ADDENDUM

RENE092 – KORTRIGHT ENERGY YIELD TEST STANDARD PUBLIC FINAL REPORT

Prepared by:

Toronto and Region Conservation
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NOTICE

CONTACT INFORMATION

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the data and analytical tools necessary to support broader implementation of sustainable technologies and practices within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water, air and energy technologies;
- assess barriers and opportunities to implementing technologies;
- develop tools, guidelines and policies, and
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical products or devices; they may also include preventative measures, alternative urban site designs, and other innovative practices that help create more sustainable and livable communities.

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1.0 INTRODUCTION

This is an addendum to the report “RENE092 Kortright Energy Yield Test: Public Final Report,” and it provides greater detail to the questions posed in Table 4-1 of that report. Introductory and summary remarks are omitted in this addendum but are available in the main report. It should be noted that the additional detail provided in this addendum is itself a summary of a series of other studies that were completed as part of this funding grant. Full reports for these studies are available on sustainabletechnologies.ca.

2.0 IEC 61853-1

2.1 Q1. Are the temperature and irradiance conditions in IEC 61853-1 sufficient for a Canadian climate? Should points be added or deleted to better represent the climate?

An evaluation was conducted primarily through PV installation performance modelling, with a more limited experimental dataset providing verification of the modelling results. The aim of the modelling was to determine PV module operating hours and energy production at different levels of irradiance and different module temperatures. The modelling approach involved the use of the PVsyst modeling software package with input data for 43 locations across Canada derived from the commonly-used Canadian Weather for Energy Calculation (CWEC) files which characterize a typical meteorological year (TMY) for each city.

An assessment was made at two scales – Ontario-only and Canada-wide. The Ontario-only assessment was dedicated for two PV system configurations, roof- and ground-mount, while the Canada-wide assessment encompassed five different configurations. The input data for the PV module configuration included the maximum power point (MPP) current, MPP voltage and temperature coefficients, all of which are parameters that are typically provided in manufacturer specification sheets. The default thermal loss coefficients proposed by PVsyst were used.

Two Southern Ontario locations were chosen as the experimental sites, located in St. Catharines, ON and Toronto, ON (Table 3). Data collection occurred between August, 2014 and August, 2015. The two sites were chosen for their similarity in system configuration to the modelled scenarios, as well as the availability and ease of access to the data. Although there were gaps in both experimental datasets, a sufficient amount of datapoints were collected for each month to conduct the analysis.

An example plot from Toronto of both the experimental and modelled results is shown in Figure 4-1. The figure shows that the modelled results provide a reasonable agreement with real-world data in terms of the temperature and irradiance operating points. Furthermore, it shows that, for this location, some of the operating points in the IEC 61853-1 power matrix are never achieved in practice while other operating points (low temperature and low-medium irradiance) are not fully represented.

For locations above 50° N, 58% of operating hours occur with module temperatures below 15 °C, yielding 28% of their total annual energy production. Additionally, a non-negligible amount of energy is produced at module operating temperatures below 5 °C. Approximately 32% of operating hours at these sites occur below 5 °C, resulting in 12% of total energy production. In the extreme case of Resolute, Nunavut, 92% of operating hours are below 15 °C, accounting for 45% of total energy production.

Results indicate that a notable portion of the annual energy production occurs outside of the current IEC 61853-1 test matrix. To address this gap, the following changes to the existing matrix would be ideal:

- Six new test points are at 0 °C for all existing irradiance bins up to 1,000 W/m2 , while the 1,100 W/m2 point is to be designated as optional only;
- Two existing test points, 50 °C x 200 W/m^2 and 75 °C x 600 W/m^2 , are suggested to be designated as optional.

It should be noted explicitly that, while changes proposed would be ideal, there also must be some thought towards the incremental increases in cost and difficulty for testing labs to actually implement these changes. As an example, informal conversations with testing labs have indicated that at 0° C module frosting would become an issue and in that case, additional testing points at 5° C may be a more realistic addition.

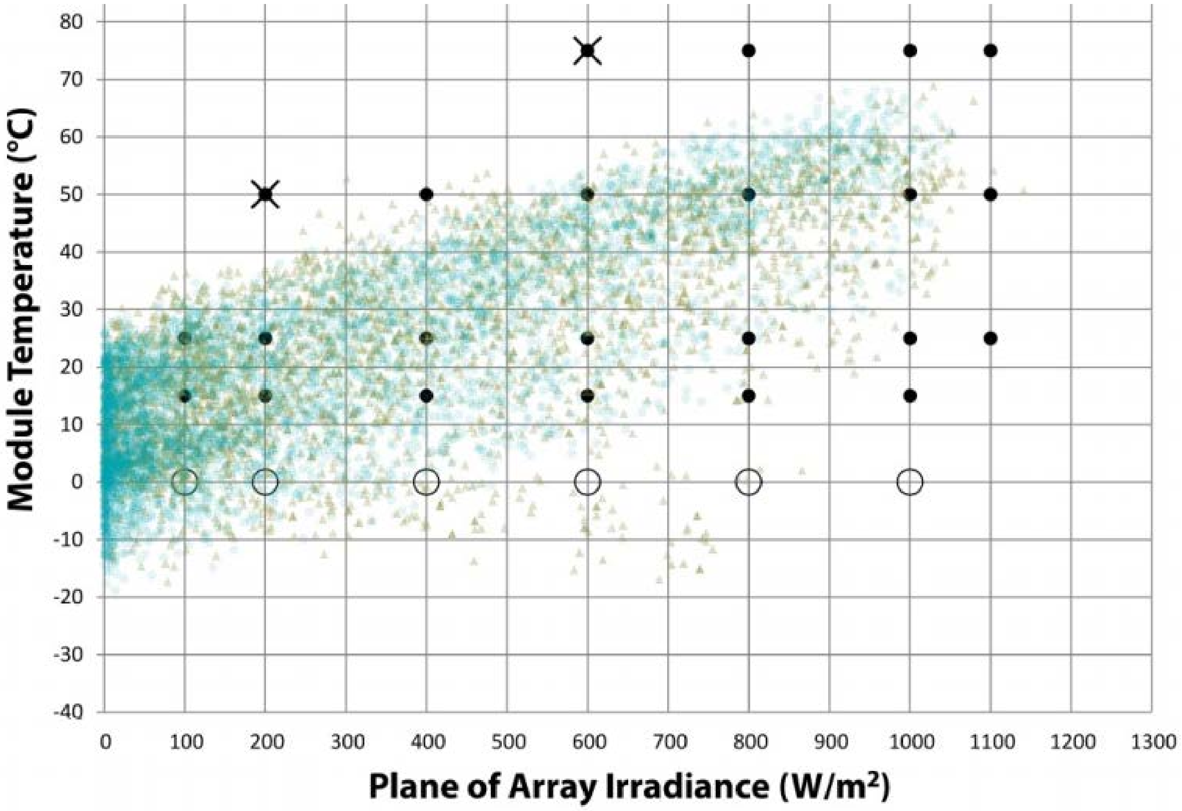


Figure 4-1. Hourly operating points of module temperature and irradiance for the Toronto, ON experimental location (beige triangles) and the Toronto, ON PVsyst modelled location (blue circles). Each circle/triangle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.

2.2 Q2. Does Procedure 3 (the new procedure) produce results that are in agreement with the other established procedures?

PV modules underwent testing according to Procedure 3 at the Living City Campus (LCC) PV Testing Facility located at the Kortright Centre for Conservation in Vaughan, ON, from January 2014 to March 2016. During Phase 1 of this project, six different modules were tested – three mono-c-Si modules of the same model and from the same manufacturer and three poly-c-Si module, also of the same model and from the same manufacturer. Prior to mounting at the PV Testing Facility, the modules were characterized according to IEC 61853-1 and -2 by Exova, an ISO 17025 testing laboratory, using indoor methods. During Phase 2 of the project, additional modules were added but issues with data collection were encountered that limited the analysis.

A custom automated IV curve tracing system was designed and implemented for this project. Essentially, the Automated IV Measurement System (AIMS) records module IV curves and weather data on a timed basis and then goes through a serious of steps to filter, interpolate and aggregate that data, transforming a database of raw IV curves and weather data into a populated IEC 61853-1 power matrix.

The researchers found that, when using back-surface module temperature measurements, Procedure 3 could not produce a good quality dataset that was in agreement with indoor data. However, the procedure was successful when the equivalent cell temperature (ECT) was used instead (Table 4-1). This was not a good solution because the ECT is only valid for linear modules and there is a much simpler method for linear modules within IEC 61853-1. The issue with back-surface measurements was that, unlike IEC 60904-1, IEC 61853-1 Procedure 3 does not incorporate any measures to ensure that the back-surface temperature measurement is representative of the cell temperature.

Table 4-1. Module 1 (poly-c-Si) comparison between indoor and outdoor methods (Procedure 3) when data was analyzed using the ECT method

#	Irradiance [W/m²]	Cell Temp. [°C]	Outdoor Average [W]	Indoor Average [W]	% Diff.	# of Datafiles	Max [W]	Min [W]	Std. Dev. [%]
1	100	15	24.0	24.4	-1.7	153	28.6	14.5	5.7
2	200	15	49.2	51.4	-4.2	177	53.6	44.5	4.3
3	400	15	101.4	103.4	-2.0	138	103.7	91.0	1.9
4	600	15	153.2	155.3	-1.3	107	162.4	143.4	1.4
5	800	15	202.9	206.3	-1.7	32	203.0	196.4	0.8
6	1000	15	251.9	255.8	-1.5	3	249.4	247.9	0.3
7	100	25	23.4	23.4	-0.1	132	24.6	20.5	2.2
8	200	25	48.3	49.4	-2.2	962	54.1	39.5	2.9
9	400	25	96.1	99.3	-3.2	207	103.9	85.8	3.1
10	600	25	145.1	149.1	-2.7	92	150.4	134.1	2.0
11	800	25	194.4	197.9	-1.8	103	197.3	186.1	1.1

12	1000	25	240.7	245.5	-1.9	17	241.0	232.4	0.9
13	1100	25	262.4	268.6	-2.3	1	258.9	258.9	N/a
14	600	50	133.6	132.8	0.6	76	141.0	128.2	2.0
15	800	50	174.4	175.9	-0.8	454	184.0	166.4	0.9
16	1000	50	215.2	217.5	-1.1	378	219.9	202.1	1.2
17	1100	50	235.1	237.6	-1.1	81	237.0	224.4	1.0

It is the opinion of the authors that the procedure should not be an option in IEC 61853-1 until an improved approach can be established and demonstrated to be in agreement with other methods. The improved approach would require an irradiance sensor that is matched to the module under test in terms of spectral, time and IAM response. It would also incorporate requirements to ensure that there is an accurate measurement of the cell temperature that is valid on instantaneous basis so as to eliminate the need for applying data filters. Potential solutions may include:

- directly contacting cells with a temperature sensor,
- using back-surface temperature measurements and requiring that clear sky days be used;
- using back-surface temperature measurements and controlling the module temperature, or
- using back-surface measurements and incorporating a device to automatically shades/un-shade the module such that the procedure of IEC 61853-1 is identical to IEC 60904-1.

3.0 IEC 61853-2

3.1 Q3. Do the indoor and outdoor IAM procedures agree?

Indoor testing was done by Exova on a poly-c-Si PV module provided by STEP. Within this method, light from a solar simulator is incident on both a normally-oriented reference module and also on the PV module, termed the device under test (DUT), which is at some known angle with respect to the reference module. By collecting data at different module angles, the IAM curve can be traced out. The same PV module was then tested using the STEP outdoor incidence angle measurement set-up. The equations used for the outdoor IAM procedure are slightly different than that used in the indoor measurements because of the need to correct for the diffuse irradiance, which is present in outdoor measurements but not in indoor measurements.

Results from one iteration of the testing are shown in Figure 4-2. This iteration used a reference PV sensor from IMT as the irradiance sensor. Three different curves are shown, one for indoor data and one each for two different days of outdoor testing (designated as D1 and D2). Data points represent the actual collected data and the dashed curves are the resulting IAM curves based on a least squares fit of the experimental data according to the theoretical IAM equation. While both days of outdoor testing did not have cloud cover, the two days differed in terms of the ratio between the global direct and the global normal irradiance due to hazy conditions on one of the days. IEC 61853-2 stipulates that the ratio should be greater than 0.85 but this was only satisfied on one of the days.

The testing indicated the differences between the two days of outdoor were greater than any differences between the indoor and outdoor data. The researchers concluded that the indoor and outdoor procedures produce results that agree sufficiently.

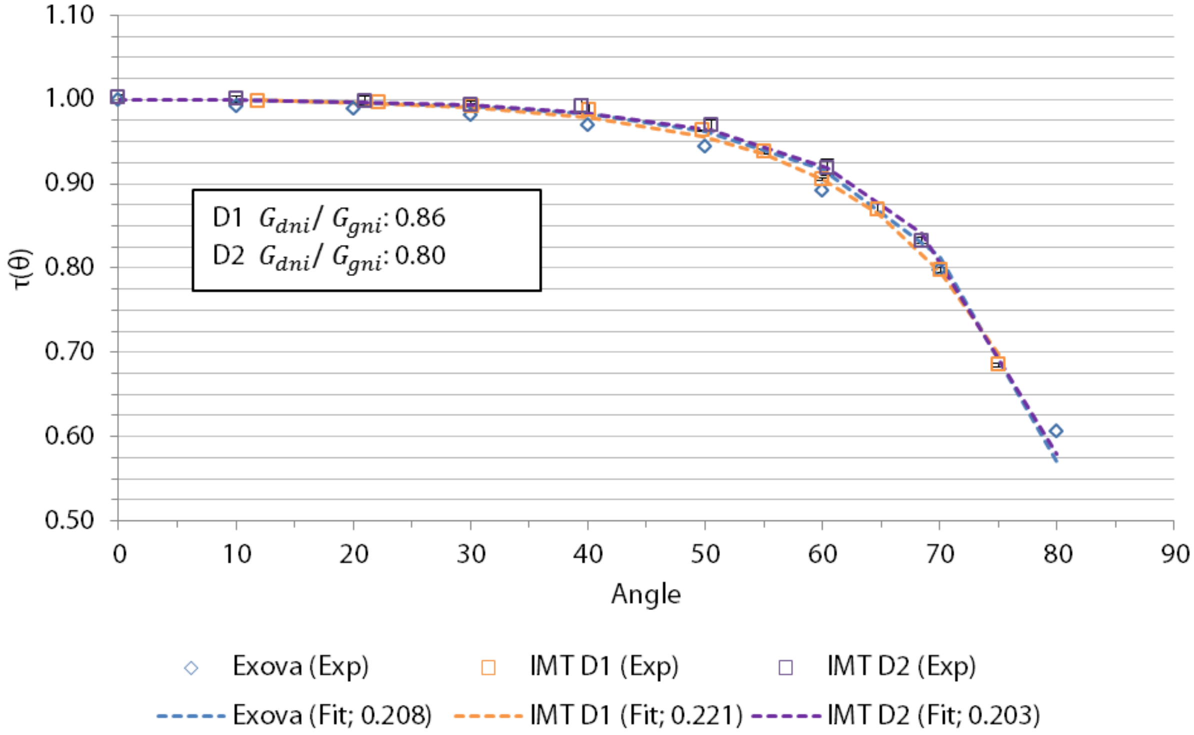


Figure 4-1. The indoor and outdoor procedures for IAM (τ(θ)) are in sufficient agreement.

3.2 Q4. Is any further guidance required in regards to the sensor type used in the IAM measurement?

The outdoor IAM testing described above also considered different irradiance sensor types. The irradiance sensors that were examined included a PV reference cell from IMT, a CMP 6 pyranometer from Kipp & Zonen and an Apogee photodiode pyranometer. The irradiance sensors were mounted co-planar to the device under test and also on the two-axis tracker oriented normally to the sun. The calculation procedure was adjusted to take into account the IAM of the IMT sensor itself but no adjustments were made for the Apogee or CMP 6 sensors. The IAM curve can be modelled using a single-parameter equation. The indoor and outdoor experimental testing was used to calculate that parameter (a_r). Note that, as above, outdoor testing took place across two days, denoted as D1and D2. The indoor and outdoor results across the different days of testing are shown in Table 4-2.

Table 4-1. IAM parameter determination from indoor and outdoor testing using different irradiance sensors

	a_r
Indoor	0.208
CMP 6 D1/D2	0.219/0.179

Apogee D1/D2	0.205/0.206
IMT D1/D2	0.221/0.203

It was anticipated that the CMP 6 pyranometer would have the best agreement with the indoor data since incidence angle effects are relatively weak due the domed geometry of the sensor. However, the pyranometer provided worse agreement with the indoor data than either the Apogee or the IMT sensors. A key deviation that may have contributed to this difference is that the IAM outdoor testing took place over the course of a whole day, rather than during only an hour that was in the vicinity of solar noon. The longer testing time was an experimental constraint related to the manual nature of the testing set-up. As there were spectral changes over the course of a day due to the air mass changes, the PV-based devices (the device under test, the Apogee and the IMT) would have been affected in a relatively similar ways whereas the CMP 6 is a thermal device that doesn't have a spectral response. The study was not able to determine if the deviation of the CMP 6 observed in the outdoor measurements could be rectified if the guidelines of the standard were more strictly followed and all testing took place under approximately the same air mass. Results for the CMP6 were therefore inconclusive while PV-based devices, whether a photo-diode or a reference cell, were shown to provide outdoor results that was in good agreement with indoor results.

3.3 Q5. Is the module thermal model achievable and is there sufficient guidance within the standard?

In the just-publicized IEC 61215-2 PV module performance standard, the decision was made to remove the Nominal Operating Cell Temperature (NOCT) measurement procedure. It was decided to replace NOCT with a Nominal Module Operating Temperature (NMOT), which measures back-of-module temperature instead of cell temperature. A key part of the NMOT procedure has been moved to IEC 61853-2. Therefore, there is pressure to release Part -2 imminently.

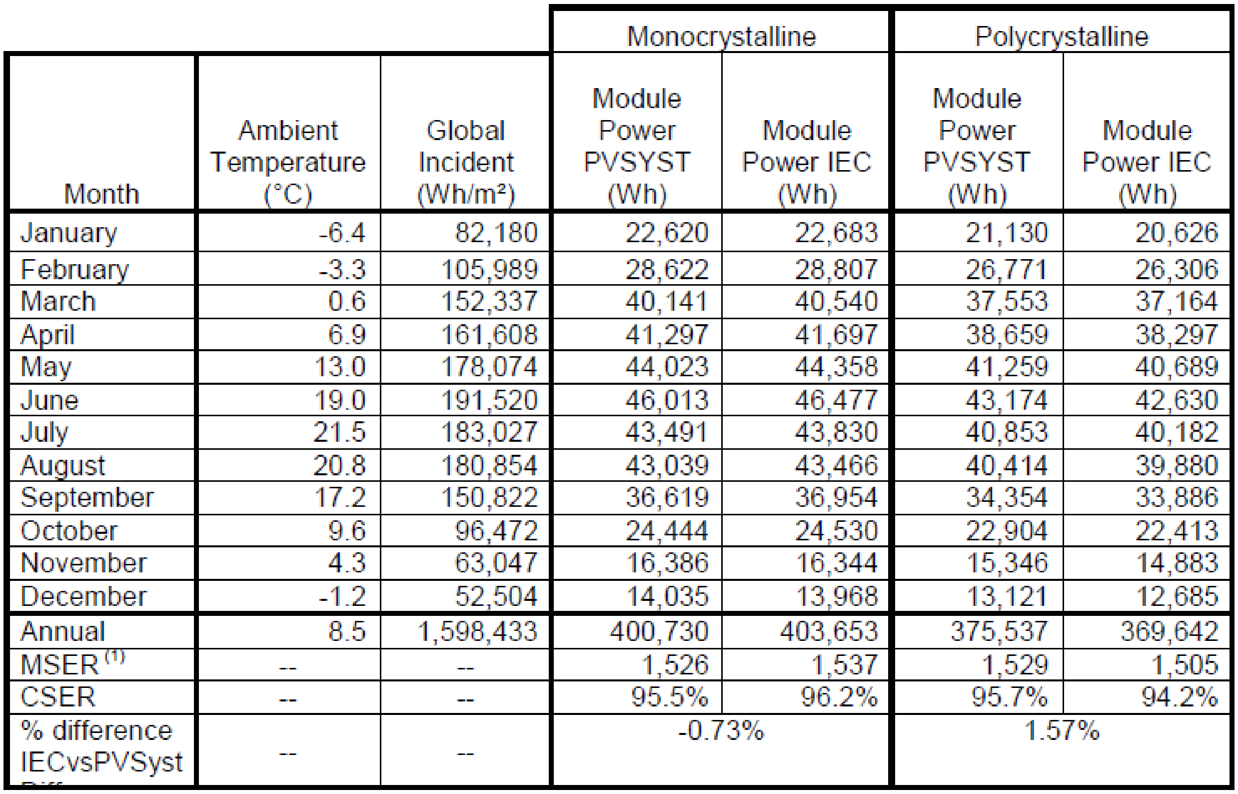
The procedure to determine the PV module thermal model was conducted at the LCC PV Test Field. Based on the experience of trying to implement the procedure a number of comments were provided to the IEC. Unfortunately, the proposed procedure does not appear to address critical issues in the test method which result in a high degree of measurement uncertainty and test result variation. These thermal coefficients are of high importance, since customers place a high amount of value on the result. A difference of 1°C could make or break a sale worth tens of millions of dollars, and yet 10°C variability in test results using the previous method was not uncommon. Due to the importance of the NMOT procedure beyond the IEC 61853-3 energy rating, it is the author's opinion that focusing available resources on this matter would be of great benefit to the PV industry, including in Canada.

4.0 IEC61853-3 & -4

4.1 Q6. Since the CSER is a performance ratio, does the IEC 61853-3 procedure agree with predictions from industry standard software like PVSyst? Does it agree with real-world data?

Mono- and poly-silicon PV modules were modelled using PVSyst for a Toronto location. The same environmental data used in the PVSyst modelling was then used in the IEC 61853-3 calculation procedure so as to compare the results from each. Results are shown in Table 4-3. For this location, IEC 61853-3 is comparable to PVSyst because the differences are small (-0.73% for mono- and 1.57% for poly-crystalline).

Table 4-1. Comparison of IEC 61853-3 against PVSyst



			Monocrystalline		Polycrystalline	
Month	Ambient Temperature (°C)	Global Incident (Wh/m²)	Module Power PVSYST (Wh)	Module Power IEC (Wh)	Module Power PVSYST (Wh)	Module Power IEC (Wh)
January	-6.4	82,180	22,620	22,683	21,130	20,626
February	-3.3	105,989	28,622	28,807	26,771	26,306
March	0.6	152,337	40,141	40,540	37,553	37,164
April	6.9	161,608	41,297	41,697	38,659	38,297
May	13.0	178,074	44,023	44,358	41,259	40,689
June	19.0	191,520	46,013	46,477	43,174	42,630
July	21.5	183,027	43,491	43,830	40,853	40,182
August	20.8	180,854	43,039	43,466	40,414	39,880
September	17.2	150,822	36,619	36,954	34,354	33,886
October	9.6	96,472	24,444	24,530	22,904	22,413
November	4.3	63,047	16,386	16,344	15,346	14,883
December	-1.2	52,504	14,035	13,968	13,121	12,685
Annual	8.5	1,598,433	400,730	403,653	375,537	369,642
MSER (1)	--	--	1,526	1,537	1,529	1,505
CSER	--	--	95.5%	96.2%	95.7%	94.2%
% difference IECvsPVSyst	--	--	-0.73%		1.57%	

IEC 61853-3 was also compared against real-world data collect on-site at the LCC PV Test Field. Actual power generation was found to be 2.9% lower than what would be predicted using IEC 61853-3 calculation for the monocrystalline PV modules, and 4.6% higher than IEC 61853-3 calculation for the polycrystalline PV modules. A detailed uncertainty analysis was not conducted but it likely is of the order of a few percent. It was concluded that the two methods in this study agree within the error or uncertainty of the experiment.

4.2 Q7. Does the standard provide sufficient guidance to complete the calculation procedure?

Based on review and implementation of Draft K of the standard a number of comments were provided to the IEC regarding how the standard could be further improved. In-depth explanations of comments are not warranted in this report. Comments on the following were provided:

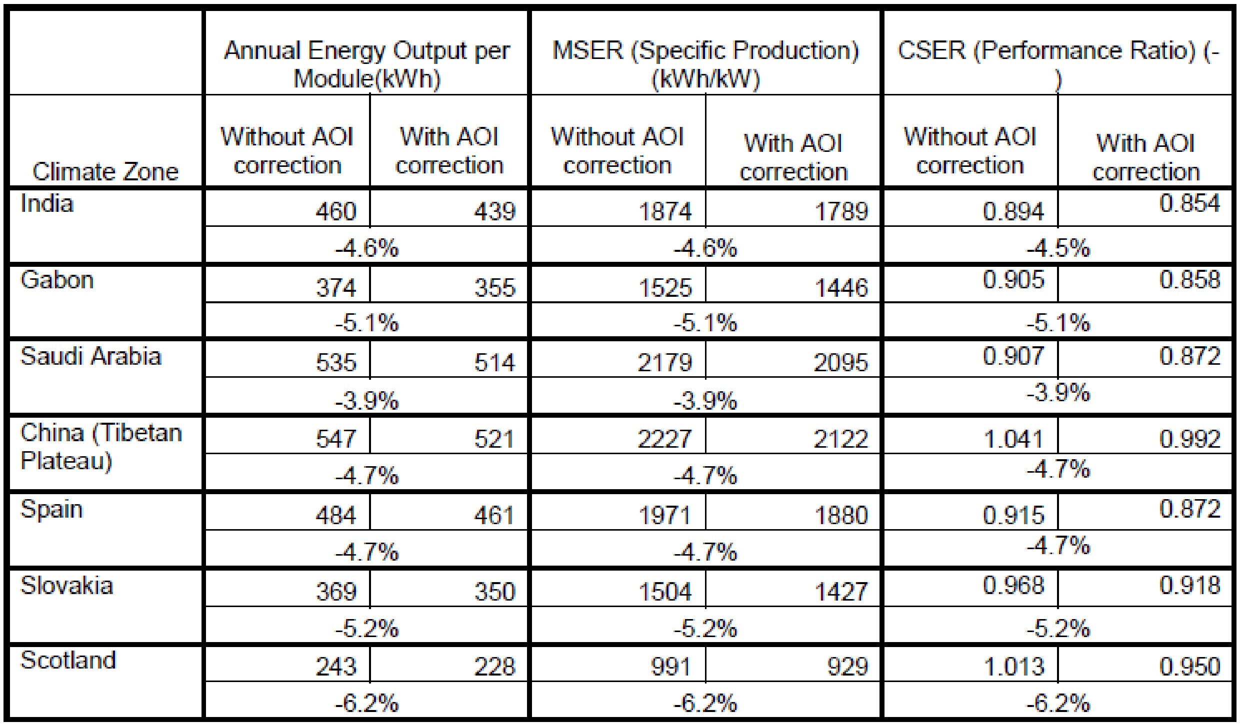
- editorial revisions;
- equation revisions;
- additional explanatory text;
- additional guidance on procedures (for example, procedure for interpolation and extrapolation of IEC 61853-1power matrix).

Most comments were accepted and incorporated into the next committee draft of the standard.

4.3 Q8. How much do IAM and spectral corrections matter?

Using the experimental IEC 61853-1 & -2 results from poly- and mono-c-Si PV modules and the climate data files in IEC 61853-4 (Draft B), the IEC 61853-3 calculation procedure was performed with and without angle-of-incidence (AOI) or spectral corrections. Table 4-4 shows the effect of incidence angle on the IEC 61853-3 calculation procedure. It affects the CSER metric by as much 6.2% and as little as 3.9%.

Table 4-2. Effect of incidence angle corrections on IEC 61853-3 calculation procedure



	Annual Energy Output per Module(kWh)		MSER (Specific Production) (kWh/kW)		CSER (Performance Ratio) (-)	
Climate Zone	Without AOI correction	With AOI correction	Without AOI correction	With AOI correction	Without AOI correction	With AOI correction
India	460	439	1874	1789	0.894	0.854
	-4.6%		-4.6%		-4.5%	
Gabon	374	355	1525	1446	0.905	0.858
	-5.1%		-5.1%		-5.1%	
Saudi Arabia	535	514	2179	2095	0.907	0.872
	-3.9%		-3.9%		-3.9%	
China (Tibetan Plateau)	547	521	2227	2122	1.041	0.992
	-4.7%		-4.7%		-4.7%	
Spain	484	461	1971	1880	0.915	0.872
	-4.7%		-4.7%		-4.7%	
Slovakia	369	350	1504	1427	0.968	0.918
	-5.2%		-5.2%		-5.2%	
Scotland	243	228	991	929	1.013	0.950
	-6.2%		-6.2%		-6.2%	

Table 4-5 shows the effect of spectral corrections on the IEC 61853-3 calculation procedure. The crystalline silicon spectral response curve was used in the calculation. Spectral corrections affect the CSER most notably for the Tibetan Pleateau (which is high altitude and has a lower air mass). For all locations but the Tibetan Plateau and Saudi Arabia, the spectral correction factor was less than +/-1%.

Table 4-3. Effect of spectral correction on IEC 61853-1 calculation procedure

	Annual Module Energy Output (kWh)		MSER (Specific Production) (kWh/kW)		CSER (Performance Ratio) (-)	
Climate Zone	Without Spectral Correction	With Spectral Correction	Without Spectral Correction	With Spectral Correction	Without Spectral Correction	With Spectral Correction
India	439	436	1789	1774	0.854	0.847
	-0.8%		-0.8%		-0.8%	
Gabon	355	356	1446	1448	0.858	0.860
	0.2%		0.2%		0.2%	
Saudi Arabia	514	503	2095	2048	0.872	0.852
	-2.2%		-2.2%		-2.2%	
China (Tibetan Plateau)	521	496	2122	2020	0.992	0.945
	-4.8%		-4.8%		-4.8%	
Spain	461	454	1880	1848	0.872	0.858
	-1.7%		-1.7%		-1.7%	
Slovakia	350	348	1427	1416	0.918	0.911
	-0.7%		-0.7%		-0.7%	
Scotland	228	230	929	935	0.950	0.956
	0.6%		0.6%		0.6%	

The spectral correction factor for different materials and for the different climate datasets are shown in Table 4-6. Amorphous silicon had the greatest spectral corrections, with a spectral correction factor that was as much as1.11.

Table 4-4. Spectral correction factors for different climate data files and PV materials

Annual Spectral Correction Factors ($C_{s,Annual}$)	India	Gabon	Saudi Arabia	China (Tibetan Plateau)	Spain	Slovakia	Scotland
Monocrystalline (Silfab)	1.00	1.01	0.99	0.96	0.99	1.00	1.02
Polycrystalline (LDK)	1.00	1.01	0.99	0.96	0.99	1.00	1.02
A. Polysilicon 1	1.01	1.02	0.99	0.97	1.00	1.01	1.02
B. Polysilicon 2	1.00	1.01	0.99	0.97	0.99	1.00	1.02
C. Monosilicon 1	1.00	1.01	0.99	0.96	0.99	1.00	1.02
D. CdTe 1	1.03	1.05	1.00	0.95	1.00	1.01	1.03
E. CdTe 2	1.04	1.07	1.01	0.96	1.01	1.02	1.04
F. CIGS 1	0.98	0.99	0.98	0.96	0.99	0.99	1.01
G. CIGS 2	1.00	1.01	0.99	0.96	0.99	1.00	1.02
H. CIGS 3	1.01	1.02	0.99	0.96	1.00	1.01	1.02
I. Single Junction aSi	1.07	1.11	1.03	0.98	1.02	1.03	1.05
J. Double Junction	1.05	1.08	1.01	0.96	1.01	1.02	1.04
K. Triple Junction	1.04	1.07	1.01	0.96	1.01	1.02	1.04

4.4 Q9. How different are the climate profiles that were selected?

Different climate profiles were selected as being representative of certain areas of the world. This project looked at the climate profiles considered in Draft K of the standard. In previous steps of the study, a mono- and poly-crystalline PV module were characterized according to IEC 61853-1 & -2. This was then used alongside the IEC 61853-4 climate datafiles to calculate CSER according to IEC 61853-3 for each climate.

Table 4-5. IEC 61853-3 calculation results for different climate considered in IEC 61853-4 Draft K

Climate Zone	Module	Average Module Temperature (°C)	Corrected Irradiance (kWh/ m²)	Annual Energy Production per Module (kWh)	MSER (Specific Yield) (kWh/kW)	CSER (Performance Ratio) (-)
India	Polycrystalline	42.3	1,982	436	1,774	0.847
	Monocrystalline	41.7	1,992	465	1,770	0.845
Gabon	Polycrystalline	39.9	1,601	356	1,448	0.860
	Monocrystalline	38.9	1,608	380	1,447	0.859
Saudi Arabia	Polycrystalline	40.8	2,257	503	2,048	0.852
	Monocrystalline	40.7	2,269	536	2,041	0.850
China (Tibetan Plateau)	Polycrystalline	9.4	1,941	496	2,020	0.945
	Monocrystalline	9.1	1,955	534	2,033	0.950
Spain	Polycrystalline	36.5	2,021	454	1,848	0.858
	Monocrystalline	35.6	2,034	486	1,853	0.860
Slovakia	Polycrystalline	23.4	1,464	348	1,416	0.911
	Monocrystalline	23.2	1,473	372	1,417	0.912
Scotland	Polycrystalline	15.6	924	230	935	0.956
	Monocrystalline	15.5	930	245	935	0.956

The results suggest that the different climates selected in Draft K may be too similar. For example, India, Gabon, Saudi Arabia and Spain have somewhat similar average module temperatures and the CSER values that are all near 0.85. Furthermore, there are no North American data points.

After the comments were received for Draft K of IEC 61853-3 and Draft B of IEC 61853-4, the climate datafiles were re-evaluated by the European Commission's Joint Research Center in Ispra, Italy, in a similar manner as in Table 4-7 (but also including different PV cell technologies). Additional climate datafiles in North America and Japan were considered. The aim was to produce climate data sets that were sufficiently different from each other and representative of the global climate zones. Based on this analysis, six new climates were selected:

- Japan, subtropical coastal
- Scotland, temperate coastal
- Gabon, tropical humid
- Phoenix, subtropical arid (desert)
- Canada, temperate continental
- Tibet, high elevation

4.5 Q10. Do the current climate data files sufficiently represent a Canadian climate? How might a Canadian climate data file be incorporated into the standard?

Climate data (irradiance, temperature and wind speed) from different locations across Canada were compared against the climate datafiles proposed in IE 61853-4 Draft B. In general, it was found that the Mediterranean (Spain), Temperate Continental (Slovakia), Temperate Coastal (Scotland) and High Elevation (Tibetan Plateau, China) did represent a Canadian climate, at least as much as could be reasonably achieved with a limited number of datasets to represent the global climate.

Since comments were received for IEC 61853-4 Draft B, the climate datafiles have been revised. Changes relevant to this discussion include:

- Canada has replaced Slovakia as the Temperate Continental data point.
- The High Elevation and Temperate Coastal data points remain unchanged.
- The Mediterranean datafile (Spain) was removed.

The new datasets were not re-evaluated against the Canadian climate but they are believed to be sufficient given that a Canadian data point has been added and two of the original four datafiles investigated have remained unchanged.

5.0 GRID INTERCONNECTION

5.1 Q11. Are there any notable issues related to current harmonic emissions that may occur outside of the operating points considered in these standards (possibly due to transient or low-irradiance conditions)?

Four power quality meters in total were deployed at partner PV installations sites and the power quality was monitored for up to a year. The only issue observed during the monitoring period that was related to current harmonic emissions was associated with the presence of a specific brand of microinverters operating at low power.

As part of the study, for a short duration, a single microinverter of this brand was left to operate with its output terminals connected to the direct input of a Yokogawa WT 1800 power quality analyzer. The 2nd order current harmonic emissions measured from the inverter are shown in Figure 4-3. The green line shows the 2nd order current harmonic emission limit recommended in the various grid interconnection standards. It is clear that above 33% of the rated load the 2nd order current harmonic emissions are compliant with the limits, and indeed the inverter is listed as compliant with CAN/CSA-C22.2 NO. 107.1-01 and IEEE 1547. However, at low power (below 33%), the current harmonic emissions greatly exceed the recommended limit but these operating points are not considered in the standard.

Note that the vertical axis is listed in units of amps. It is the opinion of the authors if the standards consider a certain magnitude of harmonic current (in units amps) to be harmful then it ultimately does not matter whether it occurs at 33% or 20% of the rated load. It is recommended that an additional low power operating point be added to the standards to ensure that current harmonic emissions are within reasonable limits across the whole real-world operating range of the PV inverters.

It should be stated explicitly that this report did not conclude that harmonic emissions should be considered as a notable barrier towards future deployment of PV. Furthermore, no negative implications of the current harmonic emissions illustrated in Figure 4-3 were actually observed within the study. Power quality is a larger topic that extends far beyond PV power generation. For example, this study also documented the high harmonic currents produced by other non-linear loads. Whether the emissions come from loads or from generation, solutions to harmonic emission issues are available and typically involve some level of harmonic filtering.

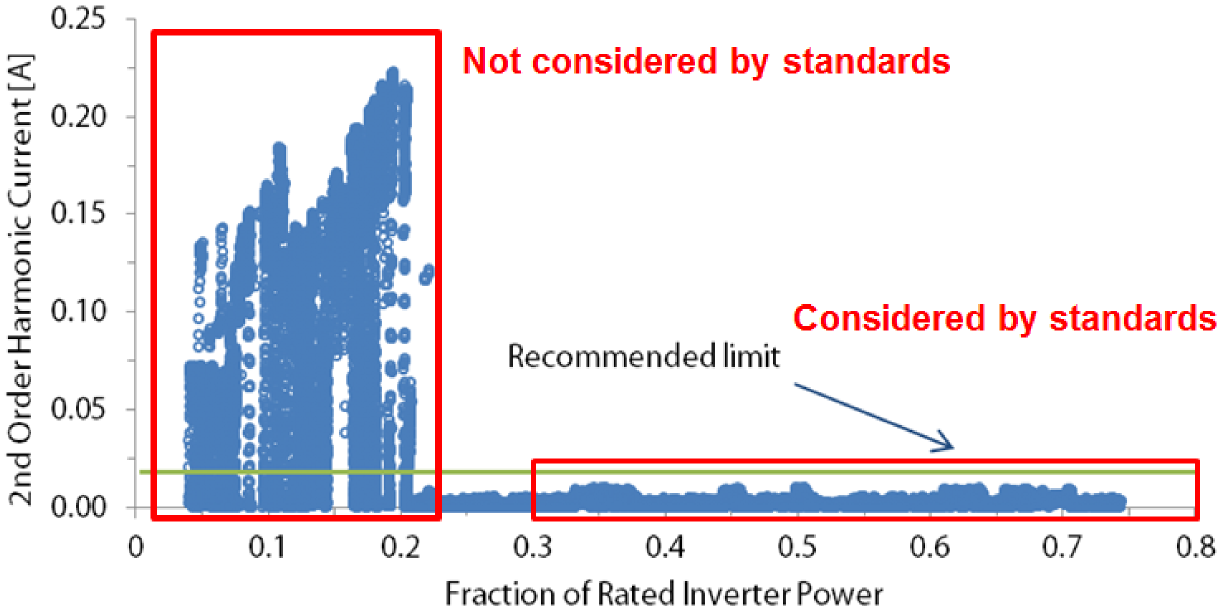


Figure 4-1. It is recommended that standards consider low-power operating points when setting inverter current harmonic emission requirements.