Assessment of IEC 61853-1 for Application in Canada

TECHNICAL BRIEF

Renewable Energy Series

The performance of photovoltaic (PV) modules changes with the module temperature and with irradiance level. The extent of the change will be related to the properties of the materials used in the PV cells and the module design. For crystalline silicon PV cells, higher temperatures will decrease performance. However, as irradiance increases, performance gains from the open circuit voltage will be accompanied by losses from parasitic resistances, making the irradiance-dependence of performance more challenging to characterize.

This study evaluates the applicability of *IEC 61853-1 Photovoltaic (PV) Module Performance Testing and Energy Rating* for PV module performance assessment in a Canadian climate. In contrast to the current rating procedure which determines performance at a single point using standard test conditions (STC), IEC 61853-1 proposes a matrix of performance rating points across a range of temperature and irradiance values intended to represent real-world conditions. This study seeks to evaluate that matrix for a Canadian climate over five different installation configurations.

Typically, the performance of PV modules is rated at standard test conditions (STC), defined by a module temperature of 25°C, an irradiance of 1000 W/m^2 and an AM1.5 irradiance spectrum, as per *IEC 61215 Crystalline Silicon Terrestrial Photovoltaic (PV) Modules: Design Qualification and Type Approval.*

The evaluation was conducted using PVsyst modelling software with input data from 43 locations across Canada. The simulated module temperature and irradiance levels were compared against the suggested matrix outlined in IEC 61853-1. Real-world experimental data provided ground-truthing to the modelled data. Results showed that six additional test points below 15 °C may be necessary to adequately capture weather conditions typical for cities across Canada. However, more work is needed to determine whether or not these points should be added to the current matrix because extrapolation from existing points may represent a better balance between accuracy and the breadth of experimental testing . Test points representing high temperatures and high irradiance levels were not commonly observed for most configurations and were classified as optional for Canadian cities.

STUDY SITE AND APPROACH

IEC 61853-1 Photovoltaic (PV) Module Performance Testing and Energy Rating addresses the issues arising from STC performance testing, in part, by rating the performance at 23 operating points (Table 1) across a temperature and irradiance spectrum, starting at 15 °C and 100 W/m^2. Although, this may offer an improvement towards the usefulness of the results, IEC 61853-1 may still not provide enough information for system designers to thoroughly assess the performance of PV installations in cold climates.

Table 1. IEC 61853-1 test conditions matrix.

Module Temperature (°C)	Irradiance (W/m^2)						
	100	200	400	600	800	1,000	1,100
75				•	•	•	•
50		•	•	•	•	•	•
25	•	•	•	•	•	•	•
15	•	•	•	•	•	•	
0							

The evaluation was conducted primarily through PV installation performance modelling, with a more limited experimental dataset providing verification of the results. The 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 (Table 2). 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. These values are: 29 W/m^2 for "free" mounted modules, 20 W/m^2 for a semi-integrated roof mount and 15 W/m^2 for an integrated mount.

Table 2. Configurations of modelled PV systems.

PV System Configuration	Modelled Geographic Areas within Canada
Roof-mount systems on flat-roofed buildings with modules installed close to the roof on semi-enclosed racking structures, facing south at a tilt of 10° above the horizontal plane	Sites below 50° N
Ground-mount systems installed in fields on open, fixed racks facing south at a tilt of 30° above the horizontal plane	Sites below 50° N
Tilt angle matches the latitude	Sites above 50° N
Dual-axis ground tracking systems	Sites above and below 50° N
BIPV modules installed at 40° tilt and integrated into the building with a fully insulated back	Selected sites across Canada

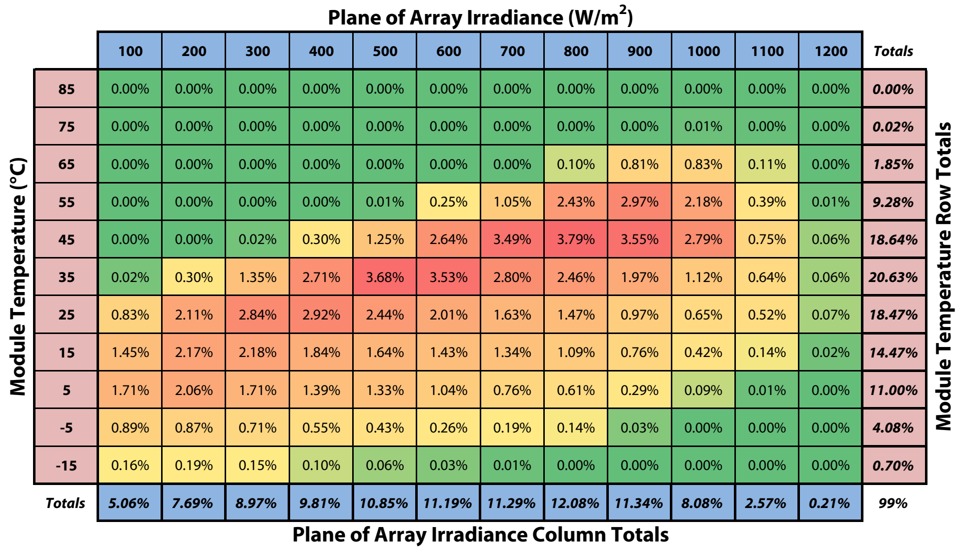
Two Southern Ontario locations were chosen as the experimental sites, located in St. Catharines, ON and Toronto, ON. Data collection occurred between August, 2014 and August, 2015. The two sites were chosen for their similarity in system configuration to the modelled scenarios, as well as the availability 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 an analysis.

FINDINGS

A significant fraction of the typical operating conditions in Ontario occur with module temperatures below the lowest IEC 61853-1 test temperature of 15°C. Figure 1 shows modelled ground- and roof-mounted configurations for cities across Ontario. On average, 40% of the operating time for both roof- and ground-mount systems occurs at module temperatures below 15 °C. This accounts for nearly 23% of annual energy production as an average across all 13 Ontario locations. Furthermore, approximately 20% of the operating time occurs at module temperatures below 5 °C, accounting for approximately 10% of the annual PV energy yield. For systems in locations with more extreme weather, such as the Timmins ground-mount scenario, these values can increase to 51% and 33%, respectively.

More than half of operating hours in Northern Canada occur at module temperatures below 15 °C. On average 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.

PV installations in Canada seldom experience both high module temperatures and low irradiance levels. Despite the presence of IEC 61853-1 testing points at high module temperatures and low irradiance levels, none of the modeled configurations experience these conditions. Additionally the configurations only



	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals*
85	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	***0.00%***
75	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	***0.02%***
65	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	0.81%	0.83%	0.11%	0.00%	***1.85%***
55	0.00%	0.00%	0.00%	0.00%	0.01%	0.25%	1.05%	2.43%	2.97%	2.18%	0.39%	0.01%	***9.28%***
45	0.00%	0.00%	0.02%	0.30%	1.25%	2.64%	3.49%	3.79%	3.55%	2.79%	0.75%	0.06%	***18.64%***
35	0.02%	0.30%	1.35%	2.71%	3.68%	3.53%	2.80%	2.46%	1.97%	1.12%	0.64%	0.06%	***20.63%***
25	0.83%	2.11%	2.84%	2.92%	2.44%	2.01%	1.63%	1.47%	0.97%	0.65%	0.52%	0.07%	***18.47%***
15	1.45%	2.17%	2.18%	1.84%	1.64%	1.43%	1.34%	1.09%	0.76%	0.42%	0.14%	0.02%	***14.47%***
5	1.71%	2.06%	1.71%	1.39%	1.33%	1.04%	0.76%	0.61%	0.29%	0.09%	0.01%	0.00%	***11.00%***
-5	0.89%	0.87%	0.71%	0.55%	0.43%	0.26%	0.19%	0.14%	0.03%	0.00%	0.00%	0.00%	***4.08%***
-15	0.16%	0.19%	0.15%	0.10%	0.06%	0.03%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	***0.70%***
Totals	***5.06%***	***7.69%***	***8.97%***	***9.81%***	***10.85%***	***11.19%***	***11.29%***	***12.08%***	***11.34%***	***8.08%***	***2.57%***	***0.21%***	***99%***

Figure 1. Percent annual energy production at different temperatures and irradiance levels for the roof- and ground-mount configurations in Ontario. Note that a given bin is comprised of all points within a 5°C range of the midpoint for temperature and 50 W/m2 for irradiance. For example, a 15°C module temperature bin holds all the data with a module temperature between 10 °C and 20 °C.

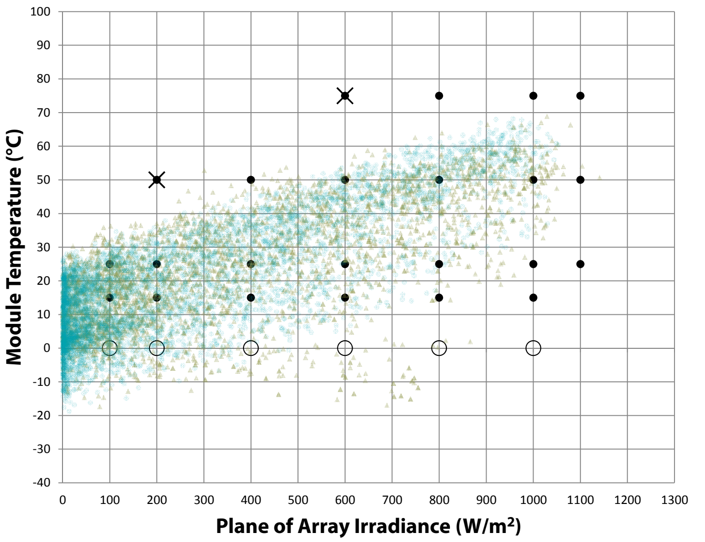


Figure 2. Hourly operating points of module temperature and irradiance for the Toronto, ON experimental location and the Toronto, ON PVsyst modelled location. Each circle/triangle represents one hour of operation, where blue circles show modelled data and beige triangles show experimental data. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.

infrequently experience high module temperatures at high irradiance levels, suggesting that in general, high module temperatures across all irradiance levels are not often encountered. The frequency at which high temperatures are encountered depends on the system configuration. Systems that are mounted with both sides exposed freely to the air are able to maintain lower operating temperatures.

When compared to ground-mount systems, roof-mount systems experience a higher frequency of operating conditions with high module temperatures. In general, roof-mount and BIPV systems have higher operating temperatures across all irradiance levels, when compared to non-roof mount systems. Generally, the rate of increase of module temperature with increasing irradiance levels is greater for roof-mount and BIPV configurations than it is for ground-mount or open-tracking systems, likely a consequence of the lower heat loss of the BIPV and roof-mount systems. Roof-mount and BIPV systems reach maximum temperatures of 75 °C and 90 °C, respectively, while ground-mount and tracking systems generally experience maximum module temperatures of 60-65 °C.

Dual-tracking systems produce higher energy at high irradiance and low operating temperatures than other configurations. Low temperatures and high irradiance operating points are much more common in dual-tracking systems than other configurations. While tracking systems have the highest frequency of operating time at high irradiance levels very little energy is actually produced at light levels beyond 1,100 W/m^2. This indicates that testing points at 1,100 W/m^2 are sufficient to effectively characterize high-irradiance module performance.

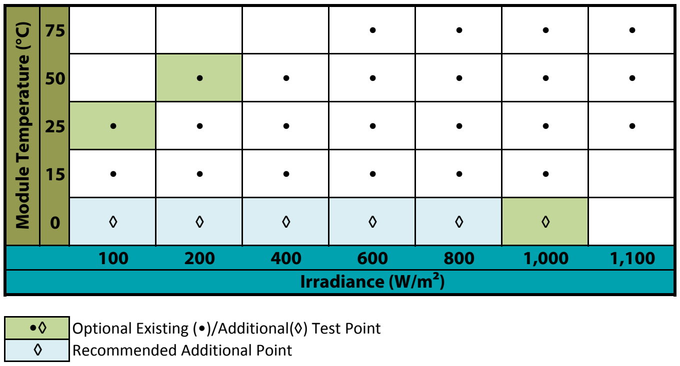
Experimental and modelled datasets follow comparable trends, providing a level of verification for the modelled data. Experimental results were compared to the modelling results for the Toronto, ON location. It was noted that environmental conditions were not entirely the same of the two datasets. This is owing to the fact that the climate conditions for any given year will fluctuate with respect to a TMY. However, the differences are not believed to be notable for this comparison exercise. Figure 2 shows the frequency of operation at different module temperature and irradiance operating points for the experimental and modelled datasets. The most notable difference is that the experimental dataset appears to show evidence of snow coverage (the data points at medium irradiance and cold temperature) and, aside from that, the datasets are in good agreement. Experimental datasets such as this are rare and as such, this comparison could only be done for a single location.

CONCLUSIONS AND RECOMMENDATIONS

The IEC 61853-1 module rating standard proposes significantly expanded performance rating testing over the IEC 61215. However, the testing matrix used within IEC 61853-1 does not consider module temperatures below 15 °C which, as this study has shown, are relevant for a cold Canadian climate. This study used PVsyst modelling, with some level of ground-truthing from ground-based experimental data, to analyze PV module temperature and irradiance operating conditions for PV installations of different configurations across Canada. 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 (Figure 3):

1. Six new test points are at 0 °C for all existing irradiance bins up to 1,000 W/m^2, while the 1,100 W/m^2 point is to be designated as optional only;

2. 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.



Module Temperature (°C)							
75				•	•	•	•
50		•	•	•	•	•	•
25	•	•	•	•	•	•	•
15	•	•	•	•	•	•	
0	◊	◊	◊	◊	◊	◊	
	100	200	400	600	800	1,000	1,100

Irradiance (W/m²)

•◊ Optional Existing (•)/Additional(◊) Test Point
◊ Recommended Additional Point

Figure 3. Changes to the IEC 61853-1 testing matrix that would increase the applicability to a Canadian climate.

Lastly, it should be noted explicitly that, while changes proposed in Figure 3 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. Future work should explore this issue further and also consider whether or not it is sufficient to simply extrapolate cold weather performance from the existing points in the matrix.

REFERENCES

Leidos Canada Inc. (2014) Implementing IEC 61853 in Canada: A Study of PV Operating Conditions in Canada. Report prepared for the Toronto and Region Conservation Authority.
Science Applications International Corporation (SAIC) (2013) Implementing IEC 61853 in Canada: A Study of Common PV Operating Conditions in Ontario. Report prepared for the Toronto and Region Conservation Authority.

For more information on STEP's other Renewable Energy initiatives, or to access the full report for this study, entitled IEC 61853-1: Photovoltaic Module Performance Testing and Energy Rating Assessment for Canada, visit us online at www.sustainabletechnologies.ca

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