POWER QUALITY ASSESSMENT OF SOLAR PHOTOVOLTAIC INVERTERS

FINAL REPORT

Sustainable Technologies Evaluation Program
www.sustainabletechnologies.ca

Toronto and Region Conservation for The Living City

POWER QUALITY ASSESSMENT OF SOLAR PHOTOVOLTAIC INVERTERS

The Living City Campus, Vaughan, Ontario

Final Report

Prepared by:

Toronto and Region Conservation

Under the

Sustainable Technologies Evaluation Program

January 2016

NOTICE

PUBLICATION INFORMATION

Report citation: Janssen, E. and St. Hilaire, L. 2016. *Power Quality Assessment of Solar Photovoltaic Inverters*. Sustainable Technologies Evaluation Program, Toronto and Region Conservation Authority, Toronto, Ontario.

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:

Erik Janssen, M.A.Sc.
Analyst II, Sustainable Technologies
Toronto and Region Conservation Authority
9520 Pine Valley Drive,
Vaughan, Ontario
L4L 1A6

Tel: 905-832-7053
E-mail: EJanssen@trca.on.ca

Leigh St.Hilaire, B.A.Sc.
Project Manager, Sustainable Technologies
Toronto and Region Conservation Authority
9520 Pine Valley Drive,
Vaughan, Ontario
L4L 1A6

Tel: 416-277-3849
E-mail: LStHilaire@trca.on.ca

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.

ACKNOWLEDGEMENTS

This work was made possible through funding provided by:

- The LDC Tomorrow Fund
- Natural Resources Canada (NRCan)
- York Region
- Peel Region
- City of Toronto

We would also like to thank Dave Rogalsky and Brett Sverkas, the facility managers at the TRCA's Restoration Services Centre Facility and the Earth Rangers Centre for Sustainable Technology, respectively, for allowing us to instrument and monitor their PV installations. We would further like the thank Dave Turcotte and Lisa Dignard of NRCan, as well as the engineers at PowerStream, for their comments on initial drafts of this report. Lastly, we would like to thank Hany Farag of York University for providing to STEP his expertise in electrical power systems and devices at various stages of this project.

EXECUTIVE SUMMARY

The *CAN/CSA-C22.2 NO. 257-06 (R2011)* and *IEEE 1547-2003* (these standards will be denoted by CSA 257 and IEEE 1547 within this report as shorthand) are the Canadian and U.S. standards that stipulate the tolerances for harmonic current emissions created by distributed resources, such as photovoltaic (PV) installations, connected to low-voltage electrical distribution systems.[1]

- *CSA 257* requires that any inverters used within a grid-connected PV installation be certified to *CAN/CSA-C22.2 NO. 107.1-01 (R2011)* (denoted by CSA 107.1 within this report as shorthand). In turn, *CSA 107.1* requires that an inverter has harmonic emissions below certain limits when the inverter is operating at 100% of its rated load.
- *IEEE 1547* requires that a PV installation obey the same general limits as *CSA 257*. However, in contrast, *IEEE 1547* requires instead that these limits be satisfied at the installation's point of common coupling to the area electrical power system when the installation is operating at 33%, 66% and 100% of the total rated load.

With either standard, the fact remains that an actual PV installation will see a much wider range of operating points, including frequent low-level and highly variable irradiance conditions and it is possible that there may be notable power quality issues outside of the recommended measurement conditions given within the standards.

This study used long-term monitoring to determine the power quality of solar PV inverters across a wide range of real-world operating conditions for four different installations in Vaughan, ON. Within the study, power quality analyzers were deployed for up to a year at the different installations, which ranged in size from approximately 6 to 40 kW. For each site, the total demand distortion (TDD) and individual harmonic distortion factors were determined across the measurement period and compared with the *CSA 257* and *IEEE 1547* harmonic current emission limits.

The harmonic current emission limits within these standards are given as a percentage of the rated load current of the inverter or installation. For example, an installation with a 100 A rated load current would need to have a third order harmonic current that is less than 4% of the rated current (i.e. the limit would be 4 A) when the inverter, or installation, is operating at either: (i) 100% of rated load as in the CSA standard, or (ii) 33%, 66% and 100% of rated load as in the IEEE standard. In contrast, this study looked at whether that 4 A limit, given in this example, was ever exceeded at <u>any</u> power output during both steady and transient conditions. This was done for all harmonic orders and the total harmonic current. The term "over-limit" is used to denote occurrences where the limits are exceeded, regardless of the current output, and similarly, the term "within limit" is used in a similar sense. It follows that "over-limit" does not necessarily mean non-compliance with the standards, simply because the standards say that the limits only have to be satisfied at specific operating points.

[1] *UL 1741 - Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources* is another important standard in this area.

There were four power quality meters in total deployed at partner sites. With a frequency greater than 99.99% of the time, two of the sites were within the *individual harmonic distortion factor limits*. The remaining two sites were within individual harmonic distortion factor limits greater than approximately 99% and 90% of the time that the inverters were producing power.

The presence of a specific brand of microinverters (termed within this report as Inverter D) was an important contributing factor to the over-limit occurrences. These occurrences were observed at part-load in steady irradiance conditions with a voltage THD below 5%. To be clear, Inverter D was certified to *CSA 107.1* and *IEEE 1547,* meaning that, individually, its harmonic current emissions were within the recommended limits at 33%, 66% and 100% of the rated load. Measurements taken on individual Inverter Ds within this study confirmed this compliance. However, Inverter D was measured to have very high harmonic content at less than 20% of the rated load (a power output level that is not considered by the standards).

If a fraction of the microinverters operating in parallel together on a given branch were shaded, or installed at a different orientation, it is feasible that the high harmonic emissions resulting from those few modules could pollute the whole branch to the extent where the *branch* would be over-limit, even when the total power output from the branch was relatively high (i.e. at or above the 33% rating point). This phenomenon was believed to have been the cause of the over-limit occurrences at installations containing Inverter D microinverters. The result was that, although (i) the installation was compliant with *CSA 257*, in that it used inverters that satisfied *CSA 107.1*, and (ii) the individual inverters were compliant with the limits in *IEEE 1547;* the entire installation would likely not have been compliant with *IEEE 1547* at all points in time. This was because individual harmonic distortion factor limits were exceeded when the inverters collectively were operating at 33% and 66% of the rated load. It is not currently known whether or not this effect is limited to Inverter D microinverters or if it also occurs across other inverter brands/topologies. This should be examined in future work and this specific issue may also warrant further consideration from standards development committees.

It should be stated explicitly that this report did <u>not</u> conclude that harmonic emissions should be considered as a notable barrier towards future deployment of PV. 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.

ABBREVIATIONS

CSA 107.1	CAN/CSA-C22.2 NO. 107.1-01 (R2011)
CSA 257	CAN/CSA-C22.2 NO. 257-06 (R2011)
CT	current transducer
DR	distributed resource
EPS	electrical power system
LDC	local distribution company
PQA	power quality analyzer
TDD	total demand distortion
THD	total harmonic distortion

TABLE OF CONTENTS