IEC 61853-1: PHOTOVOLTAIC MODULE PERFORMANCE TESTING AND ENERGY RATING ASSESSMENT FOR CANADA

FINAL REPORT

Plane of Array Irradiance (W/m²)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	Totals (Module Temperature Row Totals)
85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.7%	0.6%	0.0%	*1.34%*
75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	2.7%	3.9%	1.1%	0.0%	*8.16%*
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	1.5%	3.8%	4.6%	2.8%	0.8%	0.1%	*13.87%*
55	0.0%	0.0%	0.0%	0.0%	0.8%	2.6%	3.7%	3.5%	2.3%	1.6%	0.9%	0.1%	*15.51%*
45	0.0%	0.0%	0.3%	1.8%	3.2%	3.2%	2.3%	2.1%	1.8%	1.0%	0.4%	0.0%	*15.89%*
35	0.1%	0.9%	2.2%	2.7%	2.4%	2.0%	1.8%	1.6%	1.3%	0.5%	0.1%	0.0%	*15.62%*
25	0.9%	2.0%	2.2%	2.0%	1.5%	1.3%	1.1%	1.0%	0.8%	0.2%	0.0%	0.0%	*13.02%*
15	1.2%	1.9%	1.7%	1.3%	1.1%	0.8%	0.5%	0.5%	0.1%	0.0%	0.0%	0.0%	*9.04%*
5	1.3%	1.3%	0.9%	0.6%	0.5%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	*5.02%*
-5	0.5%	0.4%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*1.62%*
-15	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.31%*
Totals	*3.98%*	*6.64%*	*7.72%*	*8.63%*	*9.67%*	*10.38%*	*11.12%*	*12.85%*	*13.66%*	*10.62%*	*3.84%*	*0.28%*	99%

Plane of Array Irradiance Column Totals

Plane of Array Irradiance (W/m²)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	Totals (Module Temperature Row Totals)
85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.00%*
75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.00%*
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	*0.09%*
55	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.5%	1.9%	1.1%	0.0%	*3.71%*
45	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.8%	2.0%	3.8%	5.5%	2.0%	0.1%	*14.63%*
35	0.0%	0.0%	0.1%	0.4%	1.1%	2.1%	2.9%	3.3%	4.2%	4.0%	2.0%	0.4%	*20.47%*
25	0.1%	0.5%	1.2%	2.0%	2.3%	2.4%	2.7%	2.8%	2.7%	2.4%	1.4%	0.3%	*20.87%*
15	0.7%	1.5%	1.8%	1.8%	1.9%	1.7%	1.6%	1.5%	1.6%	1.3%	1.0%	0.2%	*16.67%*
5	1.0%	1.4%	1.3%	1.1%	1.0%	0.9%	1.2%	1.1%	1.2%	1.1%	0.6%	0.0%	*11.90%*
-5	0.5%	0.6%	0.6%	0.6%	0.7%	0.8%	0.9%	1.2%	0.8%	0.5%	0.1%	0.0%	*7.21%*
-15	0.2%	0.3%	0.4%	0.4%	0.5%	0.5%	0.4%	0.3%	0.1%	0.0%	0.0%	0.0%	*3.18%*
Totals	*2.49%*	*4.20%*	*5.40%*	*6.36%*	*7.66%*	*8.68%*	*10.51%*	*12.32%*	*14.94%*	*16.79%*	*8.21%*	*1.17%*	99%

Plane of Array Irradiance Column Totals

Sustainable Technologies Evaluation Program
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Toronto and Region Conservation for The Living City®

IEC 61853-1: PHOTOVOLTAIC MODULE PERFORMANCE TESTING AND ENERGY RATING ASSESSMENT FOR CANADA

Final Report

Prepared by:

Toronto and Region Conservation
Under the
Sustainable Technologies Evaluation Program
And
Leidos Canada Inc.

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Reports conducted under the Sustainable Technologies Evaluation Program (STEP) are available at www.sustainabletechnologies.ca. For more information about this project or the STEP program, please contact:

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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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EXECUTIVE SUMMARY

INTRODUCTION

Solar power generation is becoming an increasingly relevant alternative to conventional fossil fuel power production and offers clean, efficient and renewable means of generating electricity across the globe. Although the sun's energy can be harnessed from all corners of the world over a given year, local climates introduce obstacles that affect the efficiency at which photovoltaic (PV) modules perform. For example, it is widely known that efficiency decreases with increasing PV module operating temperatures. Currently, the performance of PV modules are typically rated by using a single testing point, 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*. However, this is an arbitrary operating point that is not representative of actual installed conditions. A new standard, the IEC 61853 *Photovoltaic (PV) Module Performance Testing and Energy Rating,* addresses this issue, in part, by rating the performance for 23 operating points (Table 1) across a temperature and irradiance spectrum, starting at 15 °C and 100 W/m^2, respectively (IEC 61853-1). Although, this may offer a significant improvement towards the usefulness of the resultant performance rating metrics, IEC 61853-1 may 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.*

Irradiance	**Module Temperature**			
(W/m^2)	**15 °C**	**25 °C**	**50 °C**	**75 °C**
1100		1	2	3
1000	4	5	6	7
800	8	9	10	11
600	12	13	14	15
400	16	17	18	
200	19	20	21	
100	22	23		

Ambient air temperatures in Canada vary widely both geographically and seasonally, but frequently fall below 0 °C, even in the country's southernmost cities. Since IEC 61853-1 does not consider module temperatures below 15 °C, it does not capture all of the relevant operating points for a Canadian climate. The lack of information on module performance at low temperatures reduces simulation accuracy and may also reduce investor confidence in energy yield predictions. This study was initiated to assess the applicability of the performance rating operating points, proposed IEC 61853-1, in

Canada. Towards this end, the performance of PV installations across Canada was modelled to determine the most relevant module temperatures and irradiance levels contributing to annual energy yield. Real-world experimental data were also obtained to provide some level of ground-truthing to the modelling results. This study concludes with recommendations on deletions and additions to the current IEC 61853-1 module temperature and irradiance matrix so as to better accommodate a Canadian climate.

STUDY SITE AND APPROACH

The evaluation was conducted primarily through PV installation performance modelling, with a more limited experimental dataset providing verification of the modelling results. 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 (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/m² for "free" mounted modules, 20 W/m² for a semi-integrated roof mount and 15 W/m² for an integrated mount.

Table 2. *Configurations of modelled PV systems.*

	PV System Configuration	Modelled Geographic Areas within Canada
1	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
2	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
3	Tilt angle matches the latitude	Sites above 50° N
4	Dual-axis ground tracking systems	Sites above and below 50° N
5	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 (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 an analysis.

Table 3. *Configurations of experimental PV systems.*

Site No.	AC/DC System Size (kW)/(kWp)	Location	Roof- or ground-mount	Tilt Angle	Inverter	Modules
1	100/140	St. Catharines, ON	Roof	Modules mounted at approx. tilt angle of 10° above a flat roof	Advanced Energy AE PVP 100	Canadian Solar, 245 W
2	100/133	Toronto, ON	Roof	Modules mounted at approx. tilt angle of 10° above a flat roof	Advanced Energy AE 100TX	Panasonic SCI Series, 255 W

STUDY RESULTS

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 example result from 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.

Plane of Array Irradiance (W/m²)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals* (Module Temperature Row 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 (Plane of Array Irradiance Column 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 and 20 °C.*

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

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 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 temperature with increasing irradiance levels is greater for roof-mount and BIPV configurations than it is in 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 1 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.

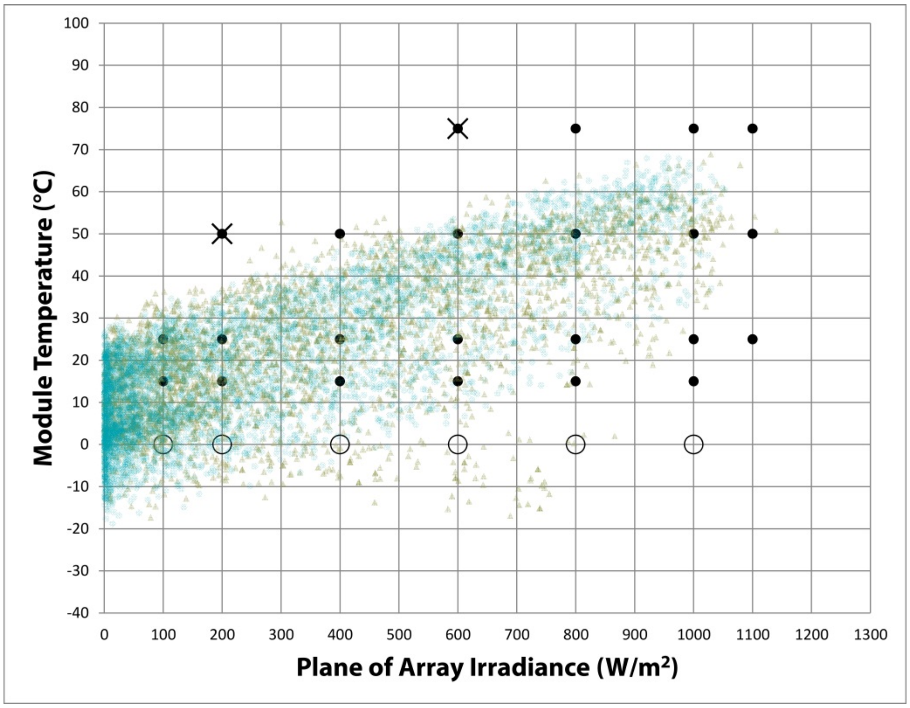

Figure 2. *Hourly operating points of module temperature and irradiance for the Toronto, ON experimental location (beige triangles) and the Toronto, ON PVsyst modelled location (blue circles). Each circle/triangle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open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

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 very 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.

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1.0 BACKGROUND AND OBJECTIVES

Photovoltaic (PV) installations are increasing in number across Ontario. This is a direct result of the province's feed-in tariff (FIT) and micro-FIT programs which offer a financial incentive for grid-tie PV electricity produced from both large- and small-scale installations. With incentives now being scaled back, an important factor towards the continued investment in PV is the level of investor confidence in the energy yield estimates that determine an installation's annual cash inflow. These estimates are typically obtained using software packages that require input data on the local climate conditions, system orientation and system component specifications. Chiefly important in the estimates is the performance specifications of the PV modules that make up the installation.

PV module performance ratings are typically obtained under standard test conditions (STC), comprising a module temperature of 25°C, an irradiance of 1000 W/m^2 and an AM1.5 irradiance spectrum, as per International Electrotechnical Commission (IEC) 61215 *Crystalline Silicon Terrestrial Photovoltaic (PV) Modules: Design Qualification and Type Approval*. However, STC is not representative of actual operating conditions. Energy yield simulations account for this to some extent by extrapolating the performance of PV modules from the STC testing point. The accuracy of this approach may vary for different module technologies and could certainly be improved upon if the performance rating of PV modules was expanded to include a wider range of physical testing conditions. The IEC 61853: *Photovoltaic (PV) Module Performance Testing and Energy Rating* is a relatively new testing standard, not currently mandatory in North America, which addresses this issue.

The approach within the IEC 61853 is to experimentally determine how a PV module will perform as the module temperature, irradiance, incidence angle and irradiance spectrum vary, such that this information could be used within simpler and more accurate energy yield calculations that are absent of bias towards any specific PV module technology. As part of the IEC 61853-1 testing methodology, it is required that PV modules be tested across a two-dimensional matrix of 23 operating points, with module temperatures ranging from 15 to 75 °C and irradiances from 100 to 1100 W/m^2 (Table 1.1). Of note is the fact that the IEC 61853-1 does not currently recommend testing at module temperatures below 15 °C. This may be problematic for cold climate regions given that Canada, among other northern countries, frequently experiences ambient temperature well below 15 °C while still receiving sunshine hours.

Table 1.1. *IEC 61853-1 test conditions matrix.*

Irradiance	Module Temperature			
(W/m^2)	**15 °C**	**25 °C**	**50 °C**	**75 °C**
1100		1	2	3
1000	4	5	6	7
800	8	9	10	11
600	12	13	14	15
400	16	17	18	
200	19	20	21	
100	22	23		

This study used PVsyst simulations to determine the most relevant module temperature and irradiance operating points in Ontario, and Canada, and evaluated the current IEC 61853-1 temperature-irradiance matrix against these conditions. It concludes with a series of recommendations on how to improve the current matrix for use within Canada. The specific objectives were to:

1. Model PV installations from cities across Canada using typical meteorological conditions and determine the expected cumulative annual energy yield at different module temperature and irradiance operating points;
2. Use experimental monitoring data to examine the temperature and irradiance operating points for two Southern Ontario PV installations so as to ground-truth the modelling results;
3. Evaluate how well the current IEC 61853-1 matrix captures energy producing conditions in Ontario and Canada;
4. Provide recommended changes to the current IEC 61853-1 matrix to better reflect conditions experienced in Ontario and Canada.

2.0 APPROACH

2.1 Modelling Approach

The modelling aspect of this study sought to identify the most commonly experienced PV module temperatures and irradiances for a Canadian climate for the sake of comparison against those operating points within the IEC 61853-1 performance rating matrix. Towards this end, PVsyst V 5.56 modeling software was used to simulate different types of PV installations at 43 locations across Canada. A separate portion of the study focused strictly on Ontario installations, considering 13 different locations and only ground- and roof-mount system configurations.

2.1.1 PV System Configuration

This study simulated PV system configurations that represent typically installed systems across Canada (Table 1.2). Note that not all system configurations were simulated at all sites. Only those configurations that were relevant for a given location were simulated; at some locations, multiple simulations were performed.

Table 1.2. *PV system configurations used in PVsyst simulations.*

	PV System Configuration	Modelled Geographic Areas within Canada
1	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
2	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
3	Tilt angle matches the latitude	Sites above 50° N
4	Dual-axis ground tracking systems	Sites above and below 50° N
5	BIPV modules installed at 40° tilt and integrated into the building with a fully insulated back	Selected sites across Canada

2.1.2 PVsyst Modelling

The various scenarios were modelled using PVsyst V 5.56, a PV system modelling package which is an industry standard for simulation and design of PV systems. For the modelling, PVsyst required inputs such as meteorological data, component specifications, system configuration information and the system orientation.

The input meteorological data were hourly, site-specific values of irradiance, temperature and wind speed. Weather information was obtained from the Environment Canada Canadian Weather for Energy Calculation (CWEC) typical meteorological year (TMY) files. TMY files contain hourly data for a single, composite year that is representative of typical weather patterns for a particular location. The TMY files are derived from a 30-year database from 1961 to 1990, and exclude extreme events. Variables included in the TMY files are global horizontal radiation, mean, maximum and minimum dry bulb temperature, dew point temperatures, and wind speed. These files are commonly used in solar system design and analysis through computer simulations.

Ground-based solar radiation data is not a readily available parameter for many locations. For this study, it was obtained using long term average datasets based on ground measurements for the Toronto and Ottawa locations. For the remaining locations, sky modelling techniques, alongside ground and/or satellite measurements, were employed to transform the global horizontal radiation in the TMY files to the plane-of-array (POA) irradiation necessary for the simulation.

The input PV module data 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 PV system design used in the model is a typical 100 kW system with Canadian Solar CSW6-285 modules and a Satcon Power Gate Plus PVS 100 kW inverter. A DC:AC ratio of 1.23 was chosen as it is representative of typical PV array designs in Ontario. The system model consists of 36 strings of 12 modules, totaling 123 kWdc of nameplate capacity.

PVsyst has the ability to account for various power losses including soiling loss, incident angle reflective loss, wiring/resistive loss, module mismatch loss, module quality loss and inverter and AC conversion losses. Any losses 'downstream' of the PV array, such as resistive losses in the DC wiring, inverter losses due to inefficiencies or clippings and AC wiring losses, were not included as part of this study. However, PVsyst does not account for winter snow coverage. Similarly, IEC 61853-1 does not account for snow coverage with respect to module performance testing.

Importantly, PVsyst differentiates between various mounting designs when calculating cell temperature (i.e. flush to roof or freely mounted). The temperature of the module depends on ambient conditions and how well heat is dissipated from the module to the surroundings. For example, a "free" mounted module that is exposed to the air at the front and back will dissipate heat better than a module mounted flush to a roof or even fully integrated into the roof where it is only exposed to the air at the front of the module. The "free" mounted module (such as in a ground-mount or tracking system) will therefore have a lower cell temperature since it is cooled more readily.

PVsyst accounts for this by assigning a thermal heat loss coefficient to each mounting design. The thermal loss coefficient is an input used in the thermal model which calculates the module temperature by taking into account ambient temperature, wind speed, solar irradiance and module efficiency. 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. These thermal loss coefficients assume an average wind speed of 1.5 m/s at the level of the installation.

2.1.3 PVsyst Locations

43 CWEC locations across Canada were selected to model performance of PV power systems for the five configurations presented in Table 1.3. The locations are summarized in Table 3 and represent a wide range of temperature and precipitation regimes experienced across Canada, and would therefore provide a realistic representation of expected energy output to assess the current IEC 61853-1 test matrix. The analysis is conducted at two geographical scales – Ontario-only as well as Canada-wide. As part of the Ontario only analysis, 13 locations were selected and only two configurations were modeled – ground-mount at 30° inclination and roof-mount at 10° inclination. As part of the Canada-wide analysis, the locations were mainly separated as those North (dark shaded rows) and South of latitude 50 °N. The locations used for each configuration are indicated with 'x.'

Table 1.3. *PV system geographical locations and long-term climate averages (1981-2010) analyzed in this study. * Maximum and minimum values are bolded.*

CWEC location		Latitude	Longitude	Annual Precipitation		Temperatures (°C)				Period of Record other than 1981-2010	Ground-mount at 30°	Tilt-angle matches latitude	Roof-mount at 10°	Tracking	Building-Integrated
Name	Prov			Rainfall (mm)	Snowfall (cm)	Daily Average		Record							
						July	Jan	High	Low						
Resolute	NU	74.72	-94.97	**59.5***	111.2	**4.5***	**-32.0***	**18.5***	-52.2			x		x	
Inuvik	NT	68.3	-133.48	114.5	158.6	14.1	-26.9	32.8	**-56.7***			x		x	
Yellowknife	NT	62.46	-114.44	170.7	157.6	17	-25.6	32.5	-51.2			x		x	
Whitehorse	YT	60.71	-135.07	160.9	141.8	14.3	-15.2	34.4	-52.2			x		x	
Churchill	MB	58.74	-94.07	276	201.2	12.7	-26	36.9	-45.4			x		x	
Kuujjuaq	QC	58.1	-68.42	262	270.5	11	-23.5	32.7	-46.7	1961-1990		x		x	
Fort McMurray	AB	56.65	-111.22	316.3	133.8	17.1	-17.4	37	-50.6			x		x	
Prince Rupert	BC	54.29	-130.44	**2530.4***	92.4	13.4	2.4	31.1	-24.4			x		x	
The Pas	MB	53.97	-101.1	336.9	146.1	18.1	-19.1	37.6	-49.4			x		x	
La Grande Rivière	QC	53.63	-77.7	453.8	261.3	14.2	-23.2	37.3	-44.6			x		x	
North Battleford	SK	52.77	-108.26	292.6	104.3	17.6	-16	39.5	-46.1			x		x	
Battle Harbour	NL	52.28	-55.58	349.3	431.1	14.8	-13.4	29.5	-34	1947-1983		x		x	
Lac Eon	QC	51.85	-63.28	494.8	**469.6***	13.6	-19.5	30	-46.1	1955-1977		x		x	
Calgary	AB	51.11	-114.02	326.4	128.8	16.5	-7.1	36.1	-45			x		x	
Regina	SK	50.43	-104.67	308.9	100.2	18.9	-14.7	**43.3***	-50			x		x	x
Saskatoon	SK	50.17	-106.72	276.7	91.3	18.5	-15.5	40.6	-50			x		x	
Medicine Hat	AB	50.02	-110.72	244.8	88.2	20	-8.4	42.2	-46.1			x		x	
Winnipeg	MB	49.92	-97.23	418.9	113.7	19.7	-16.4	40.6	-45		x		x		
Lethbridge	AB	49.63	-112.8	276.7	112.4	18.2	-6	39.4	-42.8		x		x	x	x
Cranbrook	BC	49.61	-115.78	279.5	125.3	18.7	-6.1	36.7	-40		x		x		
Summerland	BC	49.57	-119.65	261.2	67.9	20.5	-2.5	40	-30	1971-2000	x		x		
Estevan	SK	49.22	-102.97	331.6	110.7	19.4	-13.7	41.1	-43.4		x		x	x	x
Vancouver	BC	49.2	-123.18	1152.8	**38.1***	18	**4.1***	34.4	**-17.8***		x		x		
Gander	NL	48.95	-54.58	837.8	451.9	16.3	-7.1	35.6	-31.1		x		x		
Timmins	ON	48.57	-81.38	558.3	311.3	17.5	-16.8	38.9	-45.6		x		x		
Thunder Bay	ON	48.37	-89.33	559	187.6	17.6	-14.8	40.3	-41.1	1971-2000	x		x		

CWEC location				Annual Precipitation		Temperatures (°C)				Period of Record other than 1981-2010	Ground-mount at 30°	Tilt-angle matches latitude	Roof-mount at 10°	Tracking	Building-Integrated
Name	Prov	Latitude	Longitude	Rainfall (mm)	Snowfall (cm)	Daily Average		Record							
						July	Jan	High	Low						
Bagotville	QC	48.33	-71	663.8	321.7	18.4	-15.7	38.4	-43.3		x		x		
Miramichi	NB	47.01	-65.47	793.9	291.4	19.1	-10.8	37.8	-35		x		x		
Sault Ste Marie	ON	46.48	-84.51	651.3	320.7	17.9	-9.9	36.8	-38.9		x		x		
North Bay	ON	46.36	-79.42	802.8	299.6	18.9	-12.5	35.4	-40		x		x		
Charlottetown	PE	46.29	-63.13	887.1	290.4	18.7	-7.7	34.4	-30.5		x		x		
Sydney	NS	46.17	-60.05	1242.4	283	17.9	-5.4	35.5	-27.3		x		x		
Fredericton	NB	45.87	-66.53	859.1	252.3	19.3	-9.4	37.2	-37.2		x		x		
Ottawa	ON	45.32	-75.67	758.2	223.5	21	-10.3	37.8	-36.1		x		x	x	x
Muskoka	ON	44.97	-79.3	832.2	338.1	18.7	-10.3	35	-41.5		x		x		
Shearwater	NS	44.63	-63.5	1261.2	181.6	18.1	-4.6	33.3	-26.5		x		x		
Kingston	ON	44.24	-76.48	791.6	159.9	21.5	-7	35	-34		x		x	x	x
Trenton	ON	44.12	-77.53	786.3	156	20.7	-6.8	38.9	-35.1		x		x		
Mount Forest	ON	43.98	-80.75	708.5	297.8	18.1	-9	36.7	-41.1	1961-1990	x		x		
Toronto	ON	43.68	-79.63	681.6	108.5	21.5	-5.5	38.3	-31.3		x		x		
London	ON	43.03	-81.15	845.9	194.3	20.8	-5.6	38.2	-31.7		x		x	x	x
Simcoe	ON	42.85	-80.27	802.3	165.6	20.4	-6.2	36.1	-29.4	1961-1990	x		x		
Windsor	ON	42.28	-82.96	822.4	129.3	**23.0***	-3.8	40.2	-29.1		x		x	x	x

2.2 Experimental Approach

2.2.1. Locations and Available Data

The aim of the experimental portion of this study was to build a real-world dataset that the modelling results could be compared against, further increasing confidence in the modelling. The two selected locations are from Southern Ontario, ON (Table 2.1), located in St. Catharines (Figure 2.1) and Toronto, ON (Figure 2.2). Both are roof-mount installations with a tilt angle of 10° above the flat roofs. Each system is equipped with different inverter and module types. Approximately one full year of data were acquired, from August 23rd, 2014 to August 12th, 2015. The number of days in each month with available data used in the analysis are given in Table 2.2.

Table 2.1. *Experimental monitoring sites specifications.*

Site No.	AC/DC System Size (kW)/(kWp)	Location	Roof- or ground-mount	Tilt Angle	Inverter	Modules
1	100/140	St. Catharines, ON	Roof	Modules mounted at approx. tilt angle of 10° above a flat roof	Advanced Energy AE PVP 100	Canadian Solar, 245 W
2	100/133	Toronto, ON	Roof	Modules mounted at approx. tilt angle of 10° above a flat roof	Advanced Energy AE 100TX	Panasonic SCI Series, 255 W

Figure 2.1. *Site 1 is a 100 kW AC rooftop PV installation in St. Catharines, ON (Photo credit: SolarShare).*

Figure 2.2. *Site 2 is a 100 kW AC rooftop PV installation in Toronto, ON (Photo credit: SolarShare).*

Table 2.2. *Number of days with available data from the experimental sites for each month during the monitoring period.*

Month	Number of days with full data	
	Site 1	Site 2
August, 2014	7	7
September, 2014	30	30
October, 2014	31	31
November, 2014	20	20
December, 2014	21	20
January, 2015	8	31
February, 2015	0	28
March, 2015	20	31
April, 2015	30	30
May, 2015	31	31
June, 2015	7	21
July, 2015	19	31
August, 2015	12	11

2.2.2 Experimental Data Acquisition

Data acquisition was organized by the owner of both sites, SolarShare, for the purpose of performance evaluation and troubleshooting. The data were subsequently shared with STEP for further assessment and modelling. The collected data relevant to this analysis included POA irradiance, ambient temperature, back-surface module temperature and AC power. The instrumentation suite was compiled by Cachelan and incorporated into their online SolarVu monitoring portal. Electrical instrumentation was from Carlo Galvazzi while the temperature and irradiance measurements were achieved using a CG50 WeatherTrak which incorporated an IMT irradiance sensor and Pt1000 temperature sensors.

The module temperature measurement was achieved using a single temperature sensor attached to the back-surface of one module in the array. Although it would have been ideal to have had more module temperature measurements for data analysis, the instrumentation configuration was reasonable given that it was not installed particularly for the purposes of this study. Data were stored to an online server as 10-minute averages which were calculated using a logging interval of 4 seconds. Hour averages were used in the analysis. Basic quality assurance tests were performed on the dataset prior to analysis ensuring that the measured parameters followed expected trends, and were within expected ranges, throughout the monitoring period.

3.0 STUDY FINDINGS

3.1 Modelling Results

3.1.1 Ontario-wide Assessment

The Ontario-wide assessment modelled PV systems across 13 locations for two different configurations – ground- and roof-mount. The model produced an hourly dataset consisting of average irradiance, module temperature and power output, for one year of operation in typical meteorological conditions. Figure 3.1 plots the module temperature and irradiance data for all the roof-mount PV installations that were simulated. Each data point represents one hour of operation. Also plotted are the IEC 61853-1 rating points as well as proposed additions and deletions, discussed in more details in Section 3.2. It is evident that certain IEC 61853-1 test points at 50 and 75°C were not reached in the simulations. Similarly, a number of test points at 1,000 and 1,100 W/m^2 were not reached either. This plot demonstrates that there is a high frequency of weather conditions defined by low module temperature and low irradiance.

Similar results were obtained for the ground-mount system configuration, where a number of IEC 61853-1 testing points at high module temperatures were not reached in the simulation (Figure 3.2). Ground-mount configurations generally experience lower module temperatures across all irradiance levels. This is a result of the higher air flow behind the ground-mount panels, which in turn reduces the temperature of the modules.

When considering both roof- and ground-mount system configurations in Ontario, a large portion of operating conditions occur below the minimum module temperature testing point considered by IEC 61853-1, 15°C (Figure 3.3). On average, 40% of operating conditions occur below this threshold, accounting for 23% of annual energy production. Additionally, 20% of operating conditions occur below 5°C, accounting for 10% of annual energy production. For systems in locations with more extreme weather, such as the Timmins ground-mount scenario, these values can increase to 51% and 33%, respectively. As an extension of Figure 3.3, Figure 3.4 displays the percentage of power produced across the temperature-irradiance matrix for both roof- and ground-mount PV system configurations. The significant amount of operating hours and energy produced at these low temperatures indicates that the existing IEC 61853-1 testing matrix does not fully match the range of conditions seen in Ontario PV installations.

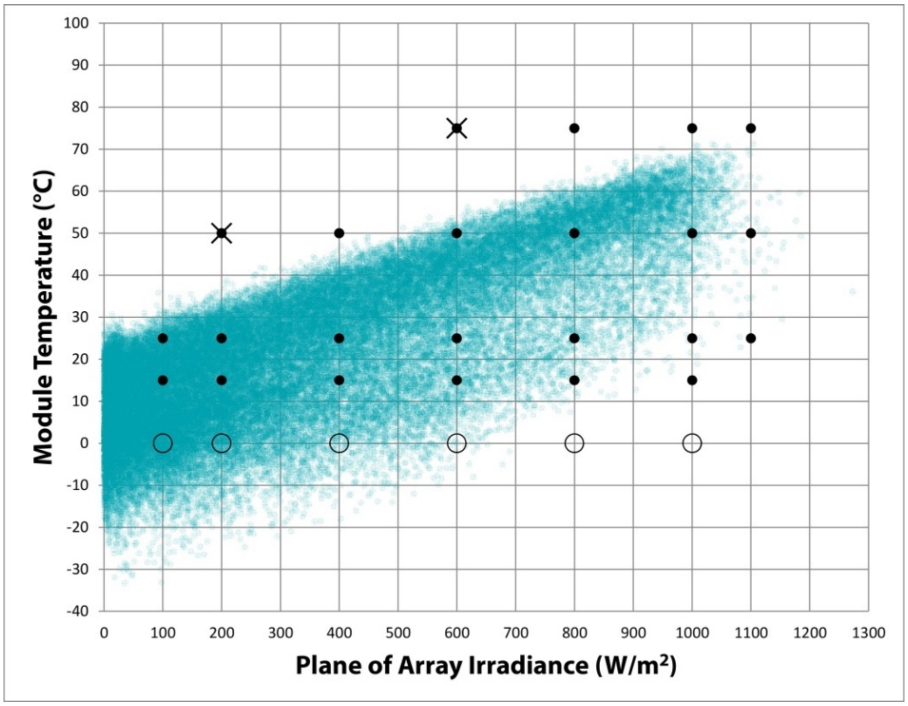

Figure 3.1. *Module temperature and irradiance operating conditions for roof-mount PV installations in Ontario. Each data point represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

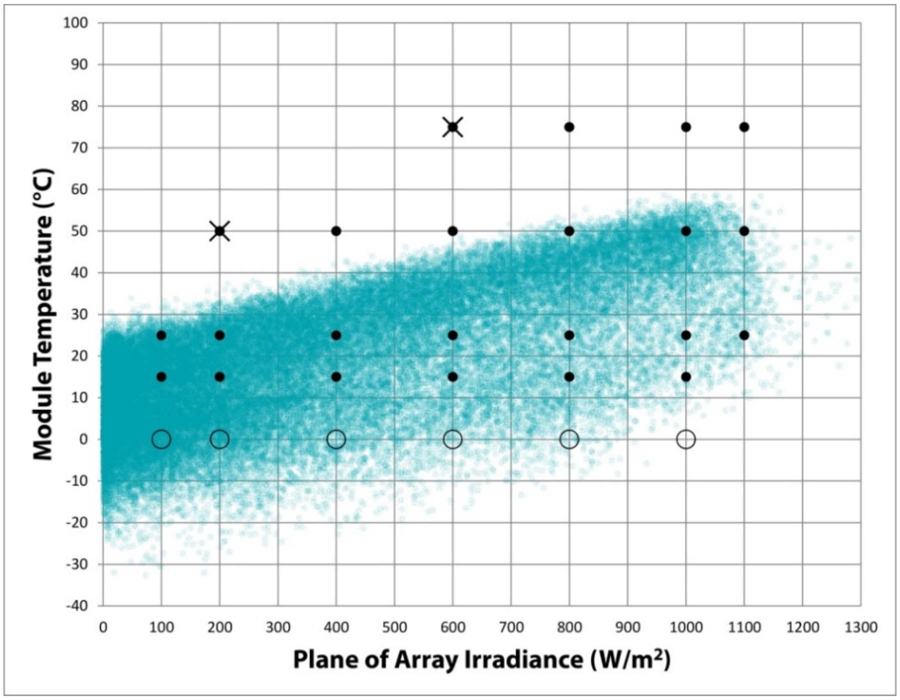

Figure 3.2. *Module temperature and irradiance operating conditions for ground-mount PV installations in Ontario. Each data point represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

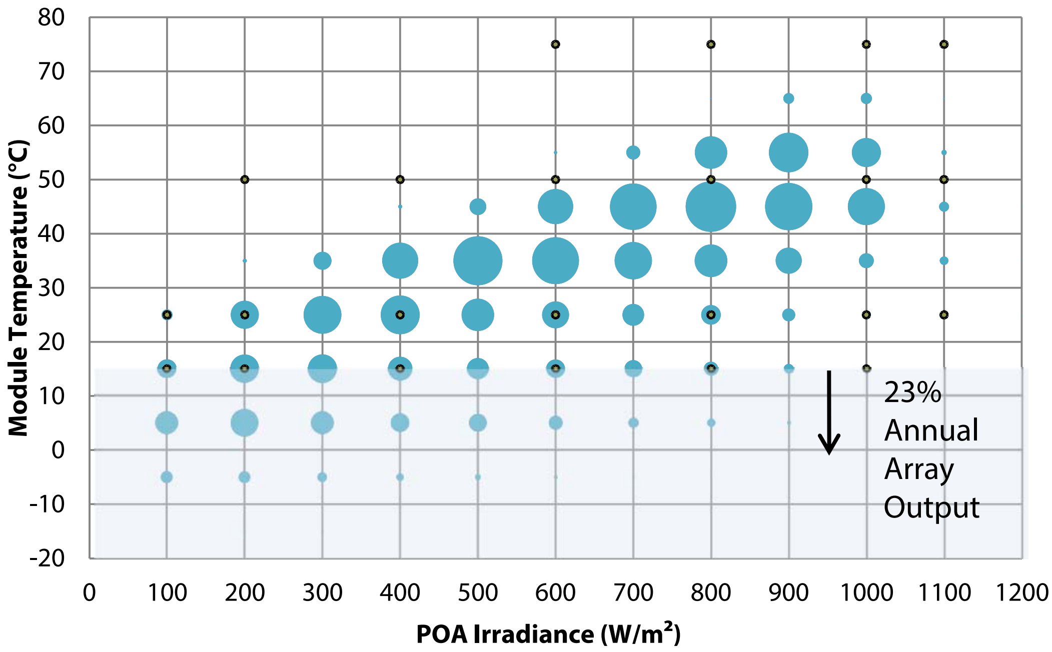

Figure 3.3. *Array energy output for both ground- and roof- mount configurations for Ontario locations. Bubble area is proportional to the energy output at the given module temperature and irradiance operating point.*

Plane of Array Irradiance (W/m²)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals* (Module Temperature Row 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 (Plane of Array Irradiance Column 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 3.4. *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 and 20 °C.*

3.1.2 Canada-wide Assessment

The Canada-wide assessment proceeded similarly to the Ontario assessment. PVsyst modeling was conducted for 5 different system types across 43 locations throughout Canada (Table 3.1). It is possible to highlight important differences between the various configurations by using the modeling results to determine the percentage of the annual energy produced below an irradiance of 500 W/m^2 and also, below a module temperature of 15ºC, for each configuration studied.

Table 3.1. *Percent annual power production at and below 500 W/m^2 and 15°C for all system configurations and for both Ontario and Canada assessments.*

	PV system configuration	% Annual Power Production up to 500 W/m^2	% Annual Power Production up to 15°C
1	Roof-mount systems installed close to the roof on flat-roofed buildings on semi-enclosed racking structures, facing south at a tilt of 10° above the horizontal plane	39	39
2	Ground-mount systems installed in fields on open, fixed racks facing south at a tilt of 30° above the horizontal plane	50	31
3	Tilt angle matches the latitude	38	47
4	Dual-axis ground tracking systems	26	39
5	BIPV modules installed at 40° tilt and integrated into the building with a fully insulated back	37	16

Canada-wide roof- and ground-mount PV system configurations show similar trends as the Ontario-only assessment (Figure 3.5 to 3.8). Additionally, despite the presence of IEC test points at high module temperatures with low irradiance levels, none of the modeled configurations across Canada commonly experience these conditions. All configurations are instead dominated by medium to high irradiance and temperature conditions.

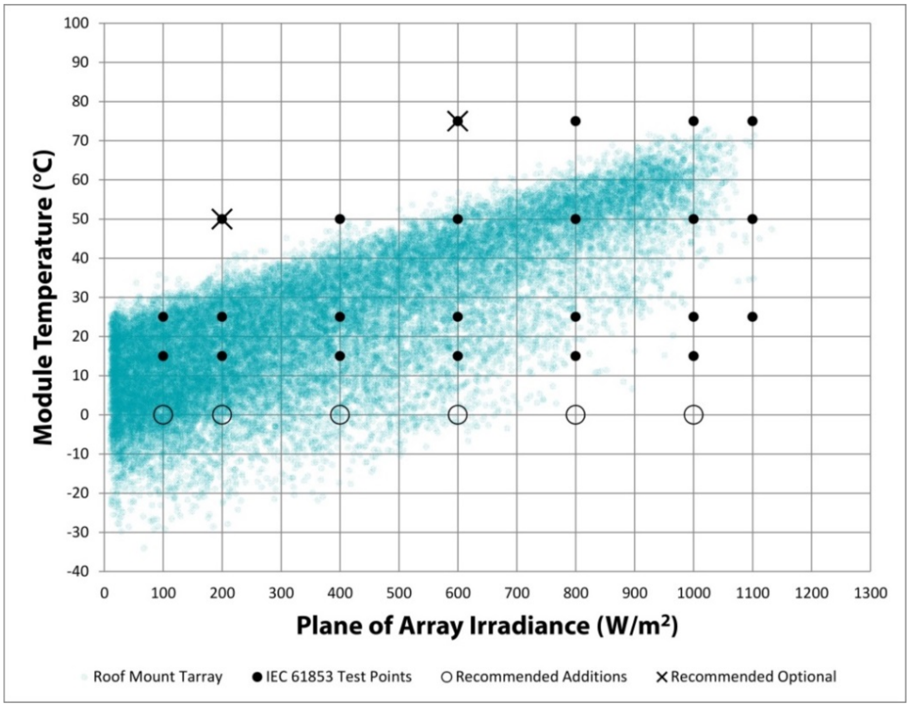

***Figure 3.5**. Frequency of occurrence for operating conditions for roof-mount PV installations in Canada. Each blue circle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

Plane of Array Irradiance (W/m^2)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	Totals (Module Temperature Row Totals)
85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.00%*
75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.04%*
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	1.4%	1.2%	0.1%	0.0%	*2.96%*
55	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	1.7%	4.0%	4.2%	1.5%	0.1%	0.0%	*11.93%*
45	0.0%	0.0%	0.0%	0.4%	1.6%	3.6%	4.5%	3.6%	1.9%	0.7%	0.1%	0.0%	*16.55%*
35	0.0%	0.3%	1.4%	3.1%	4.2%	3.8%	2.7%	1.7%	1.0%	0.3%	0.0%	0.0%	*18.51%*
25	0.7%	2.2%	3.4%	3.7%	3.0%	2.2%	1.5%	1.0%	0.4%	0.0%	0.0%	0.0%	*18.09%*
15	1.7%	2.9%	3.1%	2.5%	1.9%	1.3%	0.9%	0.4%	0.1%	0.0%	0.0%	0.0%	*14.85%*
5	2.0%	2.3%	1.7%	1.5%	1.2%	0.8%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	*9.80%*
-5	0.9%	1.0%	0.9%	0.8%	0.6%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*4.53%*
-15	0.4%	0.5%	0.4%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*1.71%*
Totals (Plane of Array Irradiance Column Totals)	*5.67%*	*9.18%*	*10.91%*	*12.32%*	*12.71%*	*12.46%*	*11.58%*	*11.08%*	*8.91%*	*3.77%*	*0.35%*	*0.03%*	99%

***Figure 3.6**. Percent annual energy production at different temperatures and irradiance levels for the roof mount configuration. Note that a given bin is comprised of all points within a 5°C range of the midpoint for temperature and 50 W/m^2 for irradiance. For example, a 15°C module temperature bin holds all the data with a module temperature between 10 and 20 °C.*

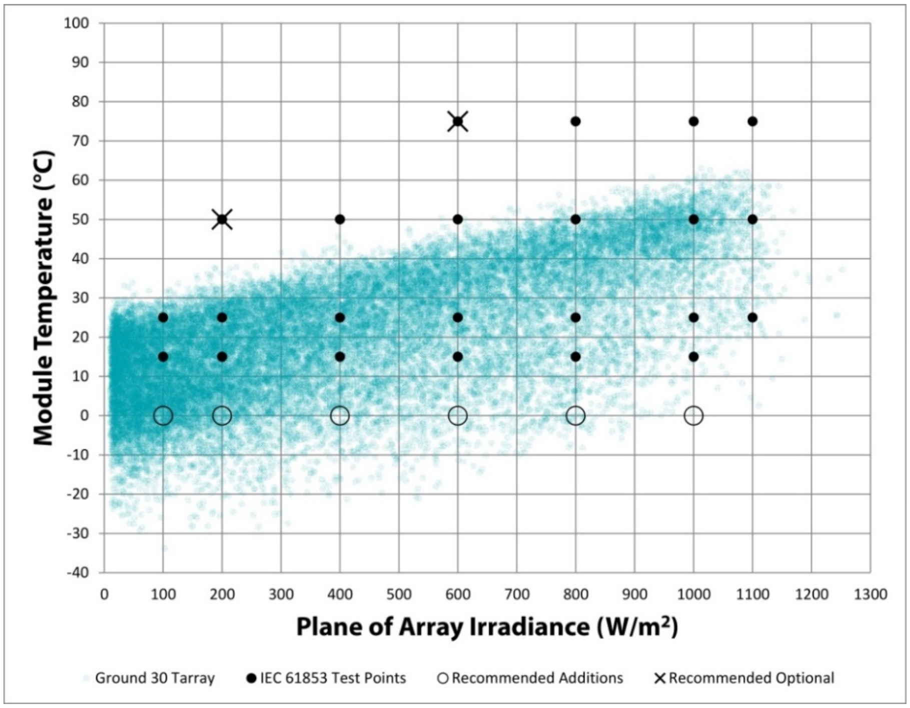

Figure 3.7. *Frequency of occurrence for operating conditions for ground-mount PV installations in Canada. Each blue circle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

Canada Ground-Mount Sites

Plane of Array Irradiance (W/m^2)

	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals*
85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.00%*
75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.00%*
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.04%*
55	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.9%	1.7%	0.5%	0.0%	*3.35%*
45	0.0%	0.0%	0.0%	0.0%	0.2%	0.8%	1.9%	3.3%	4.3%	3.6%	0.8%	0.0%	*15.08%*
35	0.0%	0.1%	0.5%	1.3%	2.6%	3.3%	3.5%	3.4%	2.8%	1.9%	0.8%	0.1%	*20.39%*
25	0.5%	1.4%	2.5%	2.8%	2.9%	2.7%	2.4%	2.1%	1.7%	1.1%	0.7%	0.1%	*20.82%*
15	1.4%	2.2%	2.4%	2.3%	2.0%	1.7%	1.8%	1.5%	1.2%	0.7%	0.3%	0.1%	*17.62%*
5	1.6%	2.0%	1.7%	1.4%	1.3%	1.2%	1.2%	1.1%	0.7%	0.4%	0.1%	0.0%	*12.81%*
-5	0.8%	0.8%	0.8%	0.7%	0.8%	0.7%	0.7%	0.7%	0.3%	0.1%	0.0%	0.0%	*6.36%*
-15	0.2%	0.3%	0.4%	0.3%	0.4%	0.3%	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	*2.30%*
Totals	*4.56%*	*6.89%*	*8.26%*	*9.00%*	*10.17%*	*10.68%*	*11.79%*	*12.45%*	*11.97%*	*9.56%*	*3.16%*	*0.30%*	*99%*

Figure 3.8 *Percent annual energy production at different temperatures and irradiance levels for the ground-mount configuration. Note that a given bin is comprised of all points within a 5°C range of the midpoint for temperature and 50 W/m^2 for irradiance. For example, a 15°C module temperature bin holds all the data with a module temperature between 10 and 20 °C.*

Among all configurations, dual-tracking systems show the lowest temperatures at high irradiances (Figures 3.9 and 3.10. Approximately 26% and 39% of power is produced at or below 15°C and 500 W/m^2, respectively (Table 3.1). Although tracking systems have the highest frequency of operating points at high irradiance levels (5.5% at 1000 W/m^2 and 45 °C), very little energy is actually produced at light levels beyond 1,100 W/m^2. This indicates that the test point at 1,100 W/m^2 is sufficient to effectively characterize high-irradiance module performance and higher irradiance testing points are not needed.

Systems that are mounted with both sides exposed freely to the air are able to maintain lower operating temperatures and thus perform more efficiently. In general, roof-mount and BIPV systems have higher operating temperatures across all irradiance levels, when compared to ground-mount systems, because only one side is freely exposed to air. The rate of increase is greater for roof-mount (Figure 3.6) and BIPV configurations (Figure 3.11) than it is in ground-mount (Figure 3.8) or open-tracking systems (Figure 3.10), 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 and 90 °C, respectively, while ground-mount and tracking systems generally experience maximum module temperatures of 60-65 °C.

Locations in Northern Canada undergo seasonally lower temperatures when compared to the rest of Canada (Figures 3.13 and 3.14). These locations were modelled by using a module tilt angle that matches the location's lattitude. It was found that 58% of operating hours occur when module temperatures are 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.

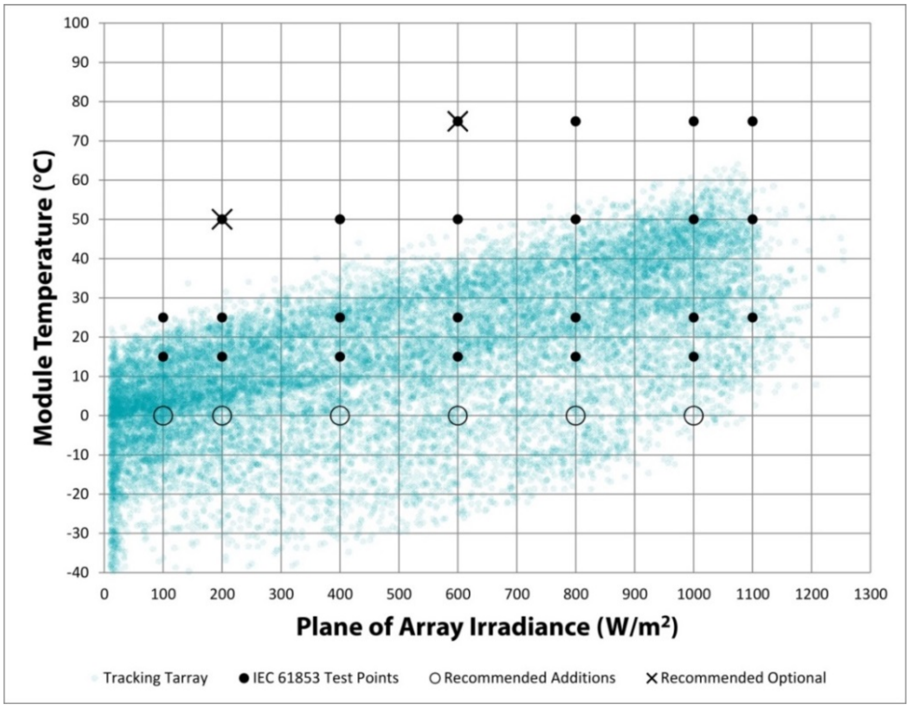

Figure 3.9. *Frequency of occurrence for operating conditions for dual-tracking PV installations in Canada. Each blue circle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

Module Temperature (°C) \ Plane of Array Irradiance (W/m²)	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals* (Module Temperature Row Totals)
85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.00%*
75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.00%*
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	*0.09%*
55	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.5%	1.9%	1.1%	0.0%	*3.71%*
45	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.8%	2.0%	3.8%	5.5%	2.0%	0.1%	*14.63%*
35	0.0%	0.0%	0.1%	0.4%	1.1%	2.1%	2.9%	3.3%	4.2%	4.0%	2.0%	0.4%	*20.47%*
25	0.1%	0.5%	1.2%	2.0%	2.3%	2.4%	2.7%	2.8%	2.7%	2.4%	1.4%	0.3%	*20.87%*
15	0.7%	1.5%	1.8%	1.8%	1.9%	1.7%	1.6%	1.5%	1.6%	1.3%	1.0%	0.2%	*16.67%*
5	1.0%	1.4%	1.3%	1.1%	1.0%	0.9%	1.2%	1.1%	1.2%	1.1%	0.6%	0.0%	*11.90%*
-5	0.5%	0.6%	0.6%	0.6%	0.7%	0.8%	0.9%	1.2%	0.8%	0.5%	0.1%	0.0%	*7.21%*
-15	0.2%	0.3%	0.4%	0.4%	0.5%	0.5%	0.4%	0.3%	0.1%	0.0%	0.0%	0.0%	*3.18%*
Totals (Plane of Array Irradiance Column Totals)	*2.49%*	*4.20%*	*5.40%*	*6.36%*	*7.66%*	*8.68%*	*10.51%*	*12.32%*	*14.94%*	*16.79%*	*8.21%*	*1.17%*	*99%*

Figure 3.10. *Percent annual energy production at different temperatures and irradiance levels for the dual-tracking system configuration. 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 and 20 °C.*

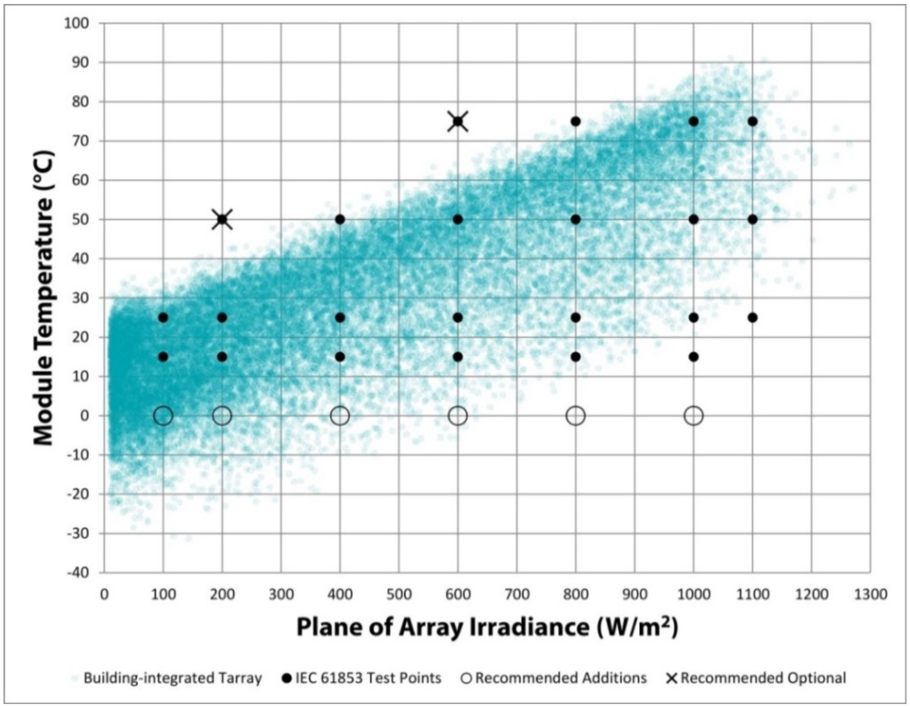

Figure 3.11 *Frequency of occurrence for operating conditions for BIPV installations in Canada. Each blue circle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

Plane of Array Irradiance (W/m^2)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals*
85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.7%	0.6%	0.0%	*1.34%*
75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	2.7%	3.9%	1.1%	0.0%	*8.16%*
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	1.5%	3.8%	4.6%	2.8%	0.8%	0.1%	*13.87%*
55	0.0%	0.0%	0.0%	0.0%	0.8%	2.6%	3.7%	3.5%	2.3%	1.6%	0.9%	0.1%	*15.51%*
45	0.0%	0.0%	0.3%	1.8%	3.2%	3.2%	2.3%	2.1%	1.8%	1.0%	0.4%	0.0%	*15.89%*
35	0.1%	0.9%	2.2%	2.7%	2.4%	2.0%	1.8%	1.6%	1.3%	0.5%	0.1%	0.0%	*15.62%*
25	0.9%	2.0%	2.2%	2.0%	1.5%	1.3%	1.1%	1.0%	0.8%	0.2%	0.0%	0.0%	*13.02%*
15	1.2%	1.9%	1.7%	1.3%	1.1%	0.8%	0.5%	0.5%	0.1%	0.0%	0.0%	0.0%	*9.04%*
5	1.3%	1.3%	0.9%	0.6%	0.5%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	*5.02%*
-5	0.5%	0.4%	0.3%	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*1.62%*
-15	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	*0.31%*
Totals	*3.98%*	*6.64%*	*7.72%*	*8.63%*	*9.67%*	*10.38%*	*11.12%*	*12.85%*	*13.66%*	*10.62%*	*3.84%*	*0.28%*	*99%*

Module Temperature Row Totals

Plane of Array Irradiance Column Totals

Figure 3.12 *Percent annual energy production at different temperatures and irradiance levels for the BIPV configuration. Note that a given bin is comprised of all points within a 5°C range of the midpoint for temperature and 50 W/m^2 for irradiance. For example, a 15°C module temperature bin holds all the data with a module temperature between 10 and 20 °C.*

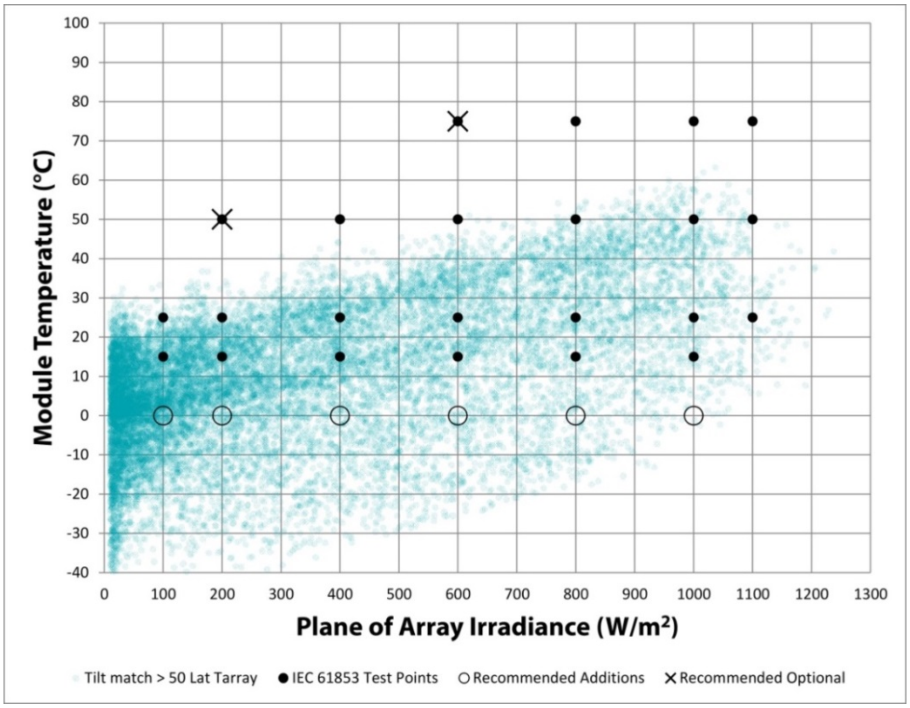

Figure 3.13. *Frequency of occurrence for operating conditions for latitude match PV installations in Canada. Each blue circle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

Plane of Array Irradiance (W/m²)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals* (Module Temperature Row Totals)
85	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	***0.00%***
75	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	***0.00%***
65	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	***0.03%***
55	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.6%	1.0%	0.4%	0.0%	***2.14%***
45	0.0%	0.0%	0.0%	0.0%	0.1%	0.5%	1.2%	2.4%	3.3%	2.6%	0.5%	0.1%	***10.70%***
35	0.0%	0.1%	0.3%	0.8%	1.8%	2.6%	2.9%	3.0%	2.7%	2.1%	0.9%	0.1%	***17.40%***
25	0.3%	1.0%	2.0%	2.5%	2.6%	2.6%	2.5%	2.4%	2.2%	1.4%	0.9%	0.2%	***20.51%***
15	1.4%	2.2%	2.4%	2.5%	2.2%	1.8%	1.7%	1.7%	1.4%	1.1%	0.6%	0.1%	***19.01%***
5	1.8%	2.0%	1.8%	1.4%	1.3%	1.2%	1.3%	1.3%	1.1%	0.8%	0.3%	0.0%	***14.31%***
-5	0.8%	0.9%	1.0%	0.9%	1.2%	1.1%	1.2%	1.2%	0.7%	0.2%	0.0%	0.0%	***9.21%***
-15	0.4%	0.5%	0.6%	0.7%	0.8%	0.7%	0.5%	0.3%	0.0%	0.0%	0.0%	0.0%	***4.55%***
Totals	***4.65%***	***6.67%***	***8.01%***	***8.85%***	***10.02%***	***10.44%***	***11.43%***	***12.39%***	***12.11%***	***9.25%***	***3.56%***	***0.48%***	***98%***

Plane of Array Irradiance Column Totals

Figure 3.14. *Percent annual energy production at different temperatures and irradiance levels for the latitude match configuration. 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 and 20 °C.*

3.2 Recommendations Based on Modeling Results

Across Canada, 43 different locations were examined for five different PV system configurations. Based on this assessment, six new test points would be required for the IEC 61853-1 is to be fully representative of a Canadian climate. These operating points would all be at 0 °C and would occur for all existing irradiance bins up to 1,000 W/m^2 with the 1,100 W/m^2 point designated as optional only (Figure 3.15). 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.

The six proposed points are necessary if the testing matrix is to be truly representative of the conditions experienced Canada-wide. The two test points proposed to be designated as optional are characterized by weather conditions that would only rarely occur in Canada. The low-irradiance and high-temperature as well as mid-irradiance and high-temperature conditions are uncommon in most of the tested configurations with the exception of BIPV. However, as the number of BIPV systems is expected to grow, these test points may still remain relevant for the characterization of PV module performance in Canada.

It should be stated explicitly that this analysis has only considered what points are necessary to characterize Canada conditions and has not yet considered the implications of implementing the proposed additional testing points in an actual laboratory. Informal conversations with laboratories have suggested that module frosting will become an issue when module temperatures approach 0 °C. As such, testing points at 5 °C may be a more realistic compromise. This should be further explored.

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

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

Figure 3.15 *Changes to the IEC 61853-1 test points for better representation of a Canadian climate.*

3.3 Experimental Results

The experimental results were included in this study as a ground-truthing measure for the modelling results. Data were filtered such that only those points where the power production is greater than 1% of rated inverter power are included. This was done to mitigate snow coverage effects where the modules may be covered with snow but the irradiance sensor is clear. There were numerous days in February and March that showed evidence of snow coverage.

A scatter plot of hourly operating points throughout the monitoring period is shown in Figure 3.16 for the St. Catharines, ON experimental site. It can be observed that the module temperatures do not approach the 75 °C IEC 61853-1 testing points, while operating points below the 15 °C IEC 61853-1 testing points are common at low-irradiance. Snow coverage did not appear to be an issue for this site but it should be noted that part of January and all of February was missing from the dataset.

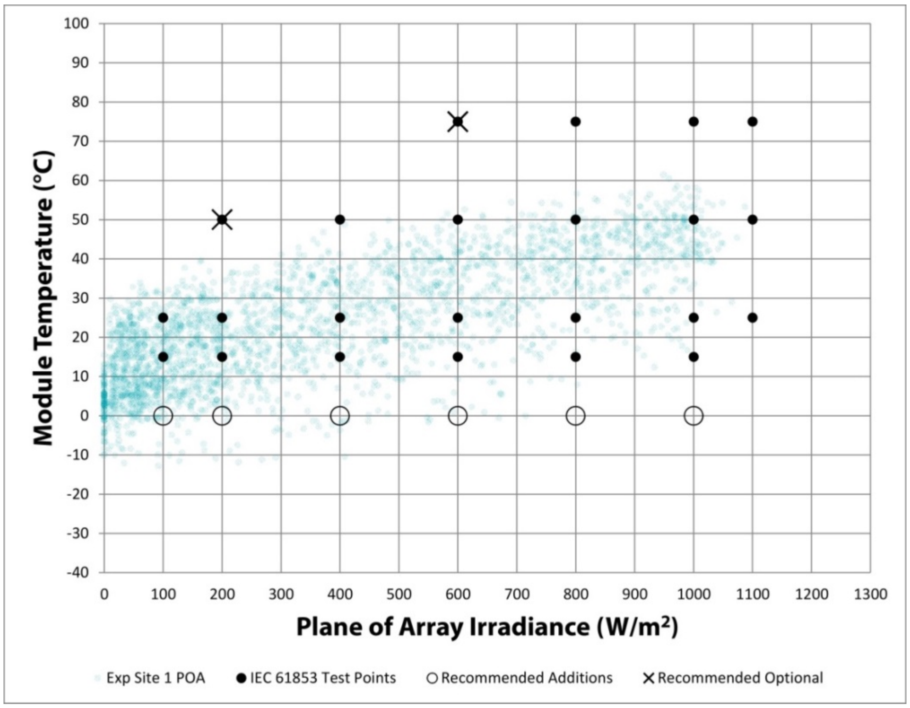

Figure 3.16. *Hourly operating points of module temperature and irradiance for the St. Catharines, ON experimental location. Each blue circle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

The hourly operating points of module temperature and irradiance for the Toronto, ON site are shown in Figure 3.17. It is clear that some of the IEC 61853-1 testing points are not approached for this site, specifically, 25 °C x 1,100 W/m^2 and 75 °C x 600 W/m^2, while operating points below 15 °C are frequent at low-irradiance. Figure 3.18 shows the energy produced as a function of irradiance and temperature.

Approximately 19% of the energy is produced at and below 15 °C while 42% of the energy is produced at or below 500 W/m^2. The points at low-temperature and mid-irradiance are likely due to partial snow coverage.

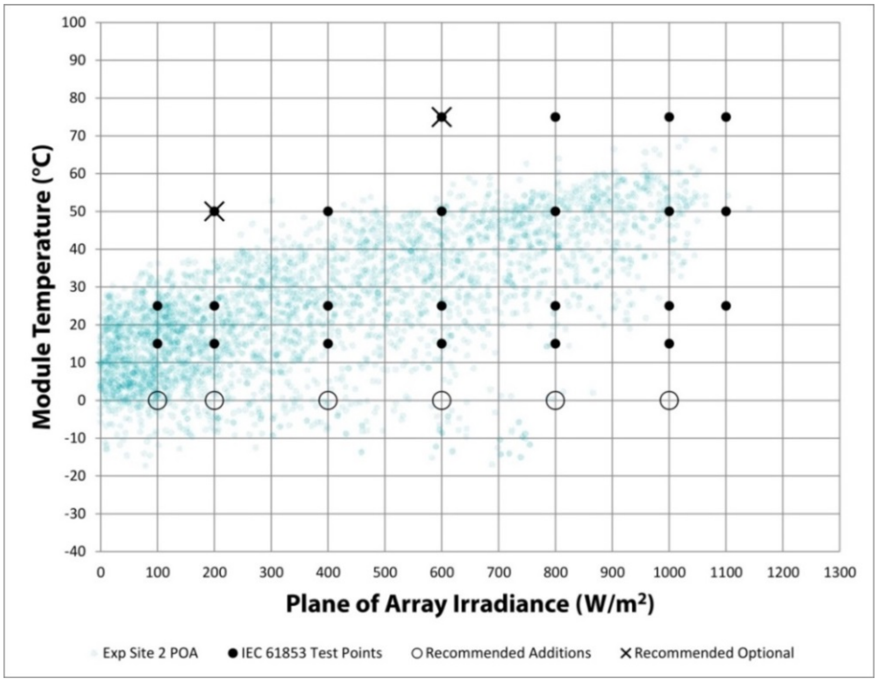

Figure 3.17 *Hourly operating points of module temperature and irradiance for the Toronto, ON experimental location. Each blue circle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

Plane of Array Irradiance (W/m^2)

Module Temperature (°C)	100	200	300	400	500	600	700	800	900	1000	1100	1200	*Totals* (Module Temperature Row 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%	0.00%	0.00%	0.00%	***0.00%***
65	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.06%	0.12%	0.12%	0.91%	0.14%	0.00%	***1.35%***
55	0.00%	0.00%	0.08%	0.06%	0.21%	0.86%	2.05%	3.65%	5.51%	4.42%	0.36%	0.00%	***17.20%***
45	0.00%	0.02%	0.45%	1.17%	3.26%	3.17%	5.05%	4.36%	3.17%	2.09%	0.08%	0.00%	***22.82%***
35	0.29%	0.97%	2.70%	1.89%	3.16%	3.66%	2.67%	2.64%	2.20%	0.91%	0.00%	0.00%	***21.08%***
25	1.69%	1.91%	2.66%	2.94%	2.51%	2.29%	1.80%	1.14%	0.94%	0.21%	0.00%	0.00%	***18.09%***
15	2.08%	2.11%	2.21%	1.06%	1.27%	1.55%	0.50%	0.53%	0.15%	0.00%	0.00%	0.00%	***11.45%***
5	2.08%	1.34%	0.91%	0.61%	0.51%	0.44%	0.12%	0.05%	0.02%	0.00%	0.00%	0.00%	***6.07%***
-5	0.46%	0.36%	0.48%	0.22%	0.12%	0.07%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%	***1.78%***
-15	0.05%	0.00%	0.01%	0.00%	0.01%	0.01%	0.05%	0.01%	0.00%	0.00%	0.00%	0.00%	***0.15%***
Totals (Plane of Array Irradiance Column Totals)	***6.66%***	***6.72%***	***9.51%***	***7.95%***	***11.04%***	***12.05%***	***12.35%***	***12.49%***	***12.11%***	***8.55%***	***0.57%***	***0.00%***	***100%***

Figure 3.18. *Percent annual energy production at different temperatures and irradiance levels for the Toronto, ON experimental location. Note that a given bin is comprised of all points within a 5°C range of the midpoint for temperature and 50 W/m^2 for irradiance. For example, a 15°C module temperature bin holds all the data with a module temperature between 10 and 20 °C.*

3.4 Comparison of Experimental and Simulation Datasets

Before comparing the results of the theoretical and experimental analysis, it useful to provide some comparison of the climate conditions under which the results were obtained. The experimental data used in this comparison is for the Toronto, ON site; however, temperature data were taken from the Toronto Pearson International Airport Environment Canada location to substitute the site data that were deemed unreliable. The modelled data is from the TMY CWEC files for Toronto, ON. As such, it should be made explicit that there are important differences. Specifically:

1. The simulations used TMY data from the CWEC files using data collected from 1961 to 1990 while the experimental data is for August, 2014 to August, 2015. Temperature data for the experimental location were obtained from the Toronto Pearson International Airport station for the August, 2014 to August, 2015 time period (temperature data during the experimental study were deemed unreliable). It follows that the solar insolation and ambient temperatures are not necessarily the same for each data set.
2. The simulations made assumptions about a standard PV configuration, size, orientation, components, etc. while the experimental data is for a real-world installation with its own particular specifications (described in Table 4).

Figure 3.19 shows the mean monthly ambient air temperatures for the experimental and simulation datasets. The experimental data monitoring period is typically warmer in the spring, summer and fall, but colder in the winter. The modelled temperature data appears to be freer of extremes. Figure 3.20 presents a comparison between modelled daily average global horizontal insolation from the Toronto, ON CWEC location with that measured at the Toronto, ON experimental location. The experimental data have generally higher mean daily insolation levels, except for the fall and early winter period. The main reason for this is the annual variability expected to occur year to year. This is a somewhat qualitative comparison and some disagreement is expected given that any given year may deviate from a TMY. However, the two datasets follow a similar trend and the experimental data set can still provide a useful comparison.

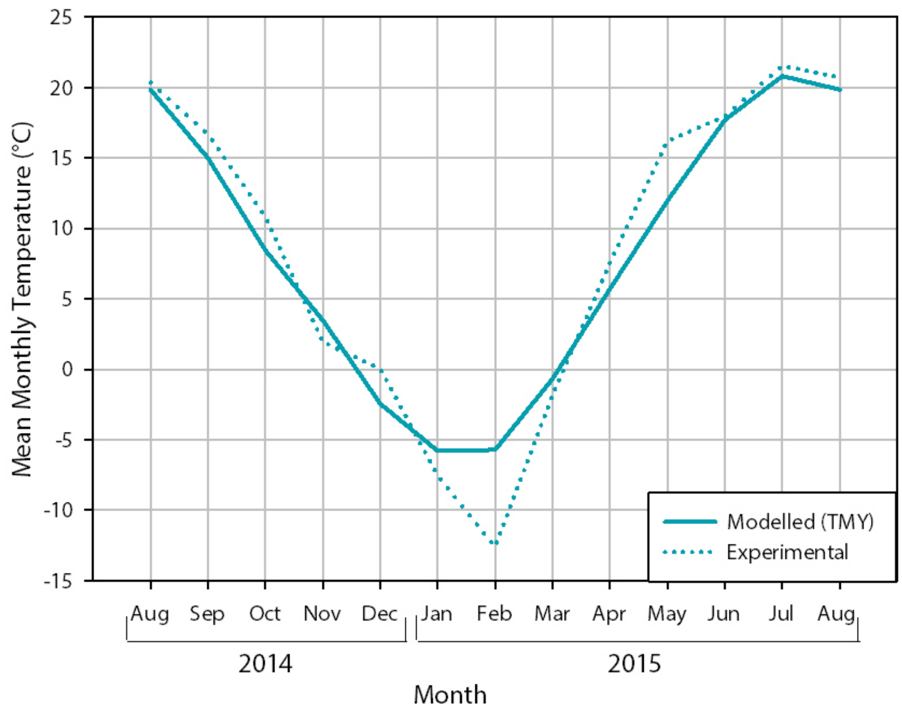

Figure 3.19. *Mean monthly air temperature for the modelled (PVsyst data for Toronto, ON) and experimental (Toronto Pearson International Airport) datasets form August 2014 to August 2015.*

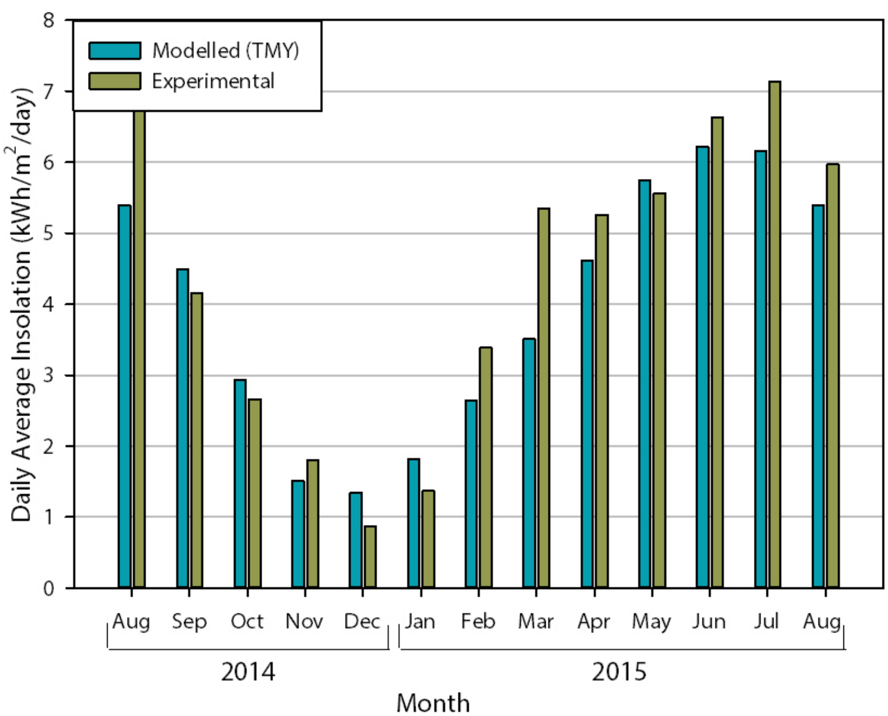

Figure 3.20. *Daily average insolation for the modelled (PVsyst data for Toronto, ON roof installation at 10° tilt) and experimental (Toronto, ON) datasets from August, 2014 to August, 2015.*

Figure 3.21 shows the frequency of different irradiance and module temperature operating points for both the experimental and modelled hourly datasets, both using the Toronto location. It can be observed that, generally, the two datasets follow the same trend and spread. An exception is a cluster of points from the expeprimental dataset between 400 W/m^2 and 800 W/m^2 and below °0 C. This can be explained by partial snow-coverage or the notably colder winter months in the experimental dataset when compared to the TMY-derived temperatures of the modelled dataset. At a course level, there is good agreement and this provides a level of verification to the modelling results for this site, and other sites by extension.

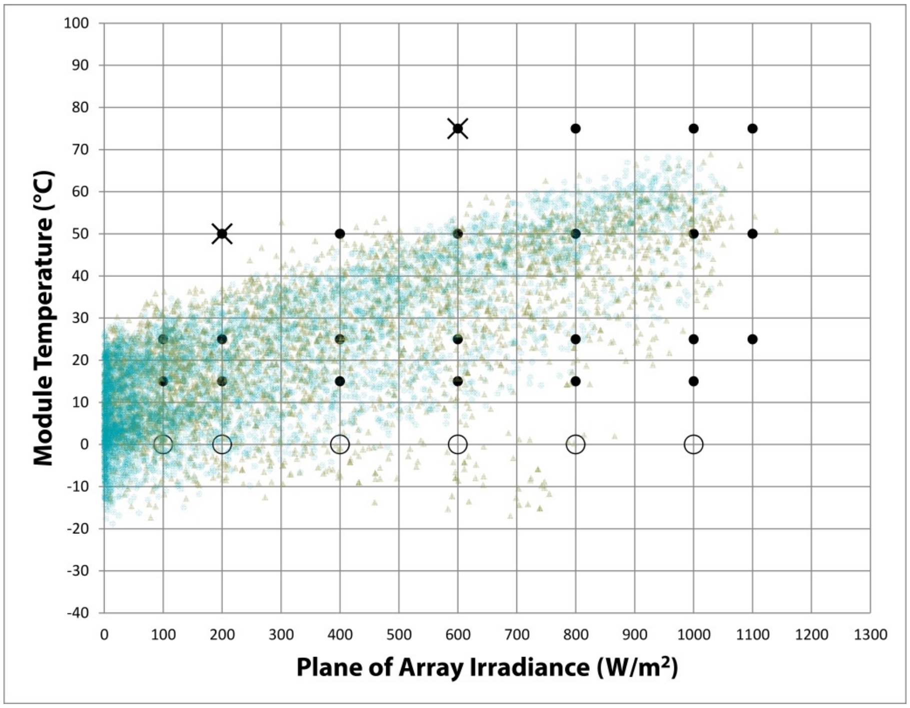

Figure 3.21. *Hourly operating points of module temperature and irradiance for the Toronto, ON experimental location and the Toronto, ON PVsyst modelled location. Each circle/triangle represents one hour of operation. Closed circles – existing IEC 61853-1 test points; Open circles – proposed new test points; X's – proposed omissions to IEC 61853-1.*

4.0 CONCLUSIONS AND RECOMMENDATIONS

The IEC 61853-1 PV module rating standard incorporates expanded performance testing, beyond that required in IEC 61215, with an aim to simplify energy yield simulations, increase simulation accuracy and create performance metrics that are unbiased towards any given PV module technology. This would provide investors with a higher degree of confidence in the profit estimates of potential PV installations and it would also allow consumers to more accurately compare PV modules among different manufacturers. This level of increased transparency is likely to be an important step to ensure continued investment in PV.

This study used PVsyst modelling to analyze PV module temperature and irradiance operating conditions for PV installations of different configurations across Canada. In addition, experimental measurements from two Southern Ontario PV installations provided some level of ground-truthing to the modelling results. The analysis compared the matrix of PV module temperature and irradiance testing points, prescribed in the current version of the IEC 61853-1 standard, against Canadian operating conditions with an aim to recommend testing point additions or deletions that may improve the standard's applicability in Canada.

In general, it was found that test points located in the low irradiance/high temperature and high irradiance/high temperature regions were never or rarely reached. In addition, a high concentration of operating points below a module temperature of 15 °C was observed. This is the lowest temperature considered in the IEC 61853-1 testing matrix. Within the analysis, power data from the PVsyst modelling was binned according to the module temperature and irradiance. The percentage of total annual energy production was then determined for each bin. As an example, results for roof- and ground-mount installations from Ontario showed that approximately 23% of annual energy is produced at or below a module temperature of 15 °C.

It appears that a notable portion of the annual energy production is produced outside of the current IEC 61853-1 testing matrix. The following additions would help the IEC 61853-1 testing matrix better reflect Canadian operating conditions:

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

If the testing matrix is to be fully representative of a Canadian climate, the proposed low temperature testing points would be a necessary addition. However, it should also be noted that the practical limitations of laboratory testing also warrant further consideration. This may result in a compromise where the optimal additions are at a higher module temperature that is more amenable to laboratory testing.

5.0 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.

IEC 61853-1: PHOTOVOLTAIC MODULE PERFORMANCE TESTING AND ENERGY RATING ASSESSMENT FOR CANADA

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