PV Lifetime Project - 2021 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-5K00-81172
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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 30294. 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 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.

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). More recently, modules from Sunpreme (2019), and LONGi (2020) have been deployed, and will be first re-measured in 2022.

Overall annual degradation rates are as follows: our first modules to be deployed (Jinko and Trina) have annual median degradation rate between -0.5%/yr and -0.8%/yr, mainly concentrated in the first year. The QCells mono-PERC and multi-PERC modules have an annual degradation rate of -0.7%/yr and -0.5%/yr respectively, also concentrated in the first year of operation.

Panasonic and LG modules displayed minor degradation loss in the past two years, at -0.2%/yr and -0.1%/yr respectively. They also were the only modules with initial IV curve measurements consistently above the nameplate rating. Possibly relatedly, these are also the only two N-type silicon module types analyzed so far.

Canadian Solar multi-PERC modules demonstrated a -1.1%/yr degradation rate which actually accelerated in the past year, so this will be a module type to monitor in future years. Mission Solar modules exhibited strong recoverable degradation, consistent with LeTID susceptibility. (The same is true for the Jinko JKM260 module type). This module type showed negligible median loss after 2 years in the field, although the module initially was measured at 3% below nameplate rating. These modules could therefore be experiencing a form of post-LeTID recovery.

Initial measurements have been conducted on the next two module types – Sunpreme n-HIT and LONGi bifacial mono-PERC. We will report on initial year-1 performance change for these modules in the next PV Lifetime annual report. For the remaining modules, an additional year of field exposure will provide greater certainty in annual degradation rates, particularly for those with degradation concentrated in the initial year of field deployment.

Three follow-on publications make use of the data in this report and 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" (http://doi.org/10.1002/pip.3573). Finally, a detailed discussion of LeTID kinetics and how this affects field performance and LCOE is provided in I. Repins et al., "Long-Term Impact of Light and Elevated Temperature Induced Degradation on Photovoltaic Arrays". This paper is still under review with MRS Impact.

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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 905 different samples from 9 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 2021, 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	-
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	-
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:

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.

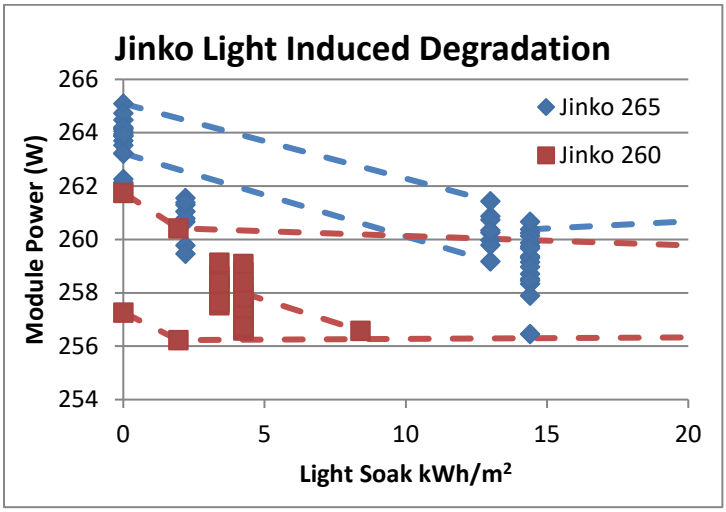

Figure 3. Jinko Solar initial LID data showing 0.5% LID loss for JKM260 and 1.5% LID loss for JKM265 modules. Data from repeated indoor IV measurements. Dashed lines shown for select modules.

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.

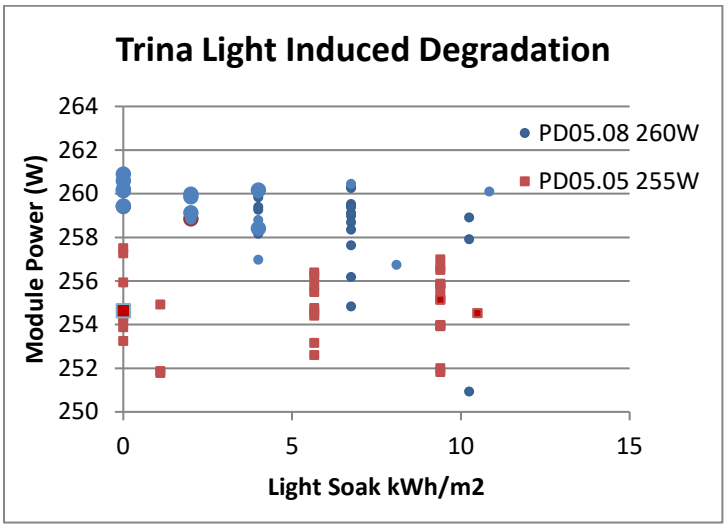

Figure 4. Trina Solar initial LID data showing 0.4% LID loss for both module types. (Data from repeated indoor IV measurements)

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 less than 1% was detected following 10 kWh/m^2 of light exposure.

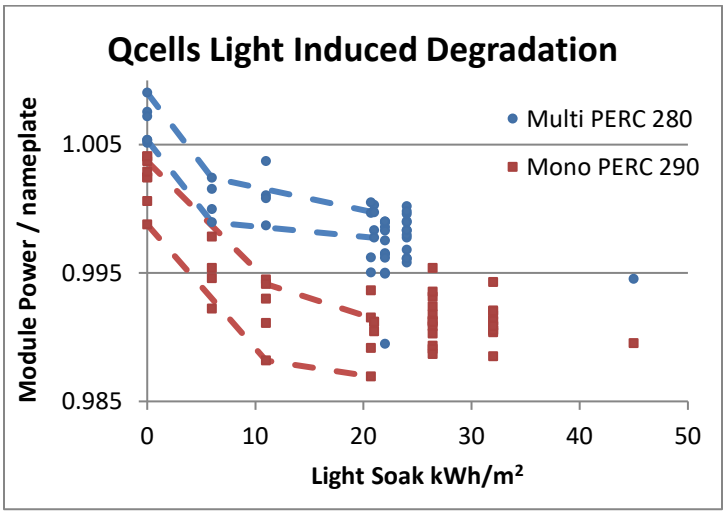

Figure 6. QCells initial LID data showing 0.9% LID loss for Qplus (multi PERC) 280W and 1.2% LID loss for QPeak (monoPERC) 290W. Data from repeated indoor IV measurements. Dashed lines shown for select modules.

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.

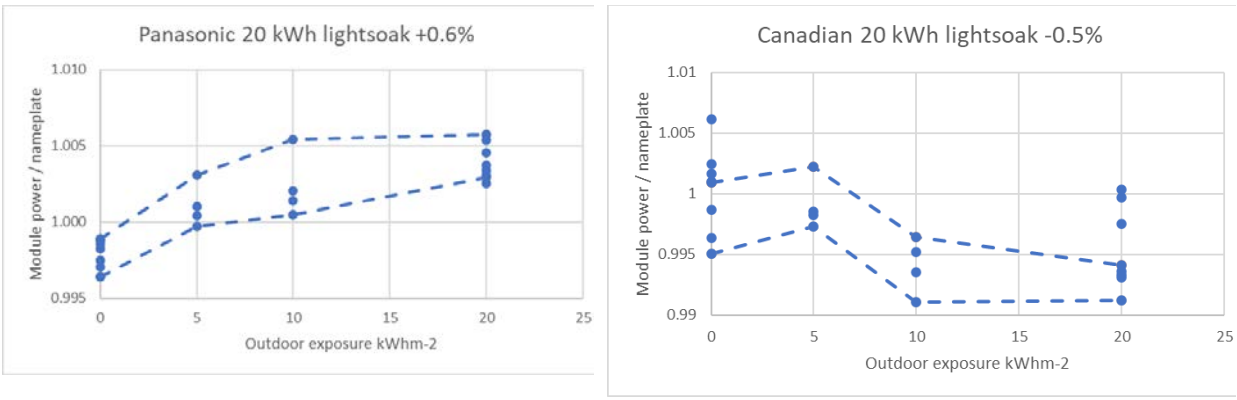

Figure 7. Panasonic initial light-soak data showing +0.6% performance gain and Canadian CS6K-300MS showing -0.5% decline. Data from repeated indoor IV measurements. Dashed lines shown for select modules.

Mission Solar, Sunpreme, 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 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.

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

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

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 on one or two samples per module type at the beginning of the experiment. The faster approach is to take flash measurements on the Spire 5600 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 flash simulator, in Figure 9 we plot the high accuracy MSR measurements taken for all module types (except Jinko and Trina) 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 and Mission Solar modules, the Spire measurement is within 1% of the true value, but for Canadian and QCells the Spire values are 2% low, and for LG modules the Spire values are measuring 4.4% below the true value. This should be considered when looking at the figures in the remainder of this report, all of which were measured with the Spire 5600 platform, and are expected to maintain this consistent level of under-performance.

Figure 9 also provides 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 and Panasonic, 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 was as much as 3% below nameplate rating.

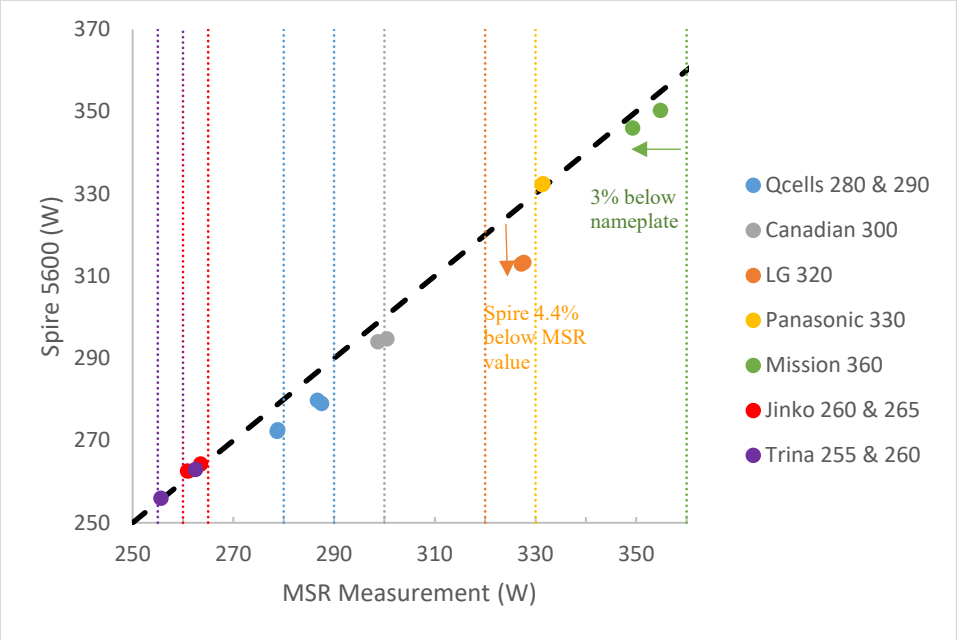

Figure 9. Initial baseline characterization of PV Lifetime modules. MSR measurement (1.1% absolute accuracy) compared with Spire 5600 measurement (lower accuracy). Vertical lines represent nameplate rating of each module type.

2 Field measurement results

2.1 Jinko JKM260

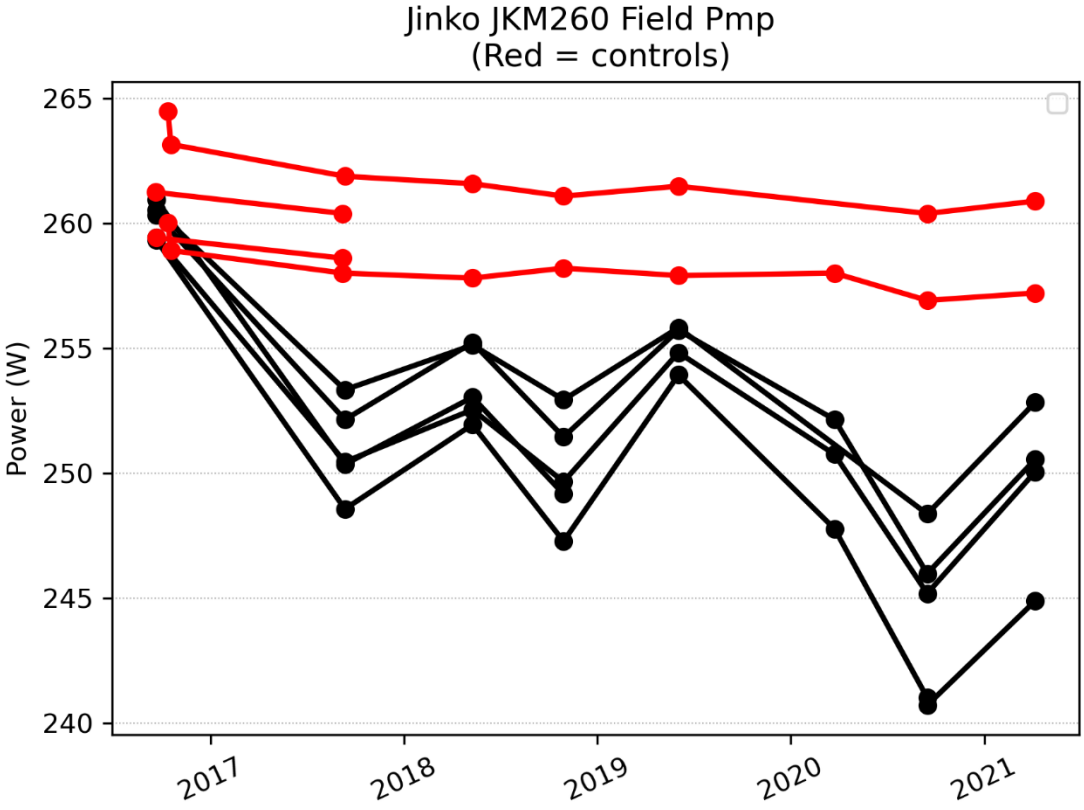

Figure 10. Jinko JKM260 flash measurements. Field modules (black) and indoor controls (red)

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 -0.7% over the entire measurement period.

2.1.3 Field module change (post-lightsoak)

Compared with the relatively stable control modules, the fielded modules demonstrate seasonal performance change, possibly 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, overall median degradation was -3.75%. The majority (-3.2%) of this loss occurred in Year 1. The overall annualized loss works out to -0.83%/yr.

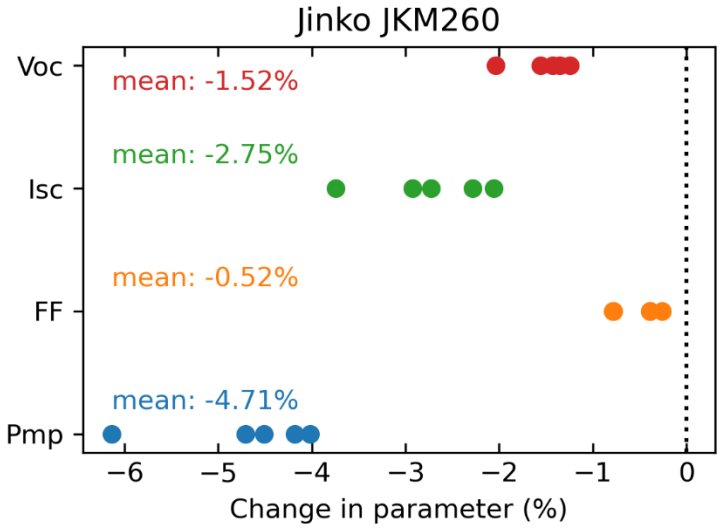

Figure 11. Jinko JKM260 IV curve parameter overall change.

Overall change in performance from 2017 to 2021 for Jinko JKM260 is due to primarily Isc, as well as Voc loss.

2.2 Jinko JKM265

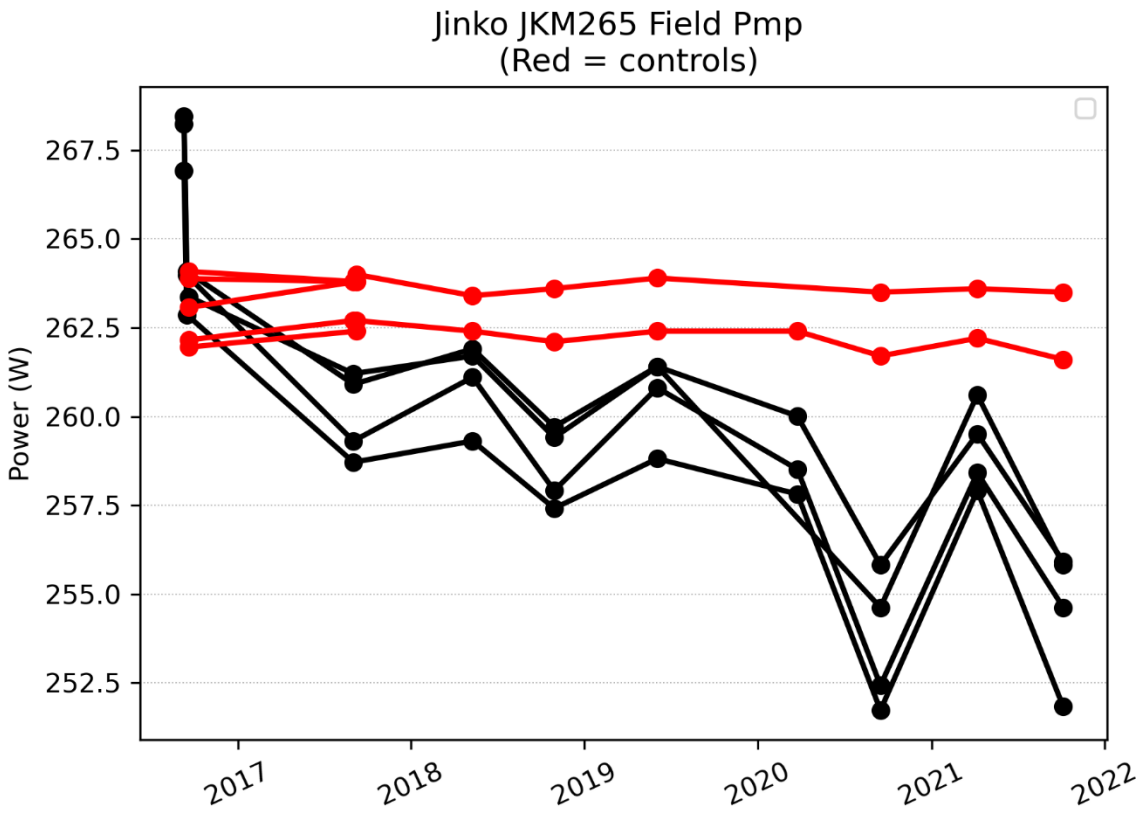

Figure 12. Jinko JKM265 flash measurements. Field modules (black) and indoor controls (red)

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 2017-2021.

2.2.3 Field module change (post-lightsoak)

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 2021 measurement as an endpoint, degradation was -3.34% or -0.66%/yr.

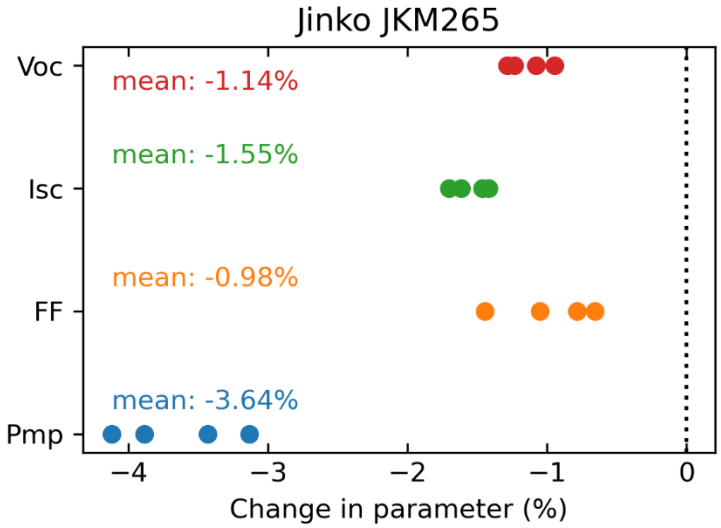

Figure 13. Jinko JKM265 IV curve parameter overall change.

Overall change in performance from 2017 to 2021 for Jinko JKM265 is due to both Isc, Voc and Fill Factor.

2.3 Trina TSM255

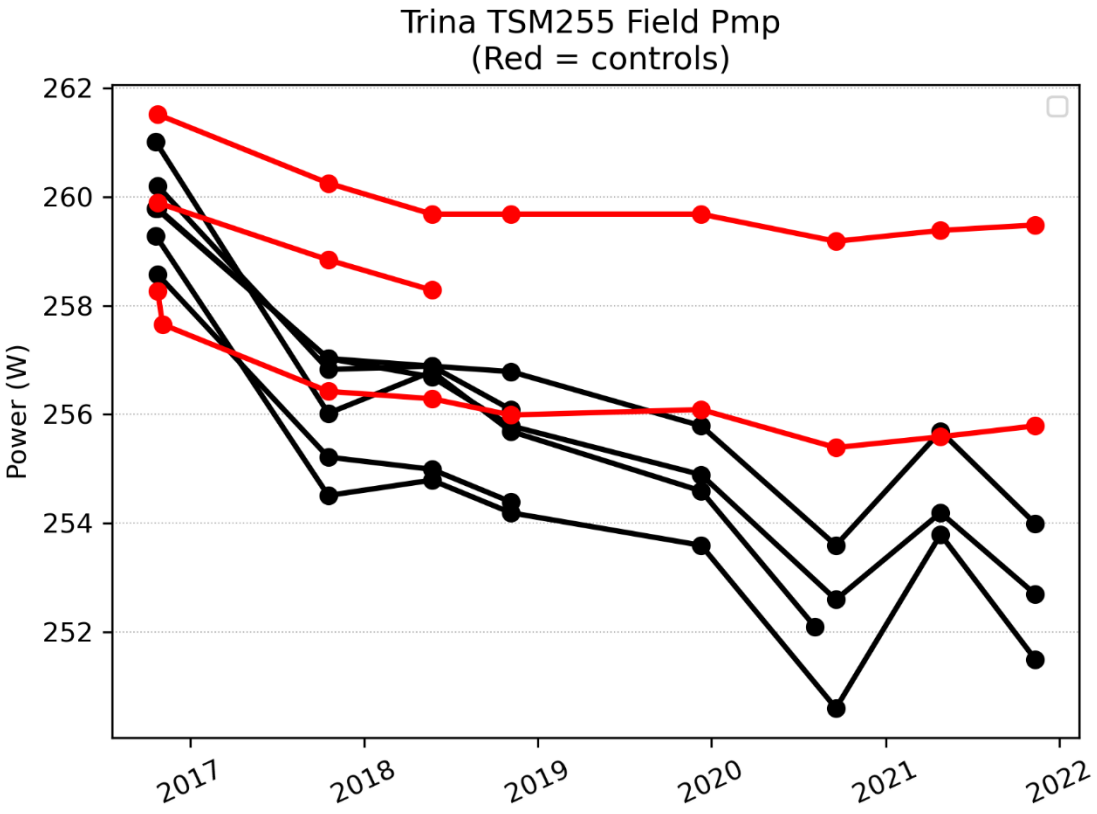

Figure 14. Trina TSM255 flash measurements. Field modules (black) and indoor controls (red)

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 -0.8% from 2017-2021.

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 fall 2021 was -2.48%, or -0.49%/yr.

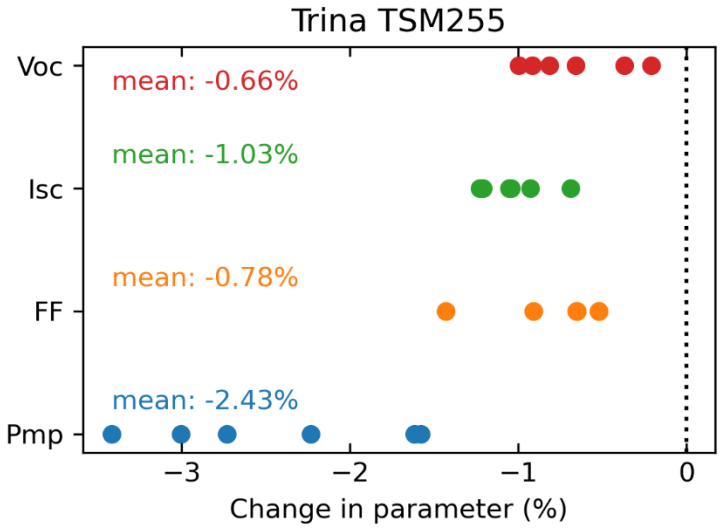

Figure 15. Trina TSM255 IV curve parameter overall change.

Overall change in performance from 2017 to 2021 for Trina TSM255 is split pretty evenly between Isc, Voc and Fill Factor.

2.4 Trina TSM260

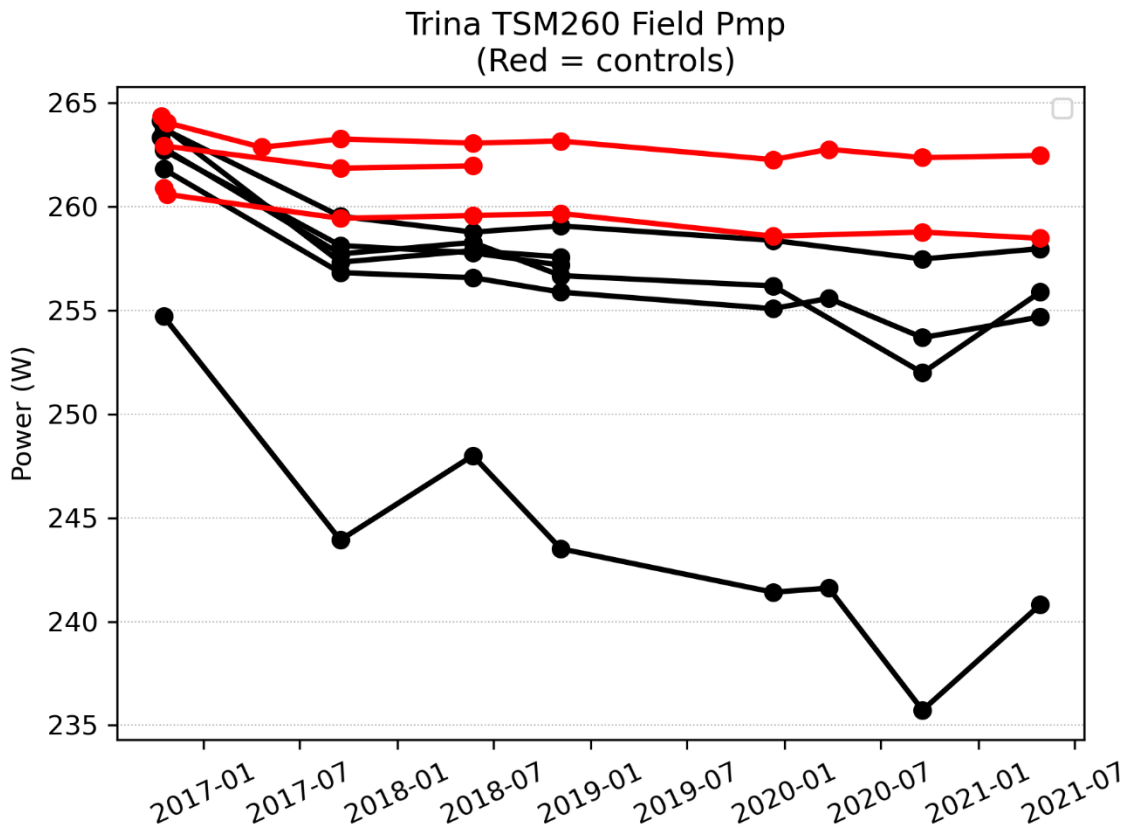

Figure 16. Trina TSM260 flash measurements. Field modules (black) and indoor controls (red)

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.

2.4.3 Field module change (post-lightsoak)

Year 1 field module degradation was roughly -2% aside from the outlier module M1610-0043 which declined -3.8% in year 1.

Without additional information it is difficult to assess the cause of the outlier's low performance. Nothing is visibly different about this module, however initial performance was lower and the rate of degradation was faster. In some cases manufacturers use a different bill of materials (BOM) for their modules, and this could be such a substitution, possibly with a different source of the cell or wafer leading to lower performance. This variability highlights the benefit of large number of samples for studies of this nature.

The TM260 fielded modules (aside from one outlier) showed only modest annual performance change. Overall post-LID degradation from 2017-2021 was -2.5%, or -0.55%/yr.

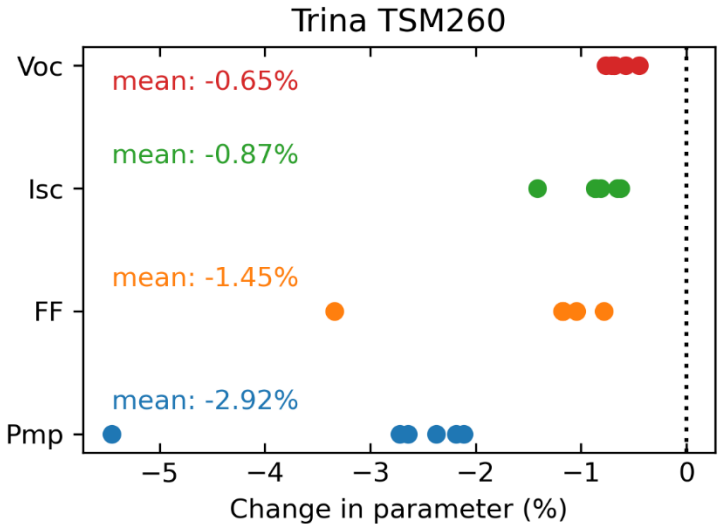

Figure 17. Trina TSM260 IV curve parameter overall change.

Overall change in performance from 2017 to 2021 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.

2.5 QCells Qplus280

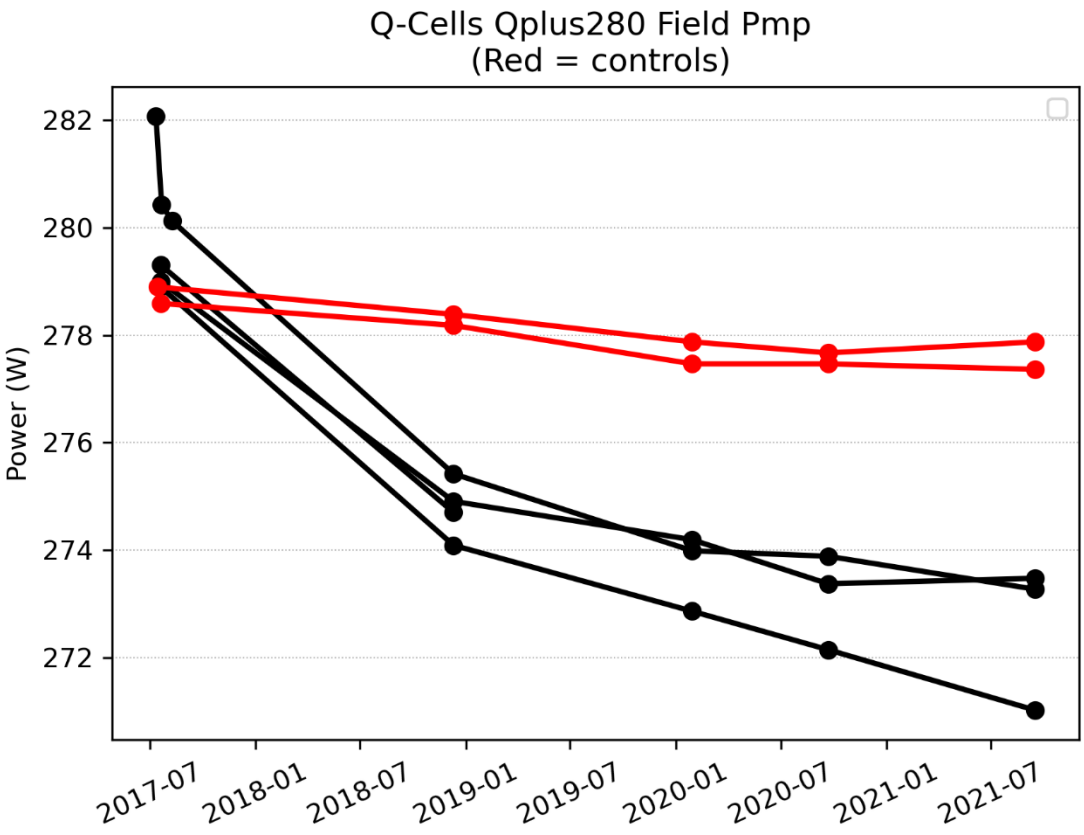

Figure 18. QCells Qplus280 flash measurements. Field modules (black) and indoor controls (red)

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)

QCells QPlus280 control modules showed a modest overall change of -0.3% from 2017-2021.

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 2017-2021 of -2.27%, or -0.54%/yr.

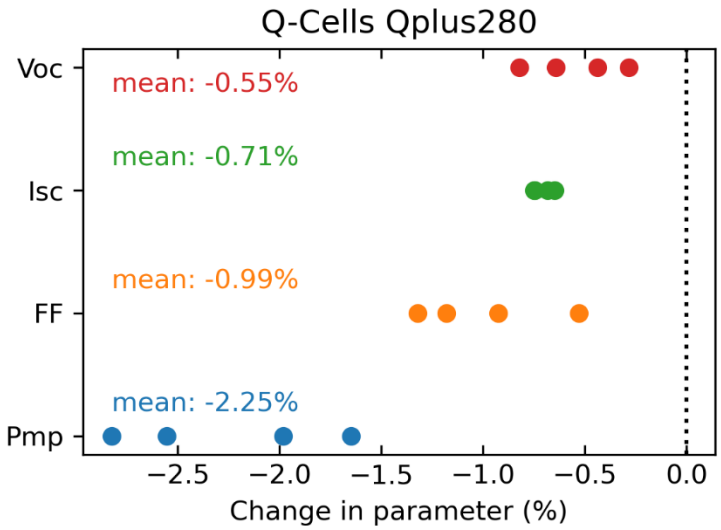

Figure 19. QCells QPlus280 IV curve parameter overall change.

Overall change in performance from 2017 to 2021 for QCells QPlus280 is due to both Isc, Voc and Fill Factor.

2.6 QCells QPeak290

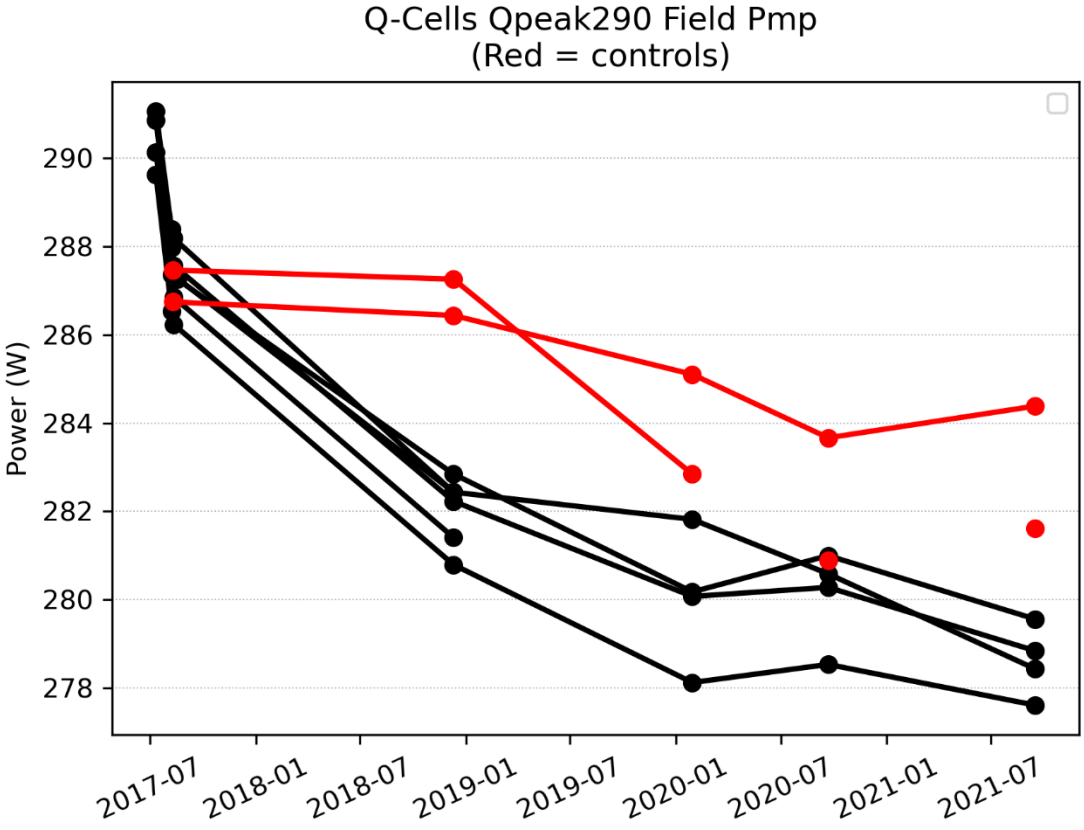

Figure 20. QCells Qpeak290 flash measurements. Field modules (black) and indoor controls (red)

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 -1.4% on average from 2017-2021.

2.6.3 Field module change (post-lightsoak)

The QPeak290 fielded modules showed overall post-LID degradation from 2017-2021 of -2.9%, or -0.71%/yr which is roughly double the control module change.

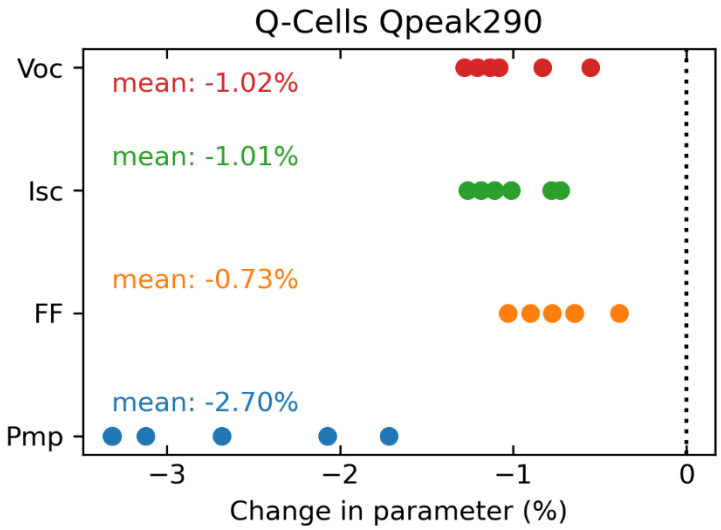

Figure 21. QCells QPeak290 IV curve parameter overall change.

Overall change in performance from 2017 to 2021 for QCells QPeak290 is due primarily to Isc and Voc change.

2.7 Canadian CS6K-300MS

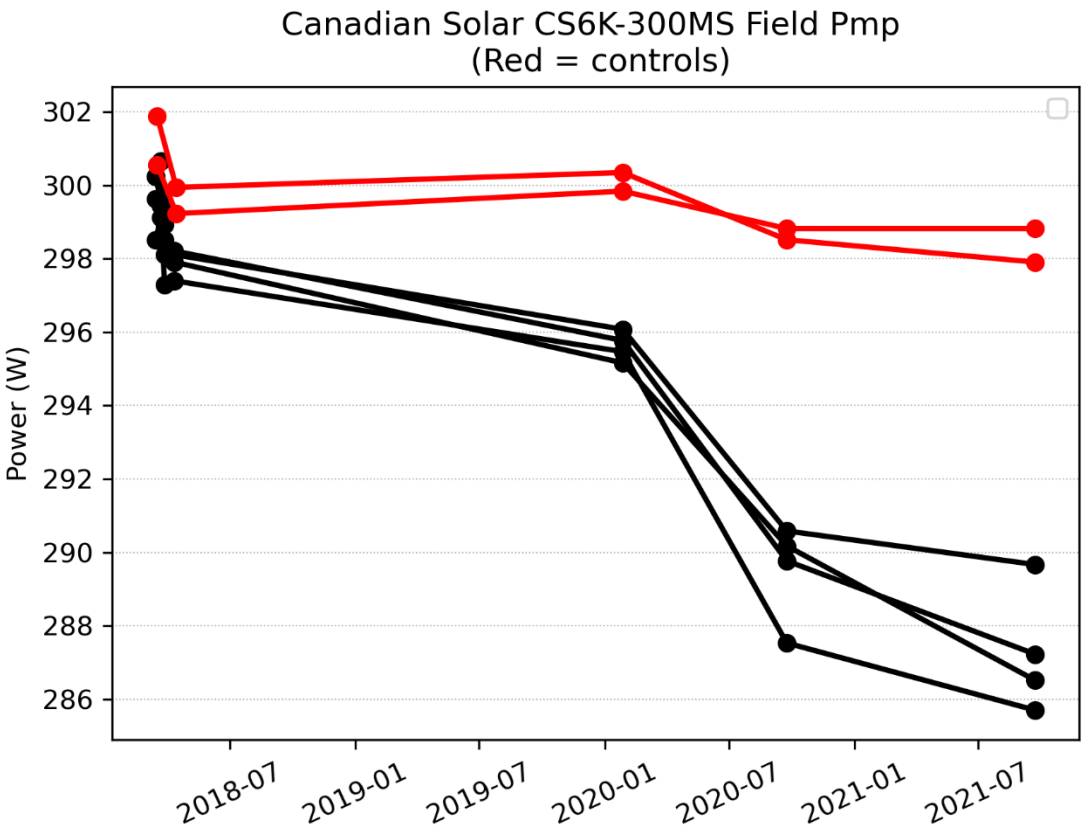

Figure 22. Canadian CS6K flash measurements. Field modules (black) and indoor controls (red)

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 < 0.5% from 2017-2021.

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 stabilizing in the third year. Overall loss from 2017-2021 was -3.8%, or -1.1%/yr. One possible explanation 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, which could be leading to the lower measurements. Additional springtime measurements may help uncover this potential effect.

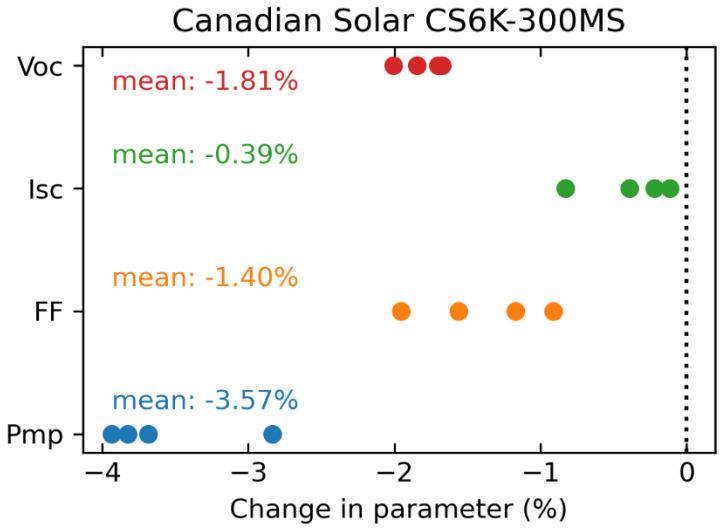

Figure 23. Canadian CS6K-300MS IV curve parameter overall change.

Degradation from 2017 to 2021 for Canadian CS6K-300MS is due primarily to Voc and FF.

2.8 LG 320N1K

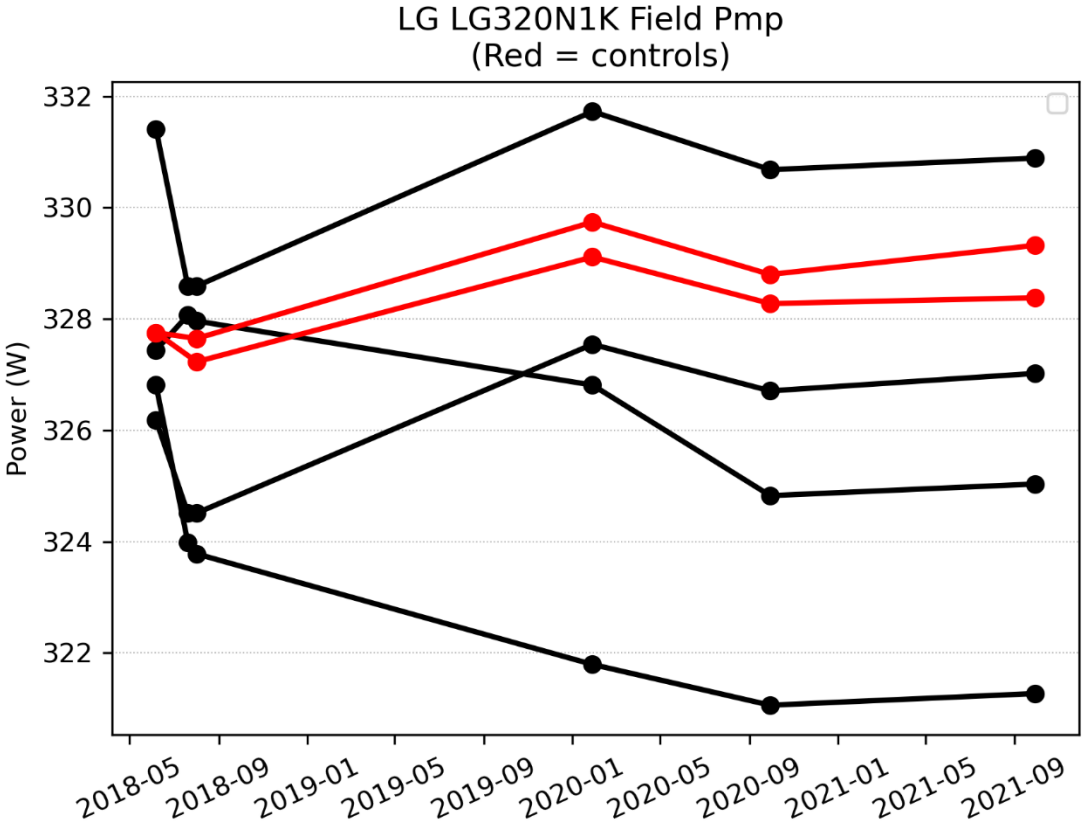

Figure 24. LG 320N1K flash measurements. Field modules (black) and indoor controls (red)

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 relatively stable performance. Overall change increased by roughly 0.3%. from 2018-2021.

2.8.3 Field module change (post-lightsoak)

The LG 320N1K fielded modules showed variable performance with two modules winding up close to their initial performance, and two decreasing slightly in performance. This leads to overall median post-LID degradation from 2017-2021 of -0.45%, or -0.13%/yr. All modules remain above their nameplate rating after three years in the field.

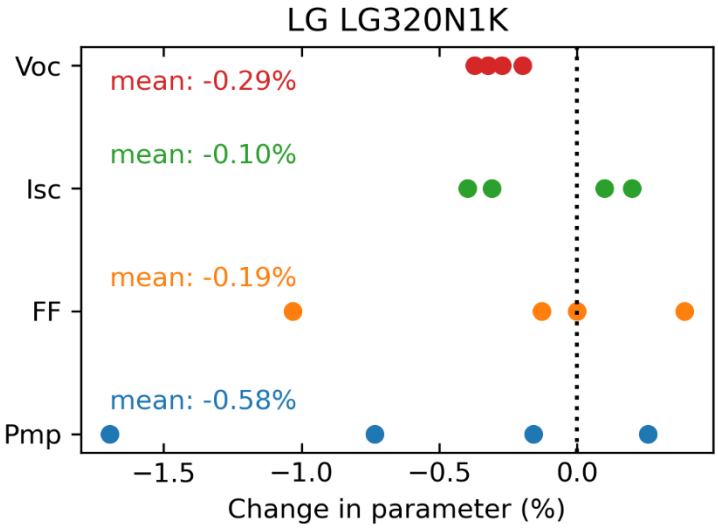

Figure 25. LG 320N1K IV curve parameter overall change.

Overall change in performance from 2017 to 2021 for LG 320N1K is stable, without much change in any particular parameter.

2.9 Panasonic VBHN330

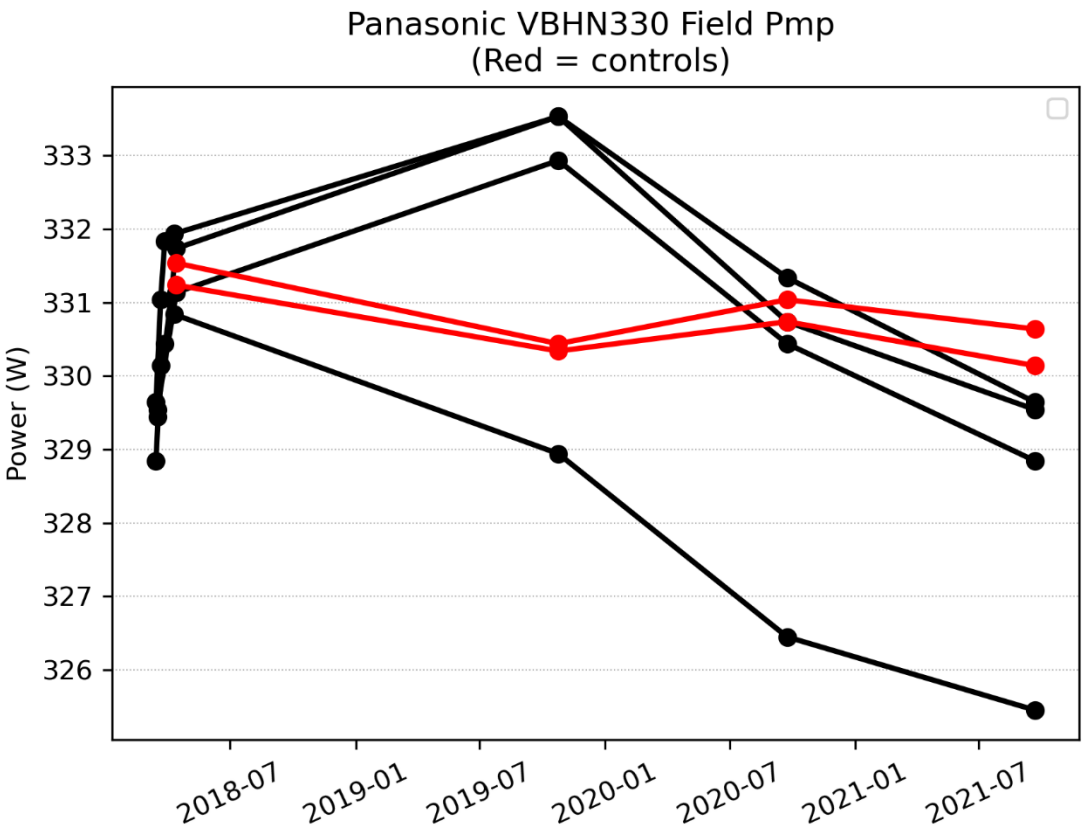

Figure 26. Panasonic flash measurements. Field modules (black) and indoor controls (red)

2.9.1 Initial light soak

Panasonic VBHN330 showed an actual increase in module performance of 0.5%. 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 relatively little overall performance change within 1W.

2.9.3 Field module change (post-lightsoak)

Year 1 field module performance change was different, with three modules declining slowly and one module declining more rapidly in performance.

The VBHN330 fielded modules showed median post-LID degradation from 2017-2021 of -0.7% or -0.2%/yr. The lowest performing module had an overall degradation of -1.3%. This low-performing module did end up having a backsheet be scratched during installation. This could partly explain the out-of-family performance if there was accompanying cell damage.

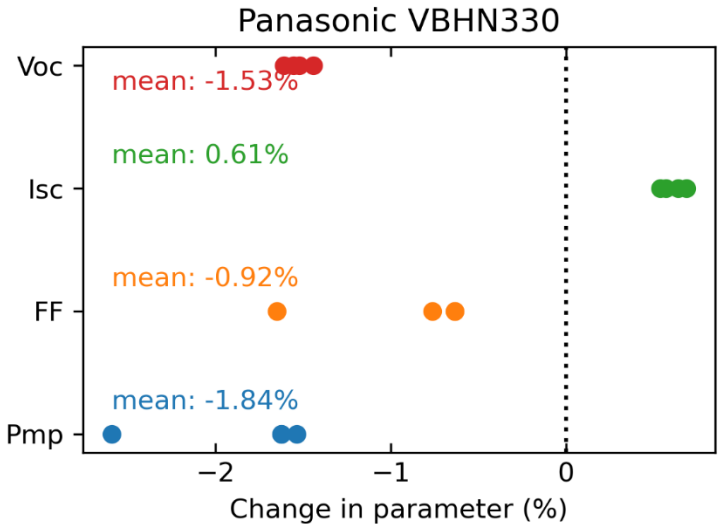

Figure 27. Panasonic VBHN330 IV curve parameter overall change.

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 installation damage, and the reduced fill factor could indicate one or more cracked cells. Follow-up electroluminescence imaging investigation will see if this is the case.

2.10 Mission Solar MSE360

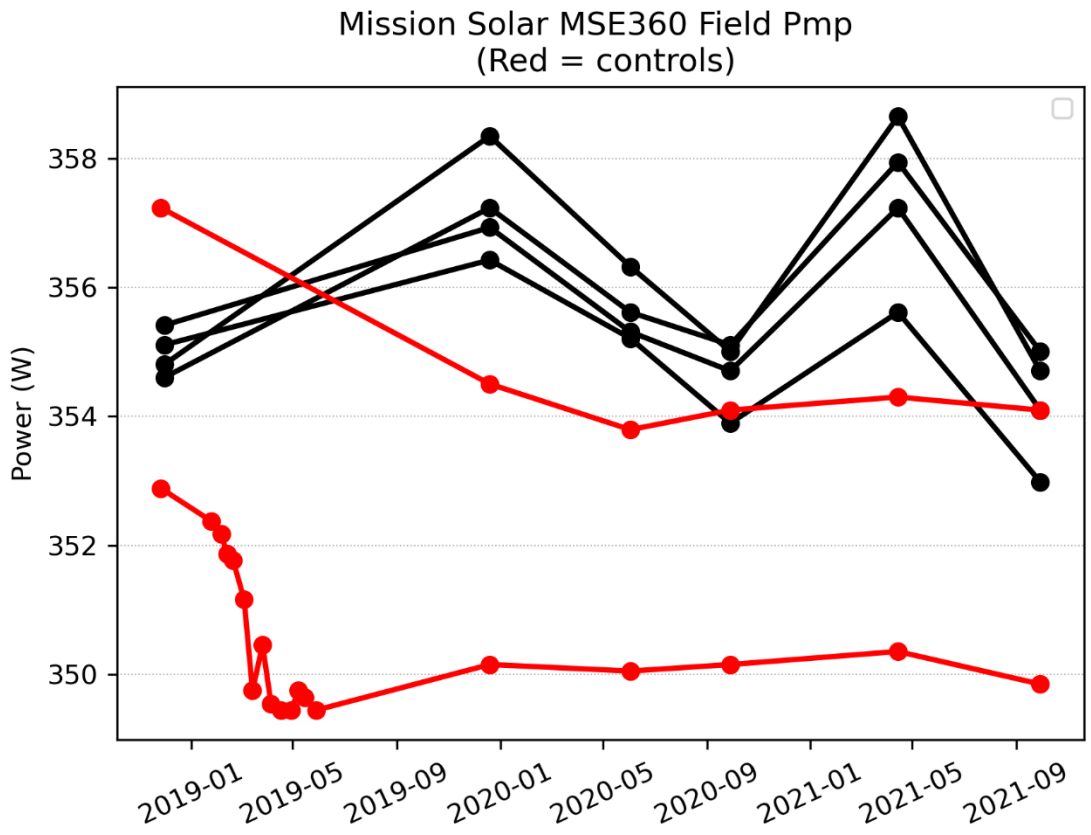

Figure 28. Mission Solar flash measurements. Field modules (black) and indoor controls (red)

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 actually are showing faster degradation than the outdoor exposed field modules. Initial performance loss is visible by periodic indoor IV curves as the control modules are maintained in dark storage. Total degradation of -0.87% is being shown in the control modules.

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 -0.2% or -0.07%/yr.

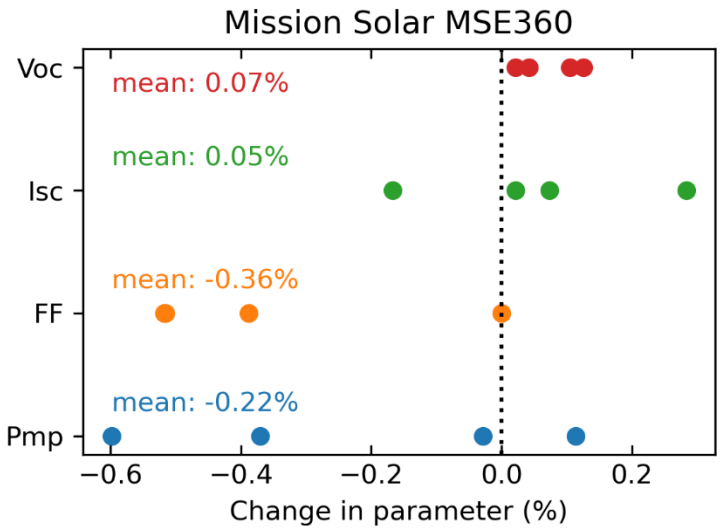

Figure 29. Mission Solar MSE360 IV curve parameter overall change.

Overall change in performance for Mission Solar MSE360 is characterized by a slight reduction in fill factor and no change in Isc or Voc.

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.

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	-0.826	-3.75	-1.22	-2.28	-0.39
Jinko	JKM265	10/2016	-0.660	-3.34	-0.96	-1.52	-0.85
Trina	TSM255	10/2016	-0.490	-2.48	-0.74	-1.05	-0.65
Trina	TSM260	10/2016	-0.554	-2.51	-0.69	-0.84	-1.17
Q-Cells	Qplus280	10/2017	-0.545	-2.27	-0.54	-0.71	-1.05
Q-Cells	Qpeak290	10/2017	-0.706	-2.90	-1.11	-1.06	-0.71
Mission Solar	MSE360	12/2018	-0.070	-0.20	0.07	0.05	-0.45
LG	LG320N1K	8/2018	-0.135	-0.45	-0.30	-0.10	-0.06
Canadian Solar	CS6K-300MS	8/2018	-1.088	-3.76	-1.77	-0.30	-1.36
Panasonic	VBHN330	6/2018	-0.200	-0.69	-1.02	0.61	-0.32
SunPreme	HxB-400	3/2019	-	-	-	-	-
LONGi	LR6-72BP-360M	11/2020	-	-	-	-	-

References

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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.

Stein JS, Robinson C, King B, Deline C, Rummel S, Sekulic B. PV Lifetime Project: Measuring PV Module Performance Degradation: 2018 Indoor Flash Testing Results. 7th IEEE World Conference on Photovoltaic Energy Conversion (WCPEC) 2018 Jun 10 (pp. 0771-0777). IEEE.

Theristis M, Stein JS, Deline C, Jordan D, Robinson C, Sekulic W, Anderberg A, Colvin DJ, Walters J, Seigneur H, and King BH "Onymous early-life performance degradation analysis of recent photovoltaic module technologies". Progress in Photovoltaics 2022 http://doi.org/10.1002/pip.3615

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. Isc and Pmp are normalized based on reported simulator setting which may have been changed from 2016 - 2017 for the Jinko and Trina measurements.

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	4/7/2021 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	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
M1609-0047	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
M1609-0055	4/7/2021 11:12	244.9	8.721	37.00	76.3

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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
M1609-0055	9/20/2016 11:39	259.3	9.021	37.72	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	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
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
M1609-0066	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	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	10/5/2021 8:46	261.6	9.120	38.05	75.6

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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
M1609-0010	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
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
M1609-0010	9/9/2016 11:57	266.9	9.189	38.20	76.3
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
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	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

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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
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
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
M1609-0045	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
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	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	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
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	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
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
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
M1610-0071	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
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	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	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
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
M1610-0025	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

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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
M1610-0041	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
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	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	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

A.9 Q-Cells Q.Plus280 Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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
M1706-0048	7/19/2017 12:34	278.6	9.516	38.76	76
M1706-0049	9/16/2021 8:15	277.9	9.470	38.85	76
M1706-0049	9/21/2020 10:47	277.7	9.480	38.81	76
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	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	9/16/2021 8:23	273.5	9.491	38.65	75
M1706-0029	9/21/2020 11:15	273.4	9.491	38.64	75
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	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	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
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	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
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	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
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	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
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
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	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
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	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

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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	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	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
M1811-0012	6/2/2020 11:27	355.3	9.752	47.54	77
M1811-0012	12/19/2019 12:54	356.9	9.732	47.65	77.4
M1811-0012	11/30/2018 10:32	355.4	9.690	47.58	77.5
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	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

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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	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	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	9/29/2021 8:21	328.4	10.509	40.32	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	9/29/2021 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	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	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

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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
M1806-0008	9/29/2021 8:36	330.9	10.519	40.41	78
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

A.17 Canadian CS6K-300MS Controls

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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
M1803-0042	3/16/2018 11:25	301.9	9.880	39.90	77
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
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	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
M1803-0036	3/14/2018 13:23	299.6	9.827	39.91	76.9
M1803-0037	9/22/2021 10:19	289.7	9.798	39.15	76
M1803-0037	9/23/2020 12:05	290.6	9.800	39.23	76
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
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
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
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	9/22/2021 10:30	285.7	9.726	38.90	76
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	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	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	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	9/21/2021 12:47	325.5	6.070	69.83	77.8

NREL ID	Timestamp	Adjusted Pmp (W)	Adjusted Isc (A)	Voc (V)	FF
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	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
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	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