable, without much change in any particular parameter.

EL imaging of module M1806-0005 shows clear cell cracking in five locations, corroborating the drop in performance.

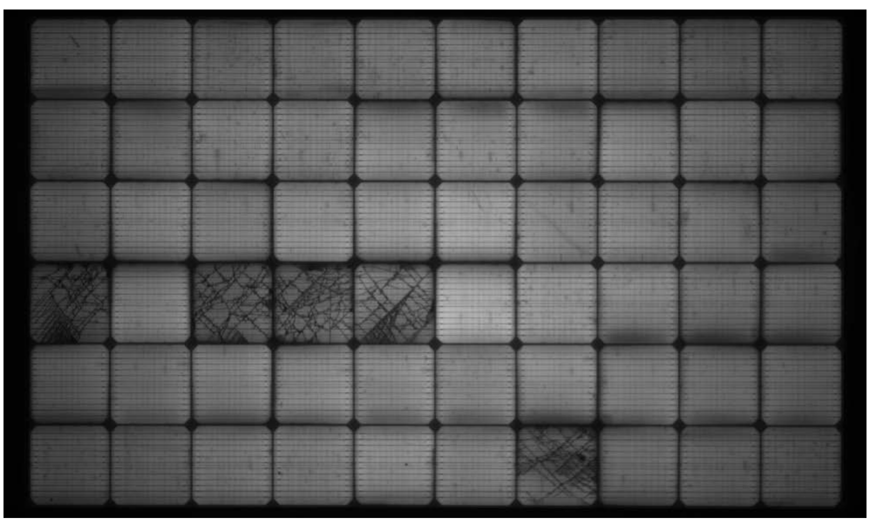

Figure 32. EL image of LG M1806-0005 showing cell cracking. The cause is unknown, but may have happened during installation.

2.9 Panasonic VBHN330

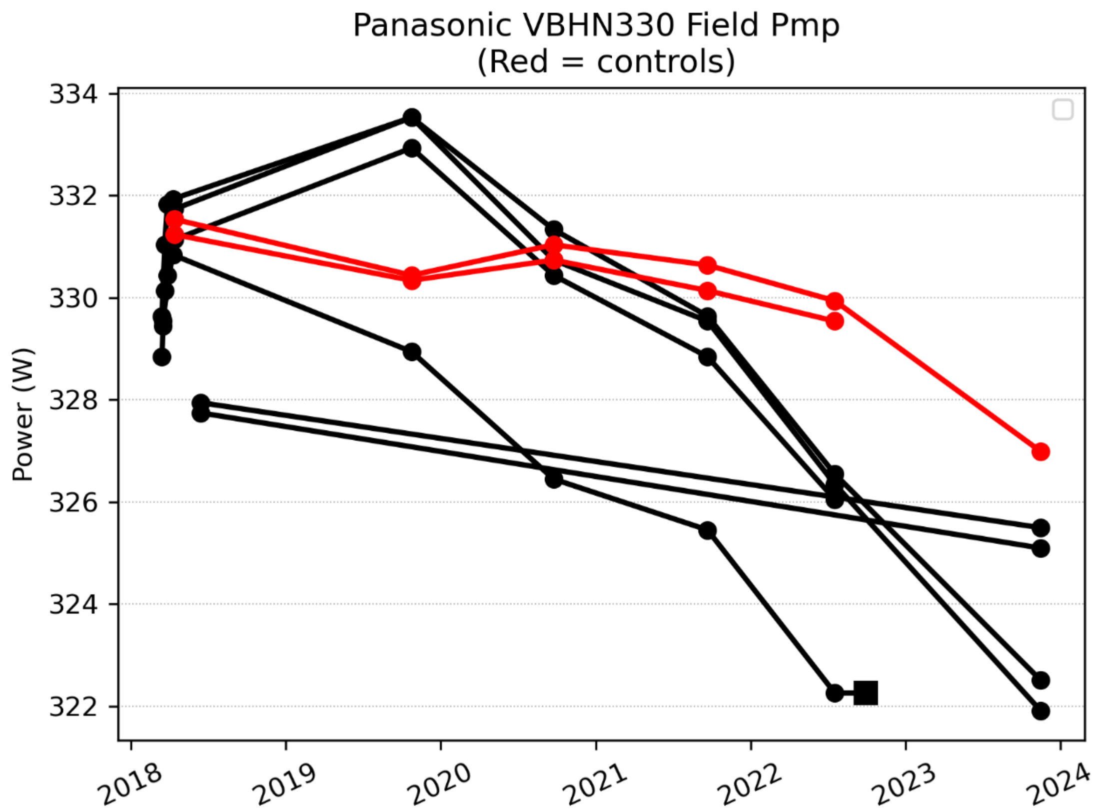

Figure 33. Panasonic flash measurements. Field modules (black) and indoor controls (red)

2.9.1 Initial light soak

Panasonic VBHN330 showed an actual increase in module performance of 0.5% through light soaking. This may be due to the N-type silicon heterojunction technology which is not affected by the standard B-O light induced degradation effect.

2.9.2 Control module change (post-lightsoak)

Following initial light soaking control modules showed a relative decline of −1%.

2.9.3 Field module change (post-lightsoak)

Year 1 field module performance showed three modules increasing slightly, and one module declining in performance. Following this year-1 increase, all modules continued to decline at a consistent rate.

Although it was monitored for several years, this low-performing module (M1803-0002) was found to have a backsheet that was scratched during shipping that was identified prior to installation. It was eventually removed from this experiment, and diverted to a separate cell-crack monitoring experiment. In 2024, two different field modules were measured in the place of this cracked module

The VBHN330 fielded modules measured in 2024 showed median post-LID degradation from 2018-2024 of −2% or −0.37%/yr. Interestingly, the newly measured modules flashed 3−4W higher than those previously measured, despite the same exposure history and indoor measurement setup.

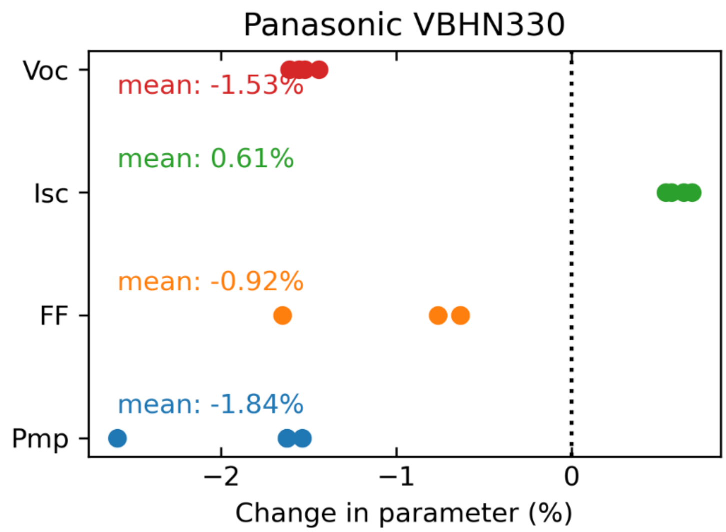

Figure 34. Panasonic VBHN330 IV curve parameter overall change.

Overall change in performance for Panasonic is due mainly to decreases in Voc offset by increases in Isc. The one module showing overall degradation was actually due to a large drop in Fill Factor, which might be indicative of cell-level mismatch. As mentioned above, this module had some handling damage, and the reduced fill factor indicates multiple cracked cells. Follow-up electroluminescence imaging investigation shows that three cells are damaged.

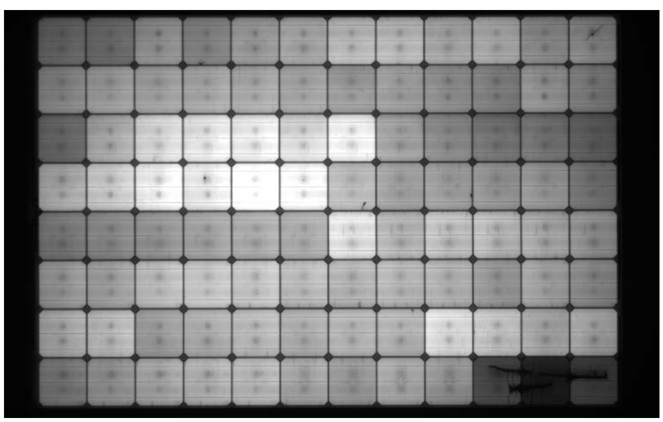

Figure 35. Panasonic module M1803-0002 showing three damaged cells.

2.10 Mission Solar MSE360

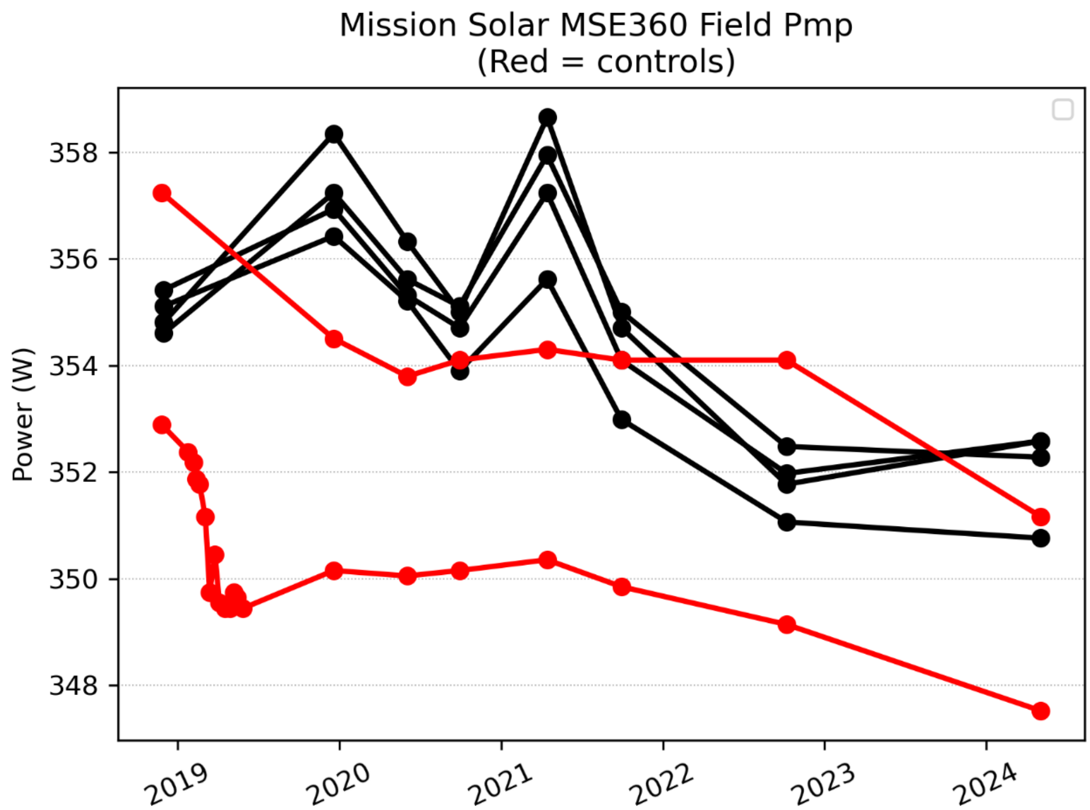

Figure 36. Mission Solar flash measurements. Field modules (black) and indoor controls (red)

2.10.1 Initial light soak

Mission Solar MSE360 modules did not have initial measurements taken of the first 10kWhm^{-2} of light exposure. However, a pronounced LeTID sensitivity was identified via indoor test screening. Two samples showed a recoverable 3%-5% LeTID performance change in response to the LeTID screening procedure of Karas et al (2022).

2.10.2 Control module change (post-lightsoak)

Mission Solar MSE360 control modules showed an initial fast degradation over the first year which leveled out, showing a total degradation of -1% in 2022. An additional decline was found again in 2024, for a total change of −1.6%. Initial performance loss is visible by periodic indoor IV curves as the control modules are maintained in dark storage. No specific changes were made in the indoor flash test procedure, so this may either be a physical effect or an as-yet unidentified instrumentation shift.

2.10.3 Field module change (post-lightsoak)

Outdoor exposed fielded modules on the other hand are showing seasonal performance changes, which may be indicative of LeTID sensitivity. These modules in particular were shown to be LeTID sensitive per LeTID screening tests and described in [Repins, 2020].

Overall post-LID performance of the field modules is showing median performance change of -0.7% or -0.1%/yr. As with Jinko and Trina modules, some seasonality may still be present in the Mission Solar measurements, but with annual measurement frequency this is not visible in the figures. Interestingly, at this point in the experiment the indoor control modules have declined more than the outdoor exposure modules for Mission Solar MSE360.

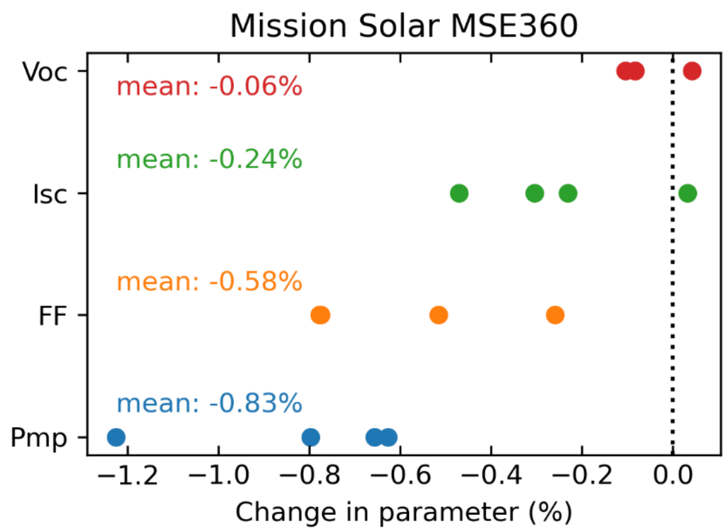

Figure 37. Mission Solar MSE360 IV curve parameter overall change.

Overall change in performance for Mission Solar MSE360 is characterized by only marginal changes in IV parameters.

2.11 Sunpreme HxB-400 (n-type heterojunction) Bifacial

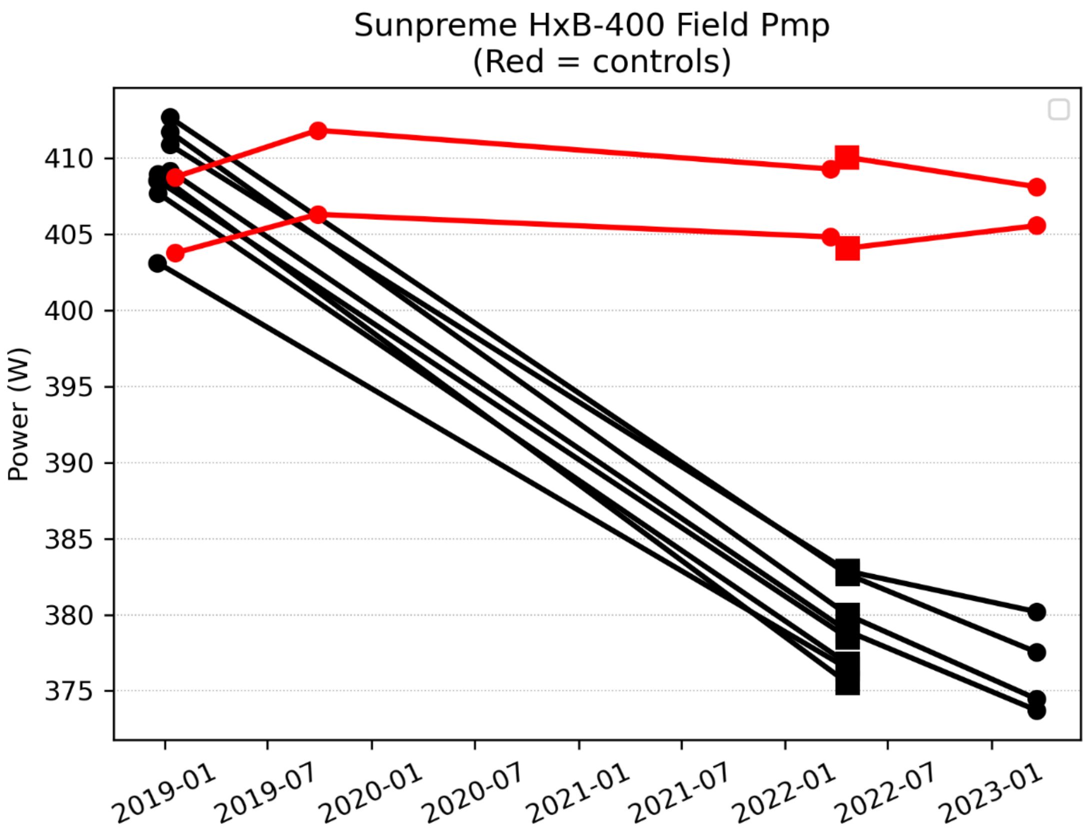

Figure 38. Sunpreme flash measurements. Field modules (black) and indoor controls (red). Square markers indicate Spire4600 measurement (post-correction).

2.11.1 Initial light soak

Sunpreme bifacial modules did not have initial measurements taken of the first $10kWhm^{-2}$ of light exposure.

2.11.2 Control module change (post-lightsoak)

Sunpreme HxB-400 control modules are stable, showing an actual performance increase of 0.2% from 2019- 2024.

2.11.3 Field module change (post-lightsoak)

Outdoor exposed fielded modules have experienced major losses, visible in the figure above. Overall post-LID performance of the field modules is showing median performance change of -7.9% overall or -1.9% per year. To confirm this large decline, real-time field data was analyzed during the string's operation. A similar -2%/yr degradation rate was also found using the RdTools analysis package, giving confidence in these numbers.

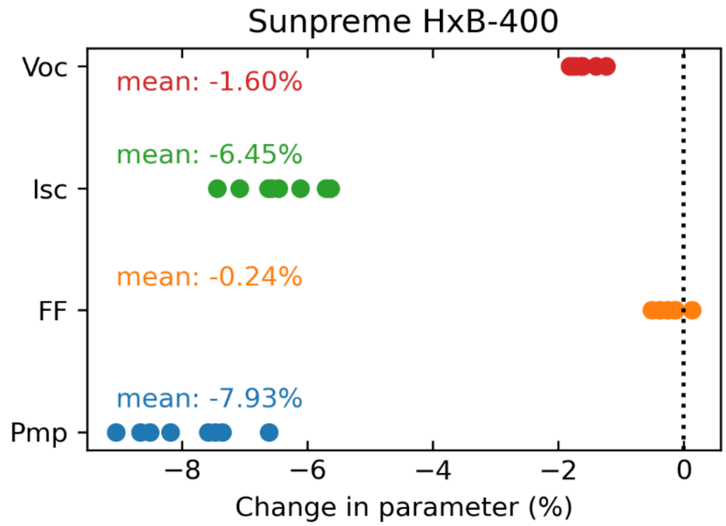

Figure 39. Sunpreme HxB-400 bifacial IV curve parameter overall change.

Overall change in performance for Sunpreme HxB-400 is characterized by a large decrease in Isc. The other two parameters —Voc and Fill Factor are relatively stable. Further study is ongoing to understand the causes of this Isc decline. It is primarily present in front-side Isc decline, rather than the backside of the bifacial module. UV degradation and PID-p (polarization type) degradation are being probed.

2.12 LONGi LR6-72BP-360M (mono-PERC bifacial)

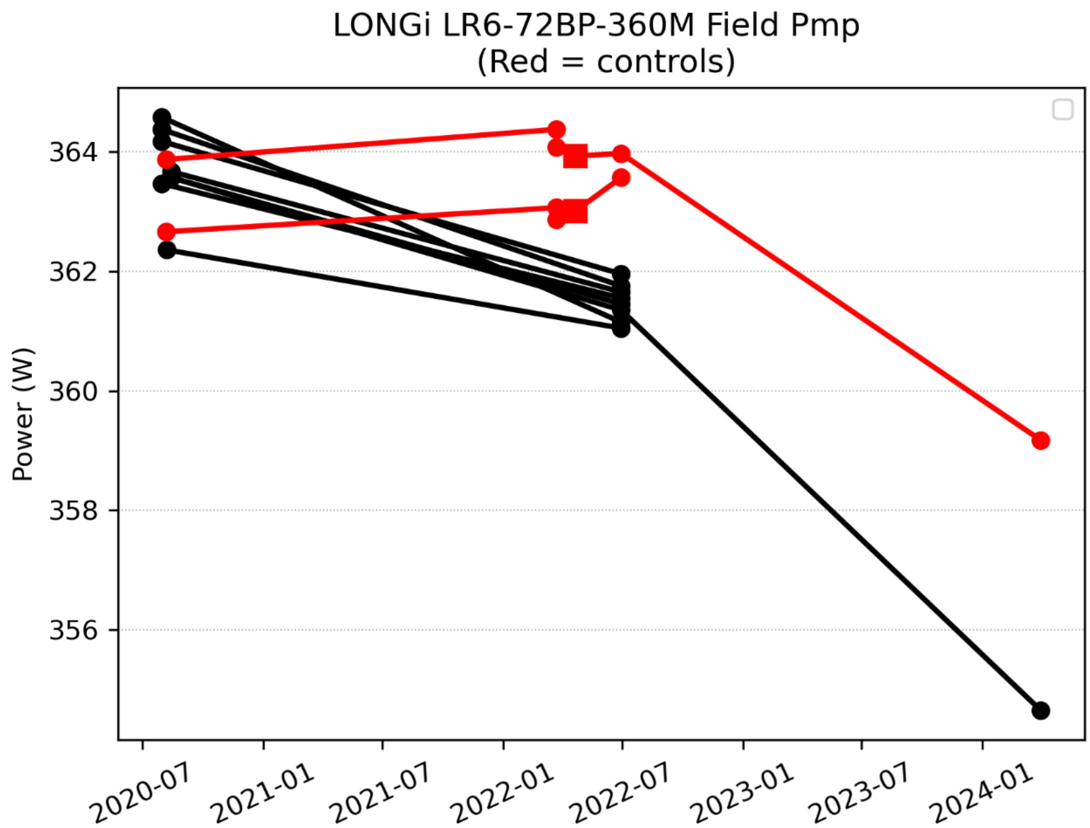

Figure 40. LONGi flash measurements. Field modules (black) and indoor controls (red)

2.12.1 Initial light soak

LONGi LR6-72BP-360 bifacial modules did not have initial measurements taken of the first 10kWhm^{-2} of light exposure.

2.12.2 Control module change (post-lightsoak)

LONGi LR6-72BP control modules showed a recent decline in 2024, with a total reduction of −0.5%. As with other module types which showed comparable declines in control module performance, this might either be a physical effect in the modules or an as-yet unidentified shift in the flash simulator instrumentation.

2.12.3 Field module change (post-lightsoak)

Outdoor exposed fielded modules showed performance comparable to the indoor control modules. Rear measurements (not shown) show stable performance.

Overall post-LID performance of the field modules is showing median performance change of −0.6% or −0.17%/yr. This is comparable to the −0.5% shift in the control modules.

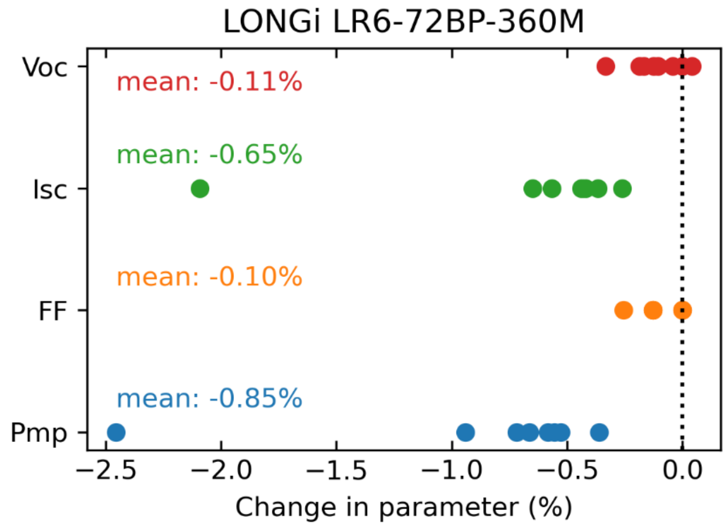

Figure 41. LONGi LR6-72BP-360M bifacial IV curve parameter overall change.

Overall change in performance for LONGi LR6-72BP is characterized by a slight reduction in Isc and stable performance in Voc and FF.

2.13 LONGi LR6-72PH-365M (mono-PERC monofacial)

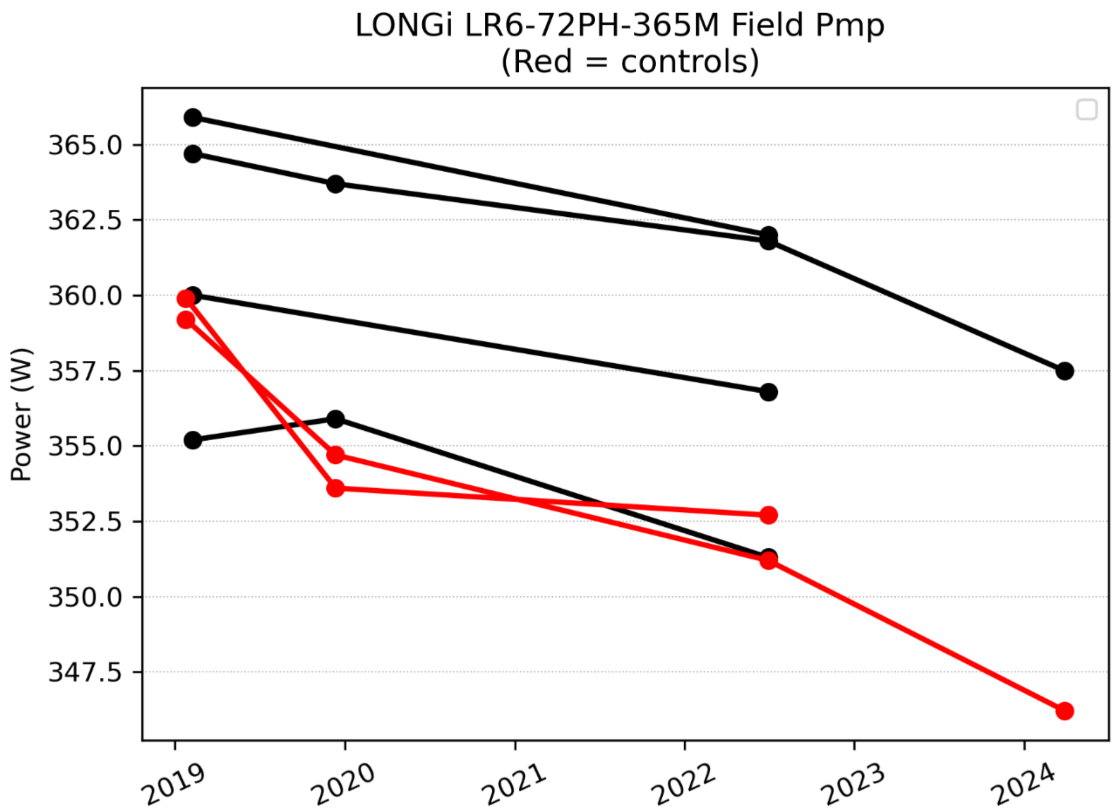

Figure 42. LONGi LR6-72PH flash measurements. Field modules (black) and indoor controls (red)

2.13.1 Initial light soak

LONGi LR6-72PH-365 monofacial modules did not have initial measurements taken of the first 10kWhm^{-2} of light exposure.

2.13.2 Control module change (post-lightsoak)

LONGi LR6-72PH-365 control modules actually declined more than field modules, showing a performance decline of −2.8% from 2019− 2024.

2.13.3 Field module change (post-lightsoak)

Outdoor exposed fielded modules have only modest declines relative to the indoor control modules. Overall post-LID performance of the field modules is showing median performance change of −1% or −0.2%/yr.

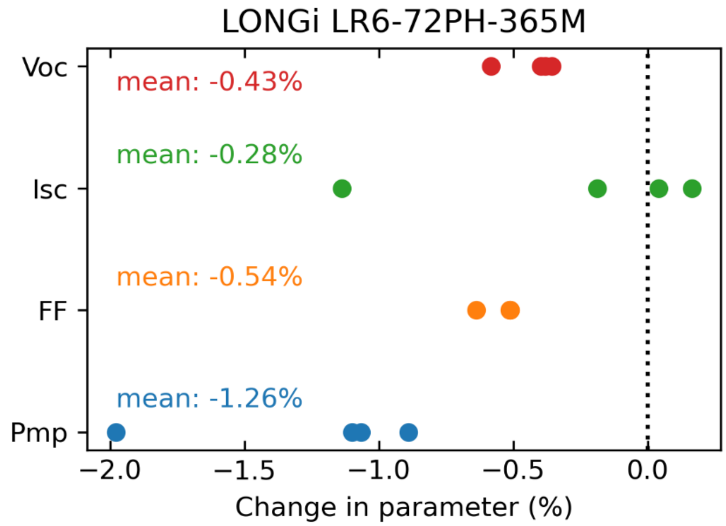

Figure 43. LONGi LR6-72PH-365 monofacial IV curve parameter overall change.

Overall change in performance for LONGi LR6-72PH-365 is characterized by relatively stable performance from 2019-2024.

3 Degradation Summary

Cumulative results are provided below for the various manufacturer and module types, for the median fielded module. Values are total cumulative percentage change, except for annualized values where noted. Values do not correct for any performance change in indoor control modules or instrumentation shifts unless noted above.

Table 2. Overall change in performance [%] over the deployment period

Manufacturer	Module type	Year deployed	Pmp Median [Annual %/yr]	Pmp Median	Voc Median	Isc Median	FF Median
Jinko	JKM260	10/2016	-0.50	-3.92	-1.27	-2.30	-0.26
Jinko	JKM265	10/2016	-0.55	-4.06	-1.10	-1.95	-1.05
Trina	TSM255	10/2016	-0.36	-2.55	-0.71	-0.84	-1.04
Trina	TSM260	10/2016	-0.43	-3.25	-0.74	-1.40	-1.17
Q-Cells	Qplus280	10/2017	-0.32	-1.97	-0.72	0.31	-1.58
Q-Cells	Qpeak290	10/2017	-0.42	-2.76	-1.31	-0.81	-0.71
Mission Solar	MSE360	12/2018	-0.15	-0.73	-0.08	-0.27	-0.65
LG	LG320N1K	8/2018	-0.22	-1.44	-0.52	-0.21	-0.39
Canadian Solar	CS6K-300MS	8/2018	-0.39	-1.83	-1.53	0.18	-0.52
Panasonic	VBHN330	6/2018	-0.34	-2.06	-1.50	0.43	-0.63
SunPreme	HxB-400	3/2019	-1.86	-7.88	-1.63	-6.52	-0.26
LONGi	LR6-72BP-360M	11/2020	-0.23	-0.62	-0.11	-0.43	-0.13
LONGi	LR6-72PH-365M	11/2020	-0.24	-1.08	-0.39	-0.07	-0.51

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Ndione PF et al., "Combining Indoor and Outdoor Measurements to Lower Uncertainty in PV Modules Performance," 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), 2020, pp. 2185-2187, https://doi.org/10.1109/PVSC45281.2020.9300723.

Repins, Ingrid L., Kersten, F., Hallam, B., VanSant, Kaitlyn, and Koentopp, M. B. "Stabilization of light-induced effects in Si modules for IEC 61215 design qualification." *Solar Energy* **208** 2020. https://doi.org/10.1016/j.solener.2020.08.025.

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Karas J, Repins I, Berger K, Kubicek B, Jiang F, Zhang D, Jaubert JN, Cuelie AB, Sample T, Jaeckel B, Pander M, Fokuhl E, Koentopp M, Kersten F, Choi JH, Bora B, Banerjee C, Wendlandt S, Erion Lorico T, Sauer KJ, Tsan J, Pravettoni M, Caccivio M, Bellenda G, Monokroussos C, Maaroufi H. "Results from an international interlaboratory study on light- and elevated temperature-induced degradation in solar modules", Progress in Photovoltaics 2022 http://doi.org/10.1002/pip.3573

Repins IL, Jordan D, Woodhouse M, Theristis M, Stein JS, Seigneur H, Colvin D, Karas JF, McPherson AN, Deline C "Long-Term Impact of Light and Elevated Temperature Induced Degradation on Photovoltaic Arrays", MRS Impact, submitted

Appendix 1 – Raw Data Results

Extract of all IV curve data for control and field modules. Measurements may be normalized depending on simulator settings which changed from 2016 - 2017 for the Jinko and Trina measurements, and all measurements which were made on the Spire 4600.

A.1 Jinko JKM260 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0013	9/7/2017 10:39	260.4	9.013	37.83	76.8
M1609-0013	9/19/2016 11:06	261.2	9.022	37.85	76.9
M1609-0065	9/7/2017 10:35	258.6	8.981	37.78	76.6
M1609-0065	9/20/2016 12:29	259.4	9.010	37.78	76.6
M1609-0086	4/18/2024 10:17	261.0	9.050	37.85	76.6
M1609-0086	9/9/2022 9:07	260.4	9.029	37.83	76.7
M1609-0086	4/7/2021 11:32	260.9	9.044	37.84	76.7
M1609-0086	9/15/2020 10:44	260.4	9.040	37.81	76.6
M1609-0086	6/3/2019 8:40	261.5	9.050	37.87	76.7
M1609-0086	10/29/2018 10:44	261.1	9.051	37.83	76.7
M1609-0086	5/10/2018 8:20	261.6	9.054	37.87	76.7
M1609-0086	9/11/2017 8:42	261.9	9.067	37.90	76.6
M1609-0086	10/17/2016 10:20	263.2	9.095	37.91	76.8
M1609-0086	10/12/2016 9:25	264.5	9.105	37.98	76.9
M1609-0087	9/29/2022 15:40	256.9	8.993	37.55	76.3
M1609-0087	9/9/2022 8:56	257.0	8.988	37.70	76.3
M1609-0087	4/7/2021 11:37	257.2	9.006	37.68	76.2
M1609-0087	9/15/2020 10:35	256.9	8.998	37.66	76.2
M1609-0087	3/24/2020 10:29	258.0	9.010	37.75	76.3
M1609-0087	6/3/2019 8:44	257.9	9.018	37.71	76.2
M1609-0087	10/29/2018 10:31	258.2	9.017	37.78	76.2
M1609-0087	5/10/2018 8:26	257.8	9.026	37.70	76.2
M1609-0087	9/7/2017 10:25	258.0	9.019	37.71	76.3
M1609-0087	10/17/2016 10:31	258.9	9.042	37.72	76.3
M1609-0087	10/12/2016 9:16	260.0	9.054	37.78	76.4

A.2 Jinko JKM260 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0014	1/11/2024 9:43	248.3	8.776	37.19	76.5
M1609-0014	9/19/2016 11:02	260.4	9.026	37.79	76.8
M1609-0015	1/4/2024 10:29	251.7	8.827	37.41	76.6
M1609-0015	9/19/2016 10:59	261.8	9.036	37.91	76.9
M1609-0016	1/4/2024 9:59	246.3	8.737	37.14	76.3
M1609-0016	9/19/2016 10:55	260.2	9.015	37.82	76.8
M1609-0017	1/11/2024 9:47	251.1	8.833	37.40	76.4
M1609-0017	9/19/2016 10:51	261.3	9.033	37.88	76.8
M1609-0018	1/4/2024 10:09	249.9	8.741	37.30	77.0
M1609-0018	9/19/2016 10:48	261.0	9.036	37.83	76.8
M1609-0019	1/11/2024 9:53	248.9	8.782	37.24	76.5
M1609-0019	9/19/2016 10:44	260.3	9.035	37.77	76.7
M1609-0020	1/4/2024 10:13	249.7	8.818	37.30	76.3
M1609-0020	9/19/2016 10:36	261.1	9.060	37.80	76.7
M1609-0046	1/11/2024 9:58	250.9	8.772	37.40	76.9
M1609-0046	9/20/2016 12:06	259.4	9.031	37.72	76.6
M1609-0047	4/18/2024 10:39	253.8	8.900	37.45	76.6
M1609-0047	9/9/2022 8:43	248.6	8.764	37.22	76.6
M1609-0047	4/7/2021 11:26	250.1	8.806	37.27	76.6
M1609-0047	9/15/2020 10:23	245.2	8.714	37.00	76.4
M1609-0047	3/24/2020 10:38	250.8	8.819	37.32	76.6
M1609-0047	6/3/2019 8:31	254.8	8.909	37.51	76.7
M1609-0047	10/29/2018 10:57	249.7	8.784	37.26	76.7
M1609-0047	5/10/2018 9:47	252.5	8.844	37.41	76.7
M1609-0047	9/11/2017 9:30	250.5	8.782	37.35	76.8
M1609-0047	9/20/2016 11:37	259.4	9.010	37.73	76.8
M1609-0048	1/11/2024 10:03	251.9	8.843	37.45	76.5
M1609-0048	9/20/2016 11:48	259.8	9.043	37.73	76.6
M1609-0049	1/11/2024 10:16	252.0	8.890	37.45	76.1
M1609-0049	9/20/2016 11:45	259.5	9.062	37.74	76.3
M1609-0055	4/18/2024 10:32	251.7	8.829	37.39	76.7
M1609-0055	9/9/2022 8:50	243.4	8.683	36.95	76.3
M1609-0055	4/7/2021 11:12	244.9	8.721	37.00	76.3
M1609-0055	9/15/2020 10:11	240.7	8.649	36.77	76.1
M1609-0055	9/15/2020 10:09	241.0	8.648	36.79	76.2
M1609-0055	3/24/2020 10:57	247.8	8.723	37.20	76.8
M1609-0055	6/3/2019 8:22	253.9	8.895	37.48	76.6
M1609-0055	10/29/2018 11:06	247.3	8.710	37.16	76.8
M1609-0055	5/10/2018 9:27	252.0	8.834	37.40	76.7
M1609-0055	9/11/2017 9:03	248.6	8.778	37.23	76.5

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0055	9/20/2016 11:39	259.3	9.021	37.72	76.6
M1609-0057	1/4/2024 10:19	248.1	8.705	37.23	77.0
M1609-0057	9/20/2016 12:02	259.9	9.051	37.71	76.6
M1609-0058	10/29/2018 10:51	249.2	8.817	37.24	76.3
M1609-0058	5/10/2018 9:41	253.0	8.892	37.46	76.4
M1609-0058	9/11/2017 9:16	250.4	8.842	37.35	76.2
M1609-0058	9/20/2016 12:25	260.9	9.023	37.83	76.9
M1609-0059	9/29/2022 15:33	250.2	8.855	37.19	76.2
M1609-0059	9/9/2022 8:28	250.1	8.864	37.33	76.0
M1609-0059	4/7/2021 11:21	252.8	8.915	37.44	76.2
M1609-0059	9/15/2020 10:29	248.4	8.830	37.22	76.0
M1609-0059	6/3/2019 8:36	255.8	8.956	37.59	76.4
M1609-0059	10/29/2018 11:14	252.9	8.899	37.47	76.3
M1609-0059	5/10/2018 9:52	255.1	8.959	37.55	76.3
M1609-0059	9/11/2017 9:26	253.3	8.913	37.51	76.2
M1609-0059	9/20/2016 12:16	260.5	9.050	37.80	76.6
M1609-0061	1/11/2024 10:07	249.7	8.758	37.35	76.7
M1609-0061	9/20/2016 12:11	259.7	9.028	37.77	76.6
M1609-0062	1/4/2024 10:24	251.2	8.838	37.37	76.5
M1609-0062	9/20/2016 12:14	260.5	9.027	37.77	76.8
M1609-0063	1/4/2024 10:35	247.9	8.753	37.27	76.4
M1609-0063	9/20/2016 12:08	259.8	9.033	37.75	76.6
M1609-0065	4/18/2024 10:49	252.7	8.882	37.47	76.4
M1609-0065	9/7/2017 10:35	258.6	8.981	37.78	76.6
M1609-0065	9/20/2016 12:29	259.4	9.010	37.78	76.6
M1609-0066	4/18/2024 10:27	253.3	8.868	37.44	76.7
M1609-0066	9/9/2022 8:36	248.1	8.773	37.21	76.4
M1609-0066	4/7/2021 11:16	250.6	8.825	37.30	76.5
M1609-0066	9/15/2020 10:02	246.0	8.723	37.07	76.5
M1609-0066	3/24/2020 10:46	252.2	8.836	37.40	76.7
M1609-0066	6/3/2019 8:27	255.7	8.935	37.55	76.7
M1609-0066	10/29/2018 11:02	251.5	8.811	37.37	76.8
M1609-0066	5/10/2018 9:32	255.2	8.915	37.55	76.7
M1609-0066	9/11/2017 9:12	252.2	8.831	37.42	76.7
M1609-0066	9/20/2016 11:07	260.3	9.037	37.75	76.7

A.3 Jinko JKM265 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0029	9/12/2022 13:13	262.3	9.100	37.95	76.2
M1609-0029	10/5/2021 8:41	263.5	9.117	38.02	76.3
M1609-0029	4/7/2021 8:13	263.6	9.121	38.02	76.3
M1609-0029	9/15/2020 9:50	263.5	9.112	38.04	76.3
M1609-0029	6/3/2019 8:48	263.9	9.120	38.04	76.3
M1609-0029	10/29/2018 9:55	263.6	9.119	38.02	76.3
M1609-0029	5/10/2018 8:08	263.4	9.125	37.98	76.3
M1609-0029	9/7/2017 11:40	264.0	9.112	38.03	76.4
M1609-0029	9/1/2017 11:14	263.8	9.121	37.99	76.4
M1609-0029	9/19/2016 14:21	264.1	9.110	38.00	76.5
M1609-0032	9/12/2022 13:30	260.8	9.103	38.02	75.6
M1609-0032	10/5/2021 8:46	261.6	9.120	38.05	75.6
M1609-0032	4/7/2021 8:19	262.2	9.124	38.10	75.7
M1609-0032	9/15/2020 9:56	261.7	9.114	38.07	75.7
M1609-0032	3/24/2020 11:03	262.4	9.135	38.10	75.6
M1609-0032	6/3/2019 8:52	262.4	9.138	38.08	75.7
M1609-0032	10/29/2018 9:43	262.1	9.144	38.07	75.6
M1609-0032	5/10/2018 8:15	262.4	9.148	38.07	75.6
M1609-0032	9/7/2017 11:32	262.7	9.150	38.09	75.6
M1609-0032	9/1/2017 10:41	262.7	9.147	38.08	75.7
M1609-0032	9/19/2016 14:08	262.2	9.139	38.01	75.7
M1609-0035	9/7/2017 11:30	263.8	9.146	38.01	76.1
M1609-0035	9/19/2016 14:17	263.9	9.135	38.03	76.2
M1609-0036	9/7/2017 10:53	262.4	9.130	38.06	75.8
M1609-0036	9/19/2016 14:14	262.0	9.121	38.01	75.8
M1609-0037	9/7/2017 10:46	263.8	9.115	38.06	76.3
M1609-0037	9/19/2016 14:12	263.1	9.102	37.99	76.3

A.4 Jinko JKM265 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0005	9/15/2016 10:28	263.7	9.142	37.97	76.2
M1609-0005	9/9/2016 11:20	267.2	9.203	38.09	76.5
M1609-0006	12/12/2023 14:36	253.3	8.945	37.67	75.4
M1609-0006	9/15/2016 10:33	264.4	9.144	38.09	76.2
M1609-0006	9/9/2016 11:44	267.4	9.210	38.13	76.4
M1609-0007	12/14/2023 13:14	253.6	8.977	37.68	75.3
M1609-0007	9/15/2016 10:46	263.5	9.128	37.96	76.3
M1609-0007	9/9/2016 11:48	267.8	9.215	38.13	76.5
M1609-0008	12/12/2023 14:23	254.0	8.954	37.69	75.5

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0008	9/15/2016 10:49	264.6	9.119	38.10	76.4
M1609-0008	9/9/2016 11:51	267.9	9.187	38.18	76.6
M1609-0009	12/14/2023 13:08	255.5	8.950	37.68	76.0
M1609-0009	9/15/2016 10:58	265.1	9.115	38.06	76.7
M1609-0009	9/9/2016 11:54	268.8	9.188	38.18	76.9
M1609-0010	9/12/2022 12:56	252.0	8.987	37.58	74.9
M1609-0010	10/5/2021 8:12	251.8	8.979	37.62	74.8
M1609-0010	4/7/2021 8:25	257.9	9.053	37.91	75.4
M1609-0010	9/15/2020 9:40	251.7	8.956	37.59	75.0
M1609-0010	3/24/2020 11:10	257.8	9.049	37.88	75.5
M1609-0010	6/3/2019 8:16	258.8	9.088	37.88	75.4
M1609-0010	10/29/2018 10:20	257.4	9.057	37.88	75.3
M1609-0010	5/10/2018 8:59	259.3	9.079	37.94	75.5
M1609-0010	9/1/2017 10:49	258.7	9.067	37.94	75.5
M1609-0010	9/15/2016 11:01	262.9	9.120	38.07	76.0
M1609-0010	9/9/2016 11:57	266.9	9.189	38.20	76.3
M1609-0011	9/12/2022 12:39	253.7	8.976	37.58	75.5
M1609-0011	10/5/2021 8:27	254.6	8.988	37.65	75.5
M1609-0011	4/7/2021 11:07	258.4	9.061	37.81	75.7
M1609-0011	9/15/2020 9:27	252.4	8.984	37.54	75.1
M1609-0011	3/24/2020 11:20	258.5	9.050	37.86	75.7
M1609-0011	6/3/2019 8:58	260.8	9.087	37.92	76.0
M1609-0011	10/29/2018 10:10	257.9	9.063	37.82	75.5
M1609-0011	5/10/2018 9:14	261.1	9.096	37.94	75.9
M1609-0011	9/1/2017 10:27	259.3	9.082	37.89	75.6
M1609-0011	9/15/2016 11:04	264.0	9.123	38.05	76.3
M1609-0011	9/9/2016 12:01	268.2	9.194	38.18	76.7
M1609-0012	9/12/2022 13:04	255.0	8.992	37.59	75.7
M1609-0012	10/5/2021 8:18	255.8	8.994	37.67	75.8
M1609-0012	4/7/2021 8:30	260.6	9.070	37.90	76.1
M1609-0012	9/15/2020 9:16	254.6	8.983	37.61	75.6
M1609-0012	6/3/2019 8:08	261.4	9.111	37.87	76.0
M1609-0012	10/29/2018 10:15	259.7	9.077	37.83	75.9
M1609-0012	5/10/2018 8:53	261.9	9.116	37.91	76.0
M1609-0012	9/1/2017 10:46	260.9	9.097	37.92	75.9
M1609-0012	9/15/2016 11:06	264.1	9.147	38.00	76.2
M1609-0012	9/9/2016 12:06	268.4	9.217	38.16	76.6
M1609-0021	12/14/2023 13:49	254.3	8.932	37.66	75.8
M1609-0021	9/16/2016 14:41	264.5	9.150	38.00	76.3
M1609-0021	9/16/2016 10:34	267.6	9.191	38.14	76.6
M1609-0022	12/12/2023 13:50	253.8	8.943	37.65	75.6

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0022	9/16/2016 14:45	264.8	9.141	38.05	76.4
M1609-0022	9/16/2016 10:31	267.9	9.198	38.15	76.6
M1609-0023	12/14/2023 13:42	251.9	8.950	37.71	74.9
M1609-0023	9/16/2016 14:49	263.2	9.152	38.04	75.8
M1609-0023	9/16/2016 10:23	266.0	9.195	38.13	76.1
M1609-0024	12/12/2023 15:04	254.4	8.948	37.68	75.7
M1609-0024	9/16/2016 14:36	265.0	9.145	38.05	76.4
M1609-0024	9/16/2016 10:17	267.9	9.201	38.14	76.6
M1609-0025	12/14/2023 13:35	251.5	8.931	37.68	75.0
M1609-0025	9/16/2016 14:55	263.5	9.138	38.08	76.0
M1609-0025	9/16/2016 10:08	265.8	9.187	38.14	76.1
M1609-0026	12/12/2023 14:16	252.1	8.937	37.69	75.1
M1609-0026	9/16/2016 14:52	264.4	9.148	38.09	76.1
M1609-0026	9/16/2016 10:05	266.9	9.197	38.16	76.3
M1609-0027	12/14/2023 13:55	254.3	8.942	37.69	75.7
M1609-0027	9/16/2016 14:31	265.1	9.152	38.04	76.4
M1609-0027	9/16/2016 9:59	267.7	9.205	38.11	76.6
M1609-0028	12/12/2023 14:46	254.8	8.927	37.74	75.9
M1609-0028	9/16/2016 14:28	265.3	9.153	38.10	76.3
M1609-0028	9/16/2016 9:53	267.6	9.189	38.16	76.6
M1609-0029	9/12/2022 13:13	262.3	9.100	37.95	76.2
M1609-0029	10/5/2021 8:41	263.5	9.117	38.02	76.3
M1609-0029	4/7/2021 8:13	263.6	9.121	38.02	76.3
M1609-0029	9/15/2020 9:50	263.5	9.112	38.04	76.3
M1609-0029	6/3/2019 8:48	263.9	9.120	38.04	76.3
M1609-0029	10/29/2018 9:55	263.6	9.119	38.02	76.3
M1609-0029	5/10/2018 8:08	263.4	9.125	37.98	76.3
M1609-0029	9/7/2017 11:40	264.0	9.112	38.03	76.4
M1609-0029	9/1/2017 11:14	263.8	9.121	37.99	76.4
M1609-0029	9/19/2016 14:21	264.1	9.110	38.00	76.5
M1609-0032	9/12/2022 13:30	260.8	9.103	38.02	75.6
M1609-0032	10/5/2021 8:46	261.6	9.120	38.05	75.6
M1609-0032	4/7/2021 8:19	262.2	9.124	38.10	75.7
M1609-0032	9/15/2020 9:56	261.7	9.114	38.07	75.7
M1609-0032	3/24/2020 11:03	262.4	9.135	38.10	75.6
M1609-0032	6/3/2019 8:52	262.4	9.138	38.08	75.7
M1609-0032	10/29/2018 9:43	262.1	9.144	38.07	75.6
M1609-0032	5/10/2018 8:15	262.4	9.148	38.07	75.6
M1609-0032	9/7/2017 11:32	262.7	9.150	38.09	75.6
M1609-0032	9/1/2017 10:41	262.7	9.147	38.08	75.7
M1609-0032	9/19/2016 14:08	262.2	9.139	38.01	75.7

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1609-0034	12/12/2023 14:53	256.0	8.974	37.74	75.9
M1609-0034	9/19/2016 13:56	263.8	9.125	37.97	76.4
M1609-0045	9/12/2022 12:49	255.1	8.987	37.63	75.7
M1609-0045	10/5/2021 8:33	255.9	8.987	37.71	75.8
M1609-0045	4/7/2021 11:03	259.5	9.067	37.83	75.9
M1609-0045	9/15/2020 9:46	255.8	8.981	37.71	75.8
M1609-0045	3/24/2020 11:16	260.0	9.053	37.89	76.1
M1609-0045	6/3/2019 8:56	261.4	9.088	37.93	76.1
M1609-0045	10/29/2018 10:01	259.4	9.049	37.85	76.0
M1609-0045	5/10/2018 9:04	261.7	9.086	37.96	76.1
M1609-0045	9/1/2017 10:16	261.2	9.079	37.96	76.1
M1609-0045	9/19/2016 13:40	263.4	9.116	37.99	76.3

A.5 Trina TSM255 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0065	4/23/2024 10:19	255.0	8.891	37.75	76.5
M1610-0065	10/7/2022 11:03	255.0	8.859	37.61	76.7
M1610-0065	9/27/2022 9:23	254.8	8.868	37.76	76.6
M1610-0065	11/11/2021 10:08	255.8	8.885	37.82	76.7
M1610-0065	4/26/2021 13:07	255.6	8.882	37.80	76.6
M1610-0065	9/18/2020 12:38	255.4	8.888	37.78	76.6
M1610-0065	12/10/2019 11:14	256.1	8.884	37.84	76.7
M1610-0065	11/5/2018 11:46	256.0	8.885	37.83	76.7
M1610-0065	5/23/2018 9:20	256.3	8.896	37.84	76.7
M1610-0065	10/17/2017 13:43	256.4	8.894	37.84	76.7
M1610-0065	11/3/2016 8:33	257.7	8.908	37.90	76.9
M1610-0065	10/24/2016 9:45	258.3	8.942	37.86	76.8
M1610-0068	4/23/2024 9:35	259.0	8.923	38.12	76.7
M1610-0068	10/7/2022 10:52	258.5	8.894	37.96	76.7
M1610-0068	9/27/2022 9:31	258.7	8.885	38.13	76.9
M1610-0068	11/11/2021 10:16	259.5	8.905	38.16	76.9
M1610-0068	4/26/2021 13:12	259.4	8.905	38.15	76.9
M1610-0068	9/18/2020 12:46	259.2	8.912	38.12	76.8
M1610-0068	12/10/2019 11:20	259.7	8.912	38.17	76.9
M1610-0068	11/5/2018 11:50	259.7	8.918	38.17	76.8
M1610-0068	5/23/2018 8:46	259.7	8.930	38.13	76.8
M1610-0068	10/17/2017 13:53	260.3	8.934	38.17	76.9
M1610-0068	10/24/2016 10:50	261.5	8.966	38.21	76.9
M1610-0082	5/23/2018 9:15	258.3	8.949	37.94	76.6
M1610-0082	10/17/2017 13:34	258.8	8.938	37.97	76.8

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0082	10/24/2016 11:04	259.9	8.973	37.99	76.8

A.6 Trina TSM255 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0050	4/23/2024 10:06	252.7	8.841	37.79	76.2
M1610-0050	10/7/2022 11:20	250.5	8.802	37.52	76.0
M1610-0050	11/11/2021 10:48	251.5	8.790	37.77	76.3
M1610-0050	4/26/2021 13:17	253.8	8.839	37.84	76.4
M1610-0050	9/18/2020 13:06	250.6	8.800	37.69	76.1
M1610-0050	12/10/2019 11:40	253.6	8.834	37.86	76.3
M1610-0050	11/5/2018 11:20	254.2	8.838	37.92	76.4
M1610-0050	5/23/2018 10:02	254.8	8.861	37.91	76.4
M1610-0050	10/17/2017 14:20	254.5	8.857	37.92	76.3
M1610-0050	10/20/2016 13:40	259.3	8.900	38.08	77.0
M1610-0051	8/5/2020 10:25	252.1	8.853	37.76	75.9
M1610-0051	12/10/2019 11:31	254.6	8.881	37.87	76.2
M1610-0051	11/5/2018 10:52	255.7	8.905	37.84	76.4
M1610-0051	5/23/2018 10:11	256.8	8.903	37.97	76.5
M1610-0051	10/17/2017 14:32	256.0	8.914	37.96	76.2
M1610-0051	10/20/2016 13:37	261.0	8.946	38.14	77.0
M1610-0060	4/23/2024 9:44	252.0	8.893	37.72	75.6
M1610-0060	10/7/2022 11:10	251.4	8.862	37.48	75.9
M1610-0060	11/11/2021 10:36	252.7	8.860	37.74	76.1
M1610-0060	4/26/2021 13:32	254.2	8.902	37.76	76.1
M1610-0060	9/18/2020 12:52	252.6	8.870	37.70	76.1
M1610-0060	12/10/2019 11:24	254.9	8.904	37.84	76.2
M1610-0060	11/5/2018 11:35	255.8	8.909	37.87	76.3
M1610-0060	5/23/2018 10:15	256.7	8.921	37.94	76.4
M1610-0060	10/17/2017 14:25	257.0	8.928	37.94	76.4
M1610-0060	10/20/2016 13:43	259.8	8.968	38.09	76.6
M1610-0066	4/23/2024 9:51	252.9	8.830	37.76	76.4
M1610-0066	10/7/2022 11:13	252.7	8.737	37.81	76.6
M1610-0066	10/7/2022 11:13	251.2	8.748	37.54	76.6
M1610-0066	11/11/2021 10:43	252.1	8.796	37.80	76.4
M1610-0066	4/26/2021 13:38	253.7	8.833	37.81	76.5
M1610-0066	9/18/2020 13:01	252.0	8.809	37.73	76.3
M1610-0066	6/5/2018 11:22	256.7	8.883	37.93	76.7
M1610-0066	10/17/2017 13:17	257.0	8.876	37.95	76.9
M1610-0066	4/20/2017 8:37	256.5	8.865	37.94	76.8
M1610-0066	4/20/2017 8:25	257.1	8.864	38.01	76.9

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0066	10/24/2016 10:59	258.3	8.898	37.99	76.9
M1610-0071	4/23/2024 10:01	248.2	8.879	37.73	74.6
M1610-0071	10/7/2022 11:17	252.6	8.854	37.49	76.3
M1610-0071	11/11/2021 10:25	254.0	8.871	37.75	76.4
M1610-0071	4/26/2021 13:22	255.7	8.889	37.80	76.6
M1610-0071	9/18/2020 13:10	253.6	8.866	37.71	76.4
M1610-0071	12/10/2019 11:36	255.8	8.882	37.84	76.6
M1610-0071	11/5/2018 11:24	256.8	8.892	37.94	76.7
M1610-0071	5/23/2018 9:42	256.9	8.916	37.92	76.5
M1610-0071	10/17/2017 14:11	257.0	8.914	37.91	76.6
M1610-0071	10/24/2016 10:34	259.8	8.965	38.00	76.8
M1610-0072	11/5/2018 11:10	256.1	8.871	37.94	76.6
M1610-0072	5/23/2018 10:06	256.9	8.888	37.99	76.6
M1610-0072	10/17/2017 14:38	256.8	8.886	37.97	76.6
M1610-0072	10/24/2016 10:30	260.2	8.954	38.02	77.0
M1610-0073	11/5/2018 11:40	254.4	8.859	37.73	76.6
M1610-0073	5/23/2018 9:36	255.0	8.869	37.77	76.6
M1610-0073	10/17/2017 14:03	255.2	8.871	37.77	76.7
M1610-0073	10/24/2016 9:30	258.6	8.920	37.87	77.1

A.7 Trina TSM260 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0027	10/31/2023 15:05	256.6	8.971	37.68	76.3
M1610-0027	3/30/2023 10:17	258.7	9.017	37.74	76.4
M1610-0027	4/27/2021 8:37	258.5	9.036	37.68	76.3
M1610-0027	9/17/2020 11:13	258.8	9.027	37.72	76.4
M1610-0027	12/10/2019 10:33	258.6	9.043	37.68	76.3
M1610-0027	11/5/2018 10:38	259.7	9.032	37.78	76.5
M1610-0027	5/23/2018 9:25	259.6	9.045	37.76	76.4
M1610-0027	9/15/2017 14:01	259.4	9.030	37.74	76.6
M1610-0027	10/24/2016 11:18	260.6	9.068	37.78	76.5
M1610-0027	10/18/2016 9:34	260.9	9.072	37.78	76.5
M1610-0030	5/23/2018 9:30	262.0	9.064	37.86	76.8
M1610-0030	9/15/2017 13:41	261.9	9.067	37.83	76.8
M1610-0030	10/18/2016 10:20	262.9	9.084	37.86	76.9
M1610-0049	10/31/2023 15:10	260.5	9.051	37.94	76.3
M1610-0049	3/30/2023 10:25	262.3	9.093	37.97	76.4
M1610-0049	4/27/2021 8:42	262.5	9.102	37.96	76.4
M1610-0049	9/17/2020 11:07	262.4	9.100	37.96	76.4
M1610-0049	3/24/2020 10:22	262.8	9.107	37.97	76.4

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0049	12/10/2019 10:13	262.3	9.105	37.93	76.4
M1610-0049	11/5/2018 10:34	263.2	9.102	38.03	76.4
M1610-0049	5/23/2018 9:05	263.1	9.113	37.99	76.4
M1610-0049	9/15/2017 14:07	263.3	9.114	37.99	76.5
M1610-0049	4/20/2017 8:45	262.9	9.104	37.97	76.5
M1610-0049	10/24/2016 11:15	264.1	9.135	37.99	76.5
M1610-0049	10/13/2016 10:14	264.4	9.130	38.02	76.6

A.8 Trina TSM260 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0020	11/5/2018 10:29	257.2	9.060	37.73	75.7
M1610-0020	5/23/2018 10:40	257.8	9.084	37.70	75.7
M1610-0020	9/15/2017 14:13	258.1	9.090	37.70	75.7
M1610-0020	10/17/2016 11:05	262.7	9.117	37.90	76.5
M1610-0020	10/12/2016 9:29	263.3	9.136	37.91	76.5
M1610-0021	11/5/2018 10:15	257.6	9.064	37.72	75.7
M1610-0021	5/23/2018 10:31	257.9	9.080	37.72	75.7
M1610-0021	9/15/2017 14:32	257.3	9.082	37.67	75.6
M1610-0021	10/17/2016 11:10	263.8	9.124	37.94	76.6
M1610-0021	10/12/2016 9:35	264.2	9.135	37.93	76.7
M1610-0024	10/31/2023 13:50	248.7	8.860	37.37	75.5
M1610-0024	10/18/2016 10:29	263.2	9.076	37.92	76.9
M1610-0025	10/31/2023 14:45	254.9	8.987	37.53	76.0
M1610-0025	3/30/2023 10:35	257.9	9.044	37.62	76.2
M1610-0025	4/27/2021 9:14	258.0	9.059	37.60	76.1
M1610-0025	9/17/2020 11:01	257.5	9.036	37.62	76.2
M1610-0025	12/10/2019 10:43	258.4	9.061	37.62	76.2
M1610-0025	11/5/2018 10:19	259.1	9.054	37.75	76.2
M1610-0025	5/23/2018 11:00	258.8	9.083	37.65	76.1
M1610-0025	9/15/2017 14:19	259.5	9.074	37.72	76.2
M1610-0025	10/18/2016 9:38	263.7	9.134	37.89	76.7
M1610-0026	10/31/2023 13:35	253.5	8.988	37.56	75.5
M1610-0026	10/18/2016 9:54	262.0	9.111	37.80	76.5
M1610-0029	10/31/2023 14:18	248.8	8.834	37.34	75.9
M1610-0029	10/18/2016 10:26	263.3	9.087	37.90	76.9
M1610-0032	10/31/2023 13:57	254.4	8.997	37.64	75.6
M1610-0032	10/18/2016 9:58	264.2	9.125	38.02	76.6
M1610-0032	10/12/2016 10:07	264.9	9.135	38.04	76.7
M1610-0033	10/31/2023 13:42	247.4	8.822	37.30	75.6
M1610-0033	10/18/2016 10:01	262.3	9.062	37.85	76.9

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0033	10/12/2016 10:01	263.3	9.088	37.87	77.0
M1610-0034	10/31/2023 14:05	247.8	8.813	37.34	75.7
M1610-0034	10/18/2016 10:06	262.7	9.042	37.95	77.0
M1610-0034	10/12/2016 9:52	264.5	9.067	38.01	77.2
M1610-0035	11/10/2023 9:30	255.8	8.998	37.76	75.7
M1610-0035	10/18/2016 10:10	263.9	9.131	38.04	76.4
M1610-0035	10/12/2016 9:47	264.5	9.151	38.04	76.4
M1610-0040	11/10/2023 10:05	253.3	9.000	37.54	75.4
M1610-0040	10/13/2016 9:42	262.6	9.112	37.81	76.6
M1610-0041	10/31/2023 14:39	249.4	8.881	37.43	75.4
M1610-0041	3/30/2023 10:42	255.9	8.992	37.68	75.9
M1610-0041	4/27/2021 9:19	255.9	9.010	37.61	75.9
M1610-0041	9/17/2020 10:43	252.0	8.951	37.44	75.6
M1610-0041	12/10/2019 10:50	256.2	9.006	37.64	76.0
M1610-0041	11/5/2018 10:25	256.7	9.001	37.70	76.1
M1610-0041	5/23/2018 10:45	258.3	9.033	37.72	76.2
M1610-0041	9/15/2017 14:17	257.7	9.017	37.71	76.2
M1610-0041	10/17/2016 10:54	262.8	9.089	37.88	76.8
M1610-0042	10/31/2023 15:00	250.7	8.946	37.48	75.2
M1610-0042	3/30/2023 10:58	254.2	9.010	37.60	75.4
M1610-0042	4/27/2021 9:02	254.7	9.025	37.55	75.6
M1610-0042	9/17/2020 10:51	253.7	8.994	37.53	75.6
M1610-0042	3/24/2020 11:25	255.6	9.033	37.62	75.6
M1610-0042	12/10/2019 11:02	255.1	9.020	37.57	75.7
M1610-0042	11/5/2018 10:03	255.9	9.022	37.63	75.8
M1610-0042	5/23/2018 10:20	256.6	9.039	37.69	75.7
M1610-0042	9/15/2017 14:40	256.8	9.040	37.64	75.9
M1610-0042	10/17/2016 10:46	261.8	9.104	37.81	76.5
M1610-0043	10/31/2023 14:54	232.6	8.768	37.28	71.6
M1610-0043	3/30/2023 10:52	239.5	8.880	37.57	72.2
M1610-0043	4/27/2021 9:08	240.8	8.935	37.50	72.3
M1610-0043	9/17/2020 10:57	235.7	8.772	37.27	72.5
M1610-0043	3/24/2020 11:28	241.6	8.915	37.57	72.5
M1610-0043	12/10/2019 11:09	241.4	8.907	37.49	72.7
M1610-0043	11/5/2018 10:12	243.5	8.911	37.53	73.2
M1610-0043	5/23/2018 10:25	248.0	8.982	37.69	73.7
M1610-0043	9/15/2017 14:36	243.9	8.962	37.59	72.8
M1610-0043	10/17/2016 11:01	254.7	9.063	37.76	74.8
M1610-0044	11/10/2023 9:47	256.1	8.980	37.78	75.9
M1610-0044	10/13/2016 9:46	264.3	9.101	38.04	76.7
M1610-0045	11/10/2023 10:01	253.8	8.973	37.59	75.7

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1610-0045	10/13/2016 9:50	262.3	9.092	37.85	76.6
M1610-0046	11/10/2023 9:41	253.7	8.978	37.72	75.3
M1610-0046	10/13/2016 9:54	263.4	9.099	37.99	76.6
M1610-0047	11/10/2023 9:55	255.8	9.003	37.72	75.7
M1610-0047	10/13/2016 9:57	264.3	9.114	37.99	76.7
M1610-0048	11/10/2023 9:35	255.9	9.013	37.62	75.9
M1610-0048	10/13/2016 10:07	263.3	9.132	37.85	76.6

A.9 Q-Cells Q.Plus280 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1706-0048	11/16/2023 12:23	279.6	9.600	38.72	75.7
M1706-0048	10/7/2022 15:21	276.8	9.450	38.68	75.9
M1706-0048	9/29/2022 10:46	276.7	9.470	38.74	75.9
M1706-0048	9/16/2021 8:08	277.4	9.484	38.76	75.9
M1706-0048	9/21/2020 10:36	277.5	9.490	38.76	75.9
M1706-0048	1/29/2020 9:12	277.5	9.497	38.72	75.9
M1706-0048	12/10/2018 14:20	278.2	9.498	38.80	76.0
M1706-0048	7/19/2017 12:34	278.6	9.516	38.76	76.0
M1706-0049	11/16/2023 12:15	279.9	9.586	38.79	75.8
M1706-0049	10/7/2022 15:14	277.0	9.476	38.64	75.9
M1706-0049	9/29/2022 10:36	277.0	9.457	38.81	75.9
M1706-0049	9/16/2021 8:15	277.9	9.470	38.85	76.0
M1706-0049	9/21/2020 10:47	277.7	9.480	38.81	76.0
M1706-0049	1/29/2020 9:21	277.9	9.476	38.80	76.1
M1706-0049	12/10/2018 14:24	278.4	9.480	38.86	76.1
M1706-0049	7/14/2017 9:09	278.9	9.492	38.86	76.1

A.10 Q-Cells Q.Plus280 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1706-0022	11/16/2023 10:22	274.0	9.524	38.53	75.1
M1706-0022	10/7/2022 15:31	271.8	9.438	38.41	75.3
M1706-0022	9/16/2021 8:30	273.3	9.435	38.59	75.5
M1706-0022	9/21/2020 10:54	273.9	9.445	38.61	75.6
M1706-0022	1/29/2020 9:27	274.0	9.426	38.62	75.8
M1706-0022	12/10/2018 14:11	275.4	9.441	38.70	75.9
M1706-0022	8/8/2017 10:13	280.1	9.492	38.86	76.4
M1706-0022	7/21/2017 7:49	280.4	9.506	38.84	76.4
M1706-0022	7/11/2017 11:11	282.1	9.532	38.92	76.5
M1706-0029	11/16/2023 10:16	274.4	9.595	38.57	74.6

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1706-0029	10/7/2022 15:26	271.5	9.473	38.55	74.6
M1706-0029	9/16/2021 8:23	273.5	9.491	38.65	75.0
M1706-0029	9/21/2020 11:15	273.4	9.491	38.64	75.0
M1706-0029	1/29/2020 9:32	274.2	9.484	38.70	75.2
M1706-0029	12/10/2018 13:56	274.9	9.492	38.72	75.3
M1706-0029	7/19/2017 11:58	279.0	9.553	38.82	75.7
M1706-0040	12/10/2018 14:01	274.7	9.472	38.69	75.5
M1706-0040	7/19/2017 12:54	279.3	9.543	38.80	75.9
M1706-0041	11/16/2023 10:29	272.1	9.576	38.51	74.3
M1706-0041	10/7/2022 15:34	269.5	9.460	38.36	74.5
M1706-0041	9/16/2021 8:44	271.0	9.469	38.51	74.8
M1706-0041	9/21/2020 11:03	272.1	9.485	38.55	74.9
M1706-0041	1/29/2020 9:42	272.9	9.442	38.66	75.3
M1706-0041	12/10/2018 14:15	274.1	9.474	38.67	75.3
M1706-0041	7/19/2017 11:26	278.9	9.534	38.83	75.8

A.11 Q-Cells Q.Peak290 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1706-0081	1/25/2024 11:12	282.3	9.422	39.32	76.8
M1706-0081	10/7/2022 10:07	282.5	9.368	39.25	77.1
M1706-0081	9/29/2022 10:51	283.2	9.389	39.43	77.1
M1706-0081	9/16/2021 9:02	284.4	9.409	39.51	77.1
M1706-0081	9/21/2020 11:56	283.7	9.416	39.43	77.0
M1706-0081	1/29/2020 10:20	285.1	9.411	39.55	77.2
M1706-0081	12/10/2018 13:50	286.4	9.421	39.64	77.3
M1706-0081	8/9/2017 9:44	286.7	9.437	39.59	77.3
M1706-0082	1/25/2024 11:20	280.1	9.355	39.17	77.0
M1706-0082	10/7/2022 10:28	280.3	9.336	39.08	77.2
M1706-0082	9/29/2022 11:01	279.7	9.313	39.20	77.2
M1706-0082	9/16/2021 9:07	281.6	9.340	39.30	77.3
M1706-0082	9/21/2020 11:51	280.9	9.340	39.24	77.2
M1706-0082	1/29/2020 10:15	282.8	9.354	39.36	77.4
M1706-0082	12/10/2018 13:47	287.3	9.396	39.64	77.7
M1706-0082	8/9/2017 9:56	287.5	9.417	39.58	77.7

A.12 Q-Cells Q.Peak290 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1706-0052	12/10/2018 13:35	282.4	9.357	39.35	77.3
M1706-0052	8/9/2017 9:14	287.4	9.431	39.57	77.6

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1706-0059	1/25/2024 11:40	277.8	9.371	39.06	76.5
M1706-0059	10/7/2022 10:37	277.0	9.326	38.96	76.6
M1706-0059	9/16/2021 9:26	278.8	9.345	39.16	76.8
M1706-0059	9/21/2020 11:39	280.3	9.359	39.24	76.9
M1706-0059	1/29/2020 10:05	280.1	9.331	39.23	77.1
M1706-0059	12/10/2018 13:25	282.2	9.358	39.36	77.2
M1706-0059	8/11/2017 9:38	287.6	9.429	39.66	77.5
M1706-0059	8/7/2017 13:56	288.4	9.450	39.67	77.5
M1706-0059	7/11/2017 8:59	291.1	9.478	39.82	77.7
M1706-0067	1/25/2024 11:32	277.5	9.326	39.04	76.8
M1706-0067	10/7/2022 10:46	275.9	9.321	38.90	76.4
M1706-0067	9/16/2021 9:13	277.6	9.314	39.14	76.7
M1706-0067	9/21/2020 11:23	278.5	9.331	39.16	76.8
M1706-0067	1/29/2020 9:57	278.1	9.279	39.20	77.0
M1706-0067	12/10/2018 13:44	280.8	9.321	39.37	77.1
M1706-0067	8/11/2017 9:18	286.2	9.434	39.59	77.2
M1706-0067	8/7/2017 13:48	286.5	9.433	39.62	77.3
M1706-0067	7/11/2017 9:14	289.6	9.469	39.77	77.5
M1706-0070	1/25/2024 11:26	280.5	9.405	39.19	76.7
M1706-0070	10/7/2022 10:40	278.4	9.334	39.07	76.7
M1706-0070	9/16/2021 9:31	279.6	9.345	39.25	76.8
M1706-0070	9/21/2020 11:30	281.0	9.363	39.32	76.9
M1706-0070	1/29/2020 9:53	280.2	9.321	39.31	77.0
M1706-0070	12/10/2018 13:41	282.8	9.353	39.46	77.2
M1706-0070	8/17/2017 9:31	287.3	9.440	39.68	77.3
M1706-0076	12/10/2018 13:30	281.4	9.358	39.34	77.0
M1706-0076	8/11/2017 10:03	286.9	9.425	39.62	77.4
M1706-0076	8/7/2017 14:24	287.4	9.427	39.67	77.5
M1706-0076	7/11/2017 9:33	290.1	9.465	39.77	77.7
M1706-0080	1/25/2024 11:45	278.7	9.356	39.07	76.8
M1706-0080	10/7/2022 10:43	276.5	9.343	38.91	76.4
M1706-0080	9/16/2021 9:18	278.4	9.341	39.17	76.7
M1706-0080	9/21/2020 11:34	280.6	9.363	39.23	77.0
M1706-0080	1/29/2020 10:07	281.8	9.346	39.32	77.3
M1706-0080	12/10/2018 13:19	282.4	9.383	39.35	77.1
M1706-0080	8/11/2017 9:03	288.2	9.455	39.63	77.5
M1706-0080	8/7/2017 13:41	288.0	9.453	39.62	77.5
M1706-0080	7/11/2017 9:23	290.9	9.475	39.79	77.7

A.13 Mission MSE360 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1811-0001	5/3/2024 9:26	351.2	9.670	47.32	77.1
M1811-0001	10/7/2022 9:00	354.1	9.708	47.43	77.3
M1811-0001	9/29/2021 8:55	354.1	9.709	47.42	77.3
M1811-0001	4/14/2021 9:27	354.3	9.720	47.40	77.3
M1811-0001	9/28/2020 11:12	354.1	9.708	47.41	77.3
M1811-0001	6/2/2020 11:46	353.8	9.721	47.36	77.2
M1811-0001	12/19/2019 13:10	354.5	9.715	47.45	77.3
M1811-0001	11/26/2018 9:57	357.2	9.724	47.62	77.6
M1811-0008	5/3/2024 9:33	347.5	9.564	47.04	77.6
M1811-0008	10/7/2022 9:11	349.1	9.619	47.07	77.5
M1811-0008	9/29/2021 9:01	349.8	9.622	47.13	77.5
M1811-0008	4/14/2021 9:36	350.4	9.641	47.12	77.5
M1811-0008	9/28/2020 11:17	350.2	9.634	47.13	77.5
M1811-0008	6/2/2020 11:35	350.1	9.638	47.10	77.5
M1811-0008	12/19/2019 13:06	350.2	9.628	47.12	77.6
M1811-0008	5/28/2019 11:02	349.4	9.617	47.07	77.6
M1811-0008	5/15/2019 8:13	349.6	9.621	47.08	77.6
M1811-0008	5/7/2019 8:46	349.7	9.613	47.11	77.6
M1811-0008	4/29/2019 12:07	349.4	9.624	47.07	77.5
M1811-0008	4/17/2019 8:04	349.4	9.617	47.08	77.6
M1811-0008	4/5/2019 8:18	349.5	9.614	47.08	77.6
M1811-0008	3/26/2019 7:50	350.5	9.616	47.16	77.7
M1811-0008	3/14/2019 10:58	349.7	9.612	47.11	77.6
M1811-0008	3/4/2019 13:04	351.2	9.635	47.19	77.6
M1811-0008	2/19/2019 10:51	351.8	9.644	47.22	77.7
M1811-0008	2/12/2019 8:56	351.9	9.643	47.22	77.7
M1811-0008	2/5/2019 13:27	352.2	9.644	47.26	77.7
M1811-0008	1/24/2019 14:46	352.4	9.649	47.25	77.7
M1811-0008	11/26/2018 9:42	352.9	9.660	47.29	77.7

A.14 Mission MSE360 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1811-0012	5/3/2024 9:45	352.6	9.667	47.53	77.1
M1811-0012	10/7/2022 8:46	352.0	9.699	47.50	76.8
M1811-0012	9/29/2021 9:20	354.1	9.697	47.60	77.1
M1811-0012	4/14/2021 9:49	357.2	9.750	47.71	77.2
M1811-0012	9/28/2020 11:01	354.7	9.733	47.55	77.0
M1811-0012	6/2/2020 11:27	355.3	9.752	47.54	77.0
M1811-0012	12/19/2019 12:54	356.9	9.732	47.65	77.4

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1811-0012	11/30/2018 10:32	355.4	9.690	47.58	77.5
M1811-0017	5/3/2024 9:48	352.6	9.700	47.54	76.8
M1811-0017	10/7/2022 8:54	351.8	9.718	47.47	76.6
M1811-0017	9/29/2021 9:15	354.7	9.724	47.57	77.1
M1811-0017	4/14/2021 9:45	358.7	9.756	47.69	77.5
M1811-0017	9/28/2020 10:50	355.0	9.744	47.49	77.1
M1811-0017	6/2/2020 11:03	356.3	9.758	47.55	77.2
M1811-0017	12/19/2019 12:47	358.3	9.744	47.64	77.6
M1811-0017	11/30/2018 10:39	354.8	9.697	47.52	77.4
M1811-0022	5/3/2024 9:38	350.8	9.683	47.50	76.6
M1811-0022	10/7/2022 8:41	351.1	9.714	47.47	76.5
M1811-0022	9/29/2021 9:10	353.0	9.712	47.55	76.8
M1811-0022	4/14/2021 9:56	355.6	9.761	47.61	76.9
M1811-0022	9/28/2020 11:06	353.9	9.739	47.52	76.9
M1811-0022	6/2/2020 11:09	355.2	9.765	47.52	76.9
M1811-0022	12/19/2019 12:58	356.4	9.755	47.59	77.2
M1811-0022	11/30/2018 10:22	355.1	9.728	47.54	77.2
M1811-0025	5/3/2024 9:54	352.3	9.689	47.50	76.9
M1811-0025	10/7/2022 8:32	352.5	9.715	47.47	76.8
M1811-0025	9/29/2021 9:25	355.0	9.720	47.60	77.1
M1811-0025	4/14/2021 9:41	357.9	9.768	47.65	77.3
M1811-0025	9/28/2020 10:57	355.1	9.744	47.52	77.1
M1811-0025	6/2/2020 10:41	355.6	9.758	47.51	77.1
M1811-0025	12/19/2019 12:39	357.2	9.757	47.58	77.3
M1811-0025	11/30/2018 10:29	354.6	9.718	47.54	77.1

A.15 LG 320N1K Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1806-0001	5/8/2024 9:45	326.9	10.519	40.26	77.4
M1806-0001	10/7/2022 12:06	328.9	10.562	40.14	77.5
M1806-0001	10/4/2022 8:06	329.1	10.582	40.29	77.3
M1806-0001	9/29/2021 8:13	329.3	10.551	40.28	77.7
M1806-0001	9/29/2020 8:46	328.8	10.572	40.24	77.4
M1806-0001	1/28/2020 14:49	329.7	10.582	40.29	77.5
M1806-0001	8/1/2018 10:57	327.6	10.509	40.27	77.6
M1806-0001	6/6/2018 11:17	327.8	10.498	40.28	77.7
M1806-0002	5/8/2024 9:53	326.1	10.481	40.27	77.4
M1806-0002	10/7/2022 12:12	328.5	10.530	40.17	77.6
M1806-0002	10/4/2022 8:13	328.3	10.509	40.32	77.7
M1806-0002	9/29/2021 8:21	328.4	10.509	40.32	77.7

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1806-0002	9/29/2020 8:52	328.3	10.509	40.29	77.7
M1806-0002	1/28/2020 14:41	329.1	10.519	40.34	77.7
M1806-0002	8/1/2018 10:40	327.2	10.481	40.31	77.6
M1806-0002	6/6/2018 11:22	327.8	10.463	40.34	77.8

A.16 LG 320N1K Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1806-0005	9/29/2022 15:26	320.8	10.529	39.73	76.6
M1806-0005	9/29/2021 8:32	321.3	10.509	39.94	76.7
M1806-0005	9/29/2020 8:57	321.1	10.509	39.91	76.7
M1806-0005	1/28/2020 14:30	321.8	10.540	39.98	76.6
M1806-0005	8/1/2018 10:15	323.8	10.540	40.06	76.9
M1806-0005	7/20/2018 8:16	324.0	10.530	40.10	76.9
M1806-0005	6/6/2018 11:42	326.8	10.551	40.07	77.5
M1806-0006	5/8/2024 10:05	322.7	10.457	40.11	77.1
M1806-0006	10/7/2022 12:23	325.8	10.502	39.98	77.5
M1806-0006	9/29/2021 8:40	325.0	10.487	40.17	77.4
M1806-0006	9/29/2020 9:25	324.8	10.509	40.14	77.2
M1806-0006	1/28/2020 14:33	326.8	10.509	40.30	77.3
M1806-0006	8/1/2018 9:54	328.0	10.519	40.36	77.4
M1806-0006	7/20/2018 8:04	328.1	10.519	40.36	77.4
M1806-0006	6/6/2018 11:36	327.4	10.519	40.32	77.4
M1806-0007	5/8/2024 10:09	323.9	10.498	40.17	77.0
M1806-0007	10/7/2022 12:17	326.7	10.540	40.06	77.3
M1806-0007	9/29/2021 8:27	327.0	10.530	40.25	77.3
M1806-0007	9/29/2020 9:07	326.7	10.530	40.21	77.3
M1806-0007	1/28/2020 14:19	327.5	10.540	40.26	77.4
M1806-0007	8/1/2018 10:03	324.5	10.519	40.40	76.6
M1806-0007	7/20/2018 8:08	324.5	10.519	40.41	76.5
M1806-0007	6/6/2018 11:32	326.2	10.519	40.36	77.0
M1806-0008	5/8/2024 10:14	328.0	10.467	40.32	77.9
M1806-0008	10/7/2022 12:26	331.4	10.517	40.22	78.2
M1806-0008	9/29/2021 8:36	330.9	10.519	40.41	78.0
M1806-0008	9/29/2020 9:11	330.7	10.530	40.38	77.9
M1806-0008	1/28/2020 14:24	331.7	10.551	40.46	77.9
M1806-0008	8/1/2018 10:09	328.6	10.519	40.51	77.3
M1806-0008	7/20/2018 8:13	328.6	10.519	40.54	77.3
M1806-0008	6/6/2018 11:27	331.4	10.498	40.49	78.1
M1806-0011	5/8/2024 10:22	320.4	10.509	39.88	76.6
M1806-0011	10/7/2022 12:19	326.8	10.626	39.88	77.1

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1806-0011	7/19/2018 7:45	325.5	10.519	40.12	77.3

A.17 Canadian CS6K-300MS Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1803-0042	4/4/2023 10:29	298.3	9.882	39.67	76.6
M1803-0042	10/7/2022 11:43	298.4	9.875	39.48	76.6
M1803-0042	9/29/2022 10:06	298.2	9.877	39.70	76.5
M1803-0042	9/22/2021 10:09	297.9	9.875	39.64	76.6
M1803-0042	9/23/2020 11:45	298.5	9.881	39.67	76.6
M1803-0042	1/27/2020 8:55	300.4	9.890	39.80	76.8
M1803-0042	4/13/2018 9:14	299.9	9.826	39.87	77.0
M1803-0042	3/16/2018 11:25	301.9	9.880	39.90	77.0
M1803-0043	4/4/2023 10:40	299.6	9.848	39.78	77.0
M1803-0043	10/7/2022 11:31	299.4	9.842	39.56	76.9
M1803-0043	9/29/2022 10:15	299.5	9.840	39.77	77.0
M1803-0043	9/22/2021 10:15	298.8	9.836	39.73	76.9
M1803-0043	9/23/2020 11:40	298.8	9.841	39.73	76.9
M1803-0043	1/27/2020 8:51	299.8	9.840	39.82	77.0
M1803-0043	4/13/2018 9:09	299.2	9.777	39.90	77.2
M1803-0043	3/16/2018 11:28	300.6	9.810	39.92	77.2

A.18 Canadian CS6K-300MS Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1803-0036	4/4/2023 11:17	289.6	9.807	39.20	75.8
M1803-0036	10/7/2022 11:55	288.0	9.753	38.95	75.8
M1803-0036	9/22/2021 10:34	286.5	9.781	39.14	75.3
M1803-0036	9/23/2020 11:49	290.2	9.795	39.27	75.9
M1803-0036	1/27/2020 8:31	295.2	9.821	39.46	76.6
M1803-0036	4/10/2018 9:39	297.9	9.793	39.88	76.8
M1803-0036	3/27/2018 10:38	298.1	9.804	39.90	76.7
M1803-0036	3/21/2018 9:38	299.4	9.799	39.96	77.0
M1803-0036	3/14/2018 13:23	299.6	9.827	39.91	76.9
M1803-0037	4/4/2023 10:51	293.8	9.839	39.21	76.7
M1803-0037	10/7/2022 12:00	289.3	9.796	38.92	75.9
M1803-0037	9/22/2021 10:19	289.7	9.798	39.15	76.0
M1803-0037	9/23/2020 12:05	290.6	9.800	39.23	76.0
M1803-0037	1/27/2020 8:41	296.1	9.826	39.50	76.8
M1803-0037	4/10/2018 9:36	298.1	9.820	39.83	76.7
M1803-0037	3/27/2018 10:34	298.5	9.821	39.86	76.8

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1803-0037	3/21/2018 9:35	299.5	9.823	39.89	76.9
M1803-0037	3/14/2018 13:27	300.3	9.846	39.87	77.0
M1803-0038	4/4/2023 11:01	291.6	9.821	39.20	76.2
M1803-0038	10/7/2022 11:50	287.4	9.750	38.91	75.8
M1803-0038	9/22/2021 10:23	287.2	9.751	39.12	75.8
M1803-0038	9/23/2020 12:00	289.8	9.778	39.23	76.0
M1803-0038	1/27/2020 8:47	295.8	9.774	39.50	77.1
M1803-0038	4/10/2018 9:27	298.2	9.789	39.79	77.0
M1803-0038	3/27/2018 10:41	298.9	9.783	39.87	77.1
M1803-0038	3/21/2018 9:40	300.7	9.795	39.96	77.3
M1803-0038	3/14/2018 13:30	300.3	9.827	39.86	77.1
M1803-0039	4/4/2023 11:07	293.5	9.823	39.10	76.9
M1803-0039	10/7/2022 11:58	285.9	9.698	38.72	76.2
M1803-0039	9/22/2021 10:30	285.7	9.726	38.90	76.0
M1803-0039	9/23/2020 11:56	287.5	9.759	39.03	75.9
M1803-0039	1/27/2020 8:37	295.5	9.823	39.35	76.9
M1803-0039	4/10/2018 9:31	297.4	9.807	39.70	76.9
M1803-0039	3/27/2018 10:43	297.3	9.802	39.72	76.8
M1803-0039	3/21/2018 9:42	299.1	9.813	39.80	77.1
M1803-0039	3/14/2018 13:32	298.5	9.836	39.72	76.9

A.19 Panasonic VBHN330 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1803-0007	11/16/2023 9:59	327.0	6.014	70.36	78.3
M1803-0007	7/18/2022 11:50	329.9	6.073	70.24	78.4
M1803-0007	9/21/2021 13:30	330.6	6.069	70.33	78.5
M1803-0007	9/23/2020 9:04	331.0	6.077	70.37	78.5
M1803-0007	10/24/2019 9:24	330.4	6.067	70.28	78.5
M1803-0007	4/13/2018 8:54	331.5	6.045	70.58	78.8
M1803-0008	7/18/2022 11:26	329.5	6.075	70.24	78.3
M1803-0008	9/21/2021 13:25	330.1	6.070	70.30	78.4
M1803-0008	9/23/2020 9:11	330.7	6.077	70.36	78.4
M1803-0008	10/24/2019 9:44	330.3	6.069	70.30	78.5
M1803-0008	4/13/2018 9:01	331.2	6.047	70.53	78.7

A.20 Panasonic VBHN330 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1803-0001	11/16/2023 9:51	322.5	6.015	69.41	78.3
M1803-0001	7/18/2022 10:26	326.6	6.092	69.45	78.2

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1803-0001	9/21/2021 12:57	329.6	6.085	69.85	78.6
M1803-0001	9/23/2020 9:17	331.3	6.090	70.08	78.7
M1803-0001	10/24/2019 10:03	333.5	6.090	70.32	78.9
M1803-0001	4/10/2018 9:44	331.9	6.051	70.58	78.8
M1803-0001	3/27/2018 10:29	331.8	6.048	70.60	78.8
M1803-0001	3/21/2018 9:31	331.0	6.044	70.53	78.7
M1803-0001	3/14/2018 13:05	329.6	6.050	70.36	78.5
M1803-0002	9/29/2022 15:15	322.3	6.067	69.45	77.5
M1803-0002	7/18/2022 10:45	322.3	6.068	69.45	77.5
M1803-0002	9/21/2021 12:47	325.5	6.070	69.83	77.8
M1803-0002	9/23/2020 9:33	326.5	6.068	70.03	77.9
M1803-0002	10/24/2019 10:28	328.9	6.071	70.28	78.1
M1803-0002	4/10/2018 9:48	330.8	6.029	70.54	78.8
M1803-0002	3/27/2018 10:26	330.4	6.021	70.52	78.9
M1803-0002	3/21/2018 9:25	330.1	6.025	70.47	78.8
M1803-0002	3/14/2018 13:10	328.8	6.029	70.31	78.6
M1803-0005	7/18/2022 10:56	326.1	6.066	69.52	78.4
M1803-0005	9/21/2021 13:13	328.8	6.071	69.82	78.6
M1803-0005	9/23/2020 9:22	330.4	6.067	70.08	78.8
M1803-0005	10/24/2019 10:16	332.9	6.069	70.35	79.0
M1803-0005	4/13/2018 8:48	331.1	6.031	70.53	78.9
M1803-0005	3/16/2018 11:30	329.5	6.027	70.45	78.7
M1803-0006	11/16/2023 9:29	321.9	6.003	69.40	78.3
M1803-0006	7/18/2022 10:51	326.4	6.073	69.57	78.3
M1803-0006	9/21/2021 13:03	329.5	6.070	69.96	78.7
M1803-0006	9/23/2020 9:28	330.7	6.080	70.11	78.6
M1803-0006	10/24/2019 10:33	333.5	6.080	70.45	78.9
M1803-0006	4/13/2018 9:04	331.7	6.041	70.64	78.8
M1803-0006	3/16/2018 11:34	329.4	6.036	70.44	78.5
M1803-0028	11/16/2023 9:41	325.5	6.017	69.87	78.5
M1803-0028	6/13/2018 8:59	327.9	5.995	70.41	78.8
M1803-0034	11/16/2023 9:10	325.1	6.020	69.83	78.4
M1803-0034	6/13/2018 8:49	327.7	5.991	70.40	78.8

A.21 Sunpreme HX-150 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1812-0010	3/21/2023 14:59	408.1	9.244	54.92	77.4
M1812-0010	4/20/2022 15:37	410.1	9.272	54.79	77.3
M1812-0010	3/22/2022 10:16	409.3	9.237	55.01	77.5
M1812-0010	9/27/2019 11:06	411.8	9.243	55.00	78.0

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1812-0010	1/18/2019 9:15	408.8	9.210	54.95	77.7
M1812-0011	3/21/2023 14:35	405.6	9.143	54.70	78.0
M1812-0011	4/21/2022 10:55	404.1	9.122	54.42	78.0
M1812-0011	3/22/2022 10:01	404.8	9.157	54.71	77.8
M1812-0011	9/27/2019 10:49	406.3	9.156	54.69	78.1
M1812-0011	1/18/2019 9:27	403.8	9.129	54.71	77.8

A.22 Sunpreme HX-150 Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1812-0016	4/21/2022 12:51	375.5	8.639	53.97	77.1
M1812-0016	12/19/2018 13:23	409.0	9.252	54.93	77.4
M1812-0018	4/21/2022 11:13	376.8	8.594	54.26	77.4
M1812-0018	12/19/2018 13:00	407.7	9.188	55.03	77.6
M1812-0025	4/21/2022 11:30	378.5	8.667	53.92	77.6
M1812-0025	12/18/2018 13:05	408.6	9.192	54.92	77.9
M1812-0026	4/21/2022 13:03	376.5	8.650	53.82	77.4
M1812-0026	12/18/2018 13:13	403.1	9.166	54.77	77.3
M1812-0030	3/21/2023 14:14	380.2	8.634	54.41	77.9
M1812-0030	4/21/2022 13:49	382.9	8.628	54.26	78.3
M1812-0030	1/9/2019 9:16	410.9	9.196	55.09	78.1
M1812-0031	3/21/2023 13:55	374.5	8.570	54.16	77.6
M1812-0031	4/21/2022 13:40	380.0	8.641	54.24	77.6
M1812-0031	1/9/2019 9:35	411.7	9.259	55.06	77.7
M1812-0032	3/21/2023 10:32	377.5	8.530	54.33	78.4
M1812-0032	4/21/2022 13:31	382.7	8.576	54.41	78.5
M1812-0032	1/9/2019 9:27	412.7	9.130	55.23	78.8
M1812-0033	3/21/2023 9:42	373.7	8.551	54.17	77.6
M1812-0033	4/21/2022 13:22	378.9	8.632	54.15	77.7
M1812-0033	1/9/2019 9:22	409.2	9.203	55.06	77.7

A.23 LONGi Bifacial Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M2003-0001	3/29/2024 13:12	359.2	9.468	48.14	78.4
M2003-0001	6/29/2022 14:10	364.0	9.594	48.16	78.4
M2003-0001	4/20/2022 16:15	363.9	9.592	47.89	77.3
M2003-0001	3/22/2022 11:23	364.1	9.588	48.15	78.4
M2003-0001	3/22/2022 11:19	364.4	9.593	48.17	78.4
M2003-0001	8/5/2020 12:10	363.9	9.589	48.14	78.4
M2003-0002	6/29/2022 14:19	363.6	9.587	48.11	78.4

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M2003-0002	4/20/2022 15:59	363.0	9.587	47.79	77.3
M2003-0002	3/22/2022 11:13	362.9	9.590	48.03	78.4
M2003-0002	3/22/2022 11:12	363.1	9.592	48.04	78.4
M2003-0002	8/5/2020 11:46	362.7	9.583	48.03	78.4

A.24 LONGi Bifacial Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M2003-0002	8/5/2020 11:46	362.7	9.583	48.03	78.4
M2003-0006	6/29/2022 15:28	361.0	9.542	47.97	78.5
M2003-0006	8/6/2020 12:49	362.4	9.577	47.97	78.5
M2003-0011	6/29/2022 14:29	361.7	9.522	48.07	78.6
M2003-0011	8/13/2020 11:00	363.7	9.562	48.09	78.7
M2003-0012	6/29/2022 14:48	361.5	9.530	48.07	78.5
M2003-0012	8/13/2020 13:55	363.6	9.592	48.05	78.5
M2003-0014	3/29/2024 13:22	354.6	9.371	47.99	78.5
M2003-0014	6/29/2022 15:15	361.4	9.519	48.09	78.5
M2003-0014	8/13/2020 14:26	363.6	9.571	48.08	78.6
M2003-0016	6/29/2022 15:37	361.8	9.542	48.08	78.4
M2003-0016	7/30/2020 10:38	364.4	9.596	48.14	78.5
M2003-0019	6/29/2022 15:05	362.0	9.538	48.04	78.6
M2003-0019	7/30/2020 9:31	364.2	9.574	48.10	78.7
M2003-0019	7/30/2020 9:30	364.4	9.579	48.12	78.6
M2003-0024	6/29/2022 15:52	361.2	9.562	47.94	78.4
M2003-0024	7/30/2020 10:07	364.6	9.604	48.10	78.5
M2003-0025	6/29/2022 15:44	361.6	9.549	47.96	78.5
M2003-0025	7/30/2020 10:28	363.5	9.574	48.01	78.7

A.25 LONGi Monofacial Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1901-0001	3/28/2024 8:51	346.2	9.454	46.95	78.0
M1901-0001	6/29/2022 10:52	351.2	9.590	46.98	77.9
M1901-0001	12/12/2019 10:43	354.7	9.620	47.25	78.0
M1901-0001	1/24/2019 13:59	359.2	9.652	47.62	78.1
M1901-0002	6/29/2022 11:04	352.7	9.600	47.15	77.9
M1901-0002	12/12/2019 10:54	353.6	9.596	47.24	78.0
M1901-0002	1/24/2019 14:10	359.9	9.626	47.75	78.3

A.26 LONGi Monofacial Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M1901-0003	6/29/2022 12:59	362.0	9.686	47.84	78.1
M1901-0003	2/8/2019 11:11	365.9	9.670	48.12	78.6
M1901-0004	3/28/2024 8:44	357.5	9.605	47.84	77.8
M1901-0004	6/29/2022 12:55	361.8	9.726	47.84	77.8
M1901-0004	12/12/2019 10:24	363.7	9.726	47.97	77.9
M1901-0004	2/8/2019 11:06	364.7	9.715	48.03	78.2
M1901-0005	6/29/2022 13:21	351.3	9.600	47.22	77.5
M1901-0005	12/12/2019 10:33	355.9	9.631	47.48	77.8
M1901-0005	2/8/2019 10:52	355.2	9.618	47.40	77.9
M1901-0006	6/29/2022 13:06	356.8	9.629	47.53	78.0
M1901-0006	2/8/2019 10:35	360.0	9.625	47.70	78.4

A.27 REC 400W SHJ Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M2301-0011	1/12/2023 8:24	389.2	9.931	48.79	81.1
M2301-0012	1/12/2023 8:09	388.6	9.944	48.75	80.9
M2301-0015	7/25/2023 13:54	391.0	9.973	48.73	81.2

A.28 Solaria 400W PERC Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M2302-0031	8/24/2023 13:05	387.8	13.107	37.23	79.5
M2302-0032	8/24/2023 13:20	387.6	13.097	37.23	79.5
M2302-0035	9/14/2023 8:50	387.1	13.035	37.25	79.7

A.29 REC 360W TOPCon Modules

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
M2304-0012	5/11/2023 10:07	359.9	11.175	40.84	79.2
M2304-0012	5/11/2023 10:06	360.6	11.175	40.86	79.3
M2304-0013	5/11/2023 14:22	361.5	11.175	40.90	79.4
M2304-0013	5/11/2023 10:49	360.8	11.175	40.92	79.3
M2304-0016	8/24/2023 9:48	354.0	10.979	40.92	79.2
M2304-0016	8/24/2023 9:45	355.2	10.990	40.93	79.4