


July 25, 2013

Halton Hills
HYDRO

Distribution System Solar Integration Project

Report to the LDC Tomorrow Fund

Submitted by Halton Hills Hydro

Distribution System Solar Integration Project

Report to the LDC Tomorrow Fund

Contents

Project Overview

Halton Hills Hydro installed 187 solar panels on hydro poles throughout the Town of Halton Hills as a pilot project to study the benefits to Ontario LDCs of integrating the distribution system with pole mounted solar modules. This innovative rate based pilot project was approved in Halton Hills Hydro's 2012 Cost of Service Application to the Ontario Energy Board. This project was undertaken with contribution from the LDC Tomorrow Fund.

> The objective of the project was to quantify the benefits to LDCs of installing pole mounted solar modules, enabling a new and innovative technology and ensuring the results are transferable to all Ontario LDCs. It is a highly visible and scalable community focused project which provides fully distributed renewable energy coupled with smart grid features within the community.

The three key benefits of this system as seen by Halton Hills Hydro are:

1. The pole mounted solar modules provide clean renewable energy generation.

2. Having generation on hydro utility poles, close to the load, reduces line losses.

3. The pole mounted solar modules create an intelligent grid infrastructure that provides real time monitoring, and troubleshooting on the secondary distribution system.

Halton Hills Hydro's experience

Halton Hills Hydro has experienced each of these benefits.

1. The pole mounted solar modules provide clean renewable energy generation. For Halton Hills Hydro and our shareholder, the Town of Halton Hills, this was a highly visible project in the community which complements the Mayor's Green Plan and the Town's Community Energy Plan. Halton Hills Hydro chose to place the solar modules on poles on major thoroughfares within the community so that they would be highly visible to customers and visitors. Halton Hills Hydro staff received a few inquiries about the panels, mostly from customers curious about the project and interested in the solar energy being produced.

2. Having generation on existing hydro utility poles, close to the load, reduces line losses. The energy generated by the panels and the resulting line loss reductions are passed on directly to Halton Hills Hydro's rate payers. Halton Hills Hydro has been pleased with the amount of energy generated which exceeded expectations. The anticipated line loss reduction is 0.02% per 100kW of installed panels. The line loss reduction is primarily on-peak losses which have been identified by the Ontario Government in their "*Conservation First – A Renewed Vision for Energy Conservation in Ontario"* as being an important factor in energy conservation and improved system efficiency.

3. The pole mounted solar modules create an intelligent grid infrastructure providing real time monitoring, and troubleshooting on the secondary distribution system. It is these “Smart Grid” benefits which were of the most interest to the utility. Halton Hills Hydro has found the capability of the smart energy modules to provide voltage information particularly useful in identifying areas with high or low voltages. Usually, the LDC only finds out about these over or under voltages when a customer calls, whereas now Halton Hills Hydro can proactively send crews to investigate and make adjustments before potential damage to customer or utility owned equipment occurs. In particular, voltages can be proactively monitored during both on and off peak periods to further improve system efficiencies.

Halton Hills Hydro retained Kinectrics Inc. to perform a detailed third party evaluation of the distribution system solar integration project to quantify the costs and benefits associated with the system and verify the claims made by the manufacturer regarding system monitoring. Their detailed report is attached. Kinectrics found that the solar modules reduce line losses through renewable energy generation and provide a “smart grid” benefit by measuring and reporting such parameters as voltage and frequency.

It is Halton Hills Hydro’s belief that this has been a valuable pilot project demonstrating that this technology can be implemented within existing rate base and with benefits which are easily transferable and scalable to any LDC in the province. Halton Hills Hydro recognizes this project as the type of initiative which complements the Province of Ontario’s “Renewed Vision for Energy Conservation”. Halton Hills Hydro will be looking at expanding the roll out of the pole mounted solar modules in the coming years.

DISTRIBUTION SYSTEM SOLAR INTEGRATION EVALUATION FOR HALTON HILLS HYDRO

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Kinectrics Inc. Report No.: K-418480-RA-001-R00

Client Purchase Order: 64566

July 23, 2013

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PRIVATE INFORMATION

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DISTRIBUTION SYSTEM SOLAR INTEGRATION EVALUATION FOR HALTON HILLS HYDRO

Kinectrics Inc. Report No.: K-418480-RA-001-R00

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DISCLAIMER

Kinectrics Inc. has prepared this report in accordance with, and subject to, the terms and conditions of the contract between Kinectrics Inc. and Halton Hills Hydro Inc.

REVISIONS

Revision Number	Date	Comments	Approved

DISTRIBUTION SYSTEM SOLAR INTEGRATION EVALUATION FOR HALTON HILLS HYDRO

EXECUTIVE SUMMARY

Kinectrics studied Halton Hills Hydro's Distribution System Solar Integration pilot project to determine and quantify the costs and benefits associated with the Pole-Mounted Solar Module (PSM) installations. The study involved a validation of the system measurements provided by the PSMs, using field measurements collected during the study, and a cost/benefit analysis to determine the net present value of the PSM installations.

The key findings of this study were:

1. The PSM measurements are sufficiently accurate for practical utility engineering applications, such as reliability assessment, voltage regulation analysis, losses studies, fault detection, and general troubleshooting.

2. The PSMs provide a benefit to Halton Hills Hydro (HHH) by producing energy. This energy reduces the amount of energy purchased by the utility and reduces losses, providing a benefit to both HHH and its customers. The forecasted annual energy output of the PSMs in the pilot project is approximately 46 MWh. It is estimated that this will reduce HHH's distribution loss factor by 0.01%. Because PSM generation typically coincides with peak loading (daytime hours), a reduction in peak losses would be expected.

3. The PSMs provide a "smart grid" benefit by measuring and reporting system parameters, such as voltage and frequency. A new version of the PSM (2014) is expected to incorporate power quality measurements and automated alert messaging.

4. The PSMs produce renewable energy, which provides an environmental benefit and a benefit to Halton Hills Hydro's reputation. The energy output from the Distribution System Solar Integration pilot project is estimated to offset approximately 26 metric tons of equivalent carbon emissions annually. This is equivalent to 0.58 metric tons per installed kW.

5. The results of the net present value (NPV) analysis indicate that:

    a. Although the pilot project will not provide a net positive value when all costs and benefits are considered, because of decreasing equipment costs future PSM installations are expected to provide a net positive value when the benefits of smart grid are considered. The 30-year NPV of the pilot project and future PSM installations, with and without the added benefits of smart grid and renewable energy, are summarized in Table 1. This table also shows the number of years required for the PSM installations to achieve neutral value (break even) for each scenario.

Table 1: Pilot Project and Future PSM 30-Year Cost/Benefit NPV Summary

Cost/Benefits Scenario	Pilot Project		Future PSMs	
	NPV (2012 $)	Years to Break Even	NPV (2012 $)	Years to Break Even
Smart Grid and Renewable Benefits	-$46,186	>30	$36,174	16
Renewable Benefits (no smart grid benefit)	-$166,474	>30	-$84,114	>30
Smart Grid Benefits (no renewable benefit)	-$66,474	>30	$10,814	24
Actual Benefits (no smart grid or renewable benefit)	-$186,762	>30	-$109,474	>30

b. The maximum total installation costs per Watt required for a PSM installation to achieve a neutral net present value after 30 years was calculated for each scenario. When the actual installation costs are less than these "break even" costs, PSM installations will provide a net positive value within a 30-year time period.
   i. When only the benefits associated with energy production and loss reduction are considered, the break even cost was calculated to be $1.75/W.
   ii. When the benefits of the smart grid functionality are also considered, the break even cost was $3.75/W.
   iii. Similarly, when the benefits of energy production and loss reduction are considered with the benefits of renewable energy, the break even cost was found to be $2.17/W.
   iv. Finally, when all benefits are considered together, the break even cost was $4.17/W.
   v. For comparison, the costs associated with the pilot project were $5.76/W and the expected cost for PSM installations in 2014 is $3.57/W.

c. The NPV analysis indicates that, of the three primary benefits associated with the PSMs (energy and loss reduction, smart grid, and renewable energy), the smart grid features provide the greatest benefit to HHH.

Based on the results of this study, Kinectrics recommends the following:

1. Provided the costs and power densities of future PSMs are less than $3.75/W, as they are predicted to be[1], HHH may wish to consider expanding the PSM program up to the point where the smart grid benefits are maximized. The maximum smart grid benefit would be achieved by having one PSM connected to each phase of each circuit. The installation of more than one PSM unit on one phase of a given circuit will not provide additional smart grid benefits and therefore would not be cost effective.

2. HHH should install the new versions of the PSM, once available, to take advantage of the additional smart grid features, such as improved power quality monitoring and automated alerts. If technically possible and cost-effective, existing PSM units should also be upgraded with this functionality.

[1] The most recent pricing from the manufacturer indicates that the 2014 price will be $1,071 for a 300W installation, or $3.57/W

3. Should the total installation price for PSM installations fall below $1.75/W, HHH should consider installing PSM units beyond the point where the maximum smart grid benefit is achieved. When the installation price is below this level, the PSMs will provide a direct financial benefit to HHH's customers.

4. It is recommended that Halton Hills Hydro confirm the effectiveness of the PSM anti-islanding protections for multiple PSM installations connected in close proximity to one another before installing large numbers of PSMs. It is also recommended that Halton Hills Hydro work with Hydro One to ensure that Hydro One is aware of the PSM installations.

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DISTRIBUTION SYSTEM SOLAR INTEGRATION EVALUATION FOR HALTON HILLS HYDRO

1.0 INTRODUCTION

Halton Hills Hydro (HHH) undertook a pilot project in 2012 to install photovoltaic (PV) solar panels on some of their distribution utility poles. Each Pole-Mounted Solar Module (PSM) installation consists of one PV solar panel and one Smart Energy Module (SEM); each PV panel is connected to the distribution system through a SEM. A total of 187 PSMs were installed during the pilot project. An additional 9 communicator units, used to relay the data transmitted by the PSMs, were also installed.

The PSM installations connect to HHH's system on the 120/240 V secondary system. In addition to exporting energy to the grid, the PSM units also measure system parameters and report this information back to HHH. This information is reported through a web-based software system, IntelliView, which is owned and maintained by the equipment vendor, Petra Solar Inc. (Petra).

Figure 1 shows an example of a typical installation.

HHH hired Kinectrics to perform a cost/benefit evaluation of the PSM installations. This evaluation was performed using information about the Distribution Solar System Integration pilot project and future installations, provided by HHH and Petra.

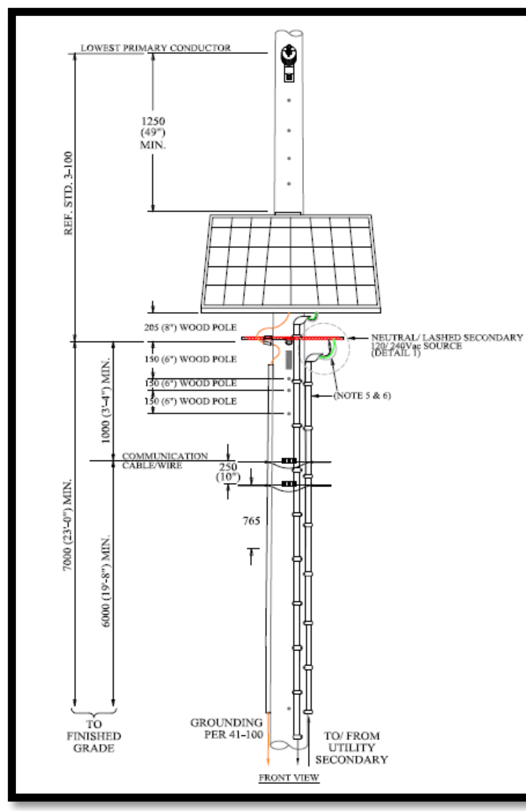

Figure 1: Typical PSM Installation

2.0 OBJECTIVES AND SCOPE

2.1 Objectives

The objective of this project was to investigate and provide commentary on a number of claims by the manufacturer (Petra) with respect to PSMs, as outlined in the proposal submitted by Halton Hills Hydro to the LDC Tomorrow Fund[2]. The investigation was performed using independent measurements and data from the 187 PSMs that were installed as part of a pilot project at HHH.

The primary objectives were to:

1. Verify the accuracy of the following parameters that are measured by the Smart Energy Modules:
    a. System secondary voltage
    b. Frequency
    c. AC current output
    d. AC real power output
    e. AC reactive power output
    f. Cumulative energy generation
2. Evaluate the impact of the Smart Energy Modules on the following:
    a. Increased reliability
    b. Power system voltage stabilization
    c. Monitoring of voltage and power quality
    d. Real-time system data
    e. Fault detection and troubleshooting
    f. Improved response time to issues
    g. Ability to proactively address system issues
3. Determine the effect of the Distribution System Solar Integration pilot project on losses
4. Investigate the voltage regulation capabilities of the Smart Energy Modules
5. Identify power quality issues that were found using the Smart Energy Modules

2.2 Scope

The scope of this project was divided into two parts. Part A involved an evaluation of the accuracy of measurements of the PSMs; this was required to determine if the quantities reported by the PSMs were sufficiently accurate to be used in Part B.

Part B was an assessment of the costs and benefits to HHH for the installation of the PSMs. This analysis assessed the Net Present Value (NPV) of the costs and benefits associated with the PSM installations. Section 3.0 describes the methodology used in this project.

[2] *Distribution System Solar Integration Project – A proposal to the LDC Tomorrow Fund*, Halton Hills Hydro

3.0 METHODOLOGY

The following sections describe the methodology used in the two phases of this project.

3.1 Part A - Measurement Validation

The methodology used in the validation of the PSM measurements is described by the following steps:

1. A calibrated Kinectrics power quality analyzer was connected to the PSM outputs at two different locations. The outputs were measured over three-hour time intervals. The following parameters were recorded:
    a. AC RMS voltage
    b. AC RMS current
    c. AC Real Power
    d. AC Reactive Power
    e. AC Apparent Power
    f. Cumulative energy output
    g. Voltage and current THD
    h. Flicker

2. The power quality analyzer measurements were then compared with the measurements reported by the PSMs through their online system, IntelliView.

3. The accuracy of the PSM measurements were calculated with respect to the power quality analyzer measurements.

3.2 Part B - Cost/Benefit Analysis

Kinectrics evaluated the costs and benefits to HHH of the PSMs using the methodology described in this section. The cost/benefit analysis involved the following steps:

1. Information about costs, maintenance, revenue, and usage was collected from HHH and Petra.

2. This information was analyzed to determine the costs and benefits associated with the Distribution System Solar Integration Pilot Project and the broader deployment of PSM installations. The benefits were grouped into the following three categories:
    a. Power production and losses
    b. Smart grid
    c. Renewable energy

3. The overall cost or benefit of the PSM installations was quantified using a Net Present Value (NPV) calculation. The value was calculated using the following formula:

$$Value = NPV \begin{bmatrix} (Energy\ Production) + (Loss\ Reduction) + (Smart\ Grid) \\ +(Renewable\ Energy) - (Installation\ Costs) - (Maintenance) \end{bmatrix}$$

4.0 PART A - MEASUREMENT VALIDATION

The results of the measurement validation phase of this project were provided in a separate report. A copy of this report is provided in Appendix A. The conclusions and recommendations are included here for the reader's benefit. Please note that the Pole-Mounted Solar Installations (PSMs) were referred to as Smart Energy Modules (SEMs) in the report for Part A.

<u>Conclusions</u>

1. The measurements recorded by the SEMs are sufficiently accurate for practical utility applications, including: reliability assessment, voltage regulation analysis, losses studies, fault detection, and general troubleshooting.
2. The measurements recorded by the SEMs may not be sufficiently accurate to be used as a substitute for field or laboratory measurements with calibrated instruments. However, the practical applications for which the SEM measurements would typically be used by a utility do not generally require highly accurate measurements.
3. SEM harmonic and flicker measurements were not available in the IntelliView system and could not be compared with the Fluke measurements. The availability of harmonic and flicker measurements should be confirmed during Part B.

<u>Recommendations</u>

1. The measurement data recorded by the SEMs were found to be sufficiently accurate for practical applications, including Part B of this project. Therefore, it is recommended that Part B – Cost/Benefit Analysis proceed.
2. A SEM should be tested in a controlled laboratory environment to determine the accuracy of the active power, reactive power, and energy measurements under controlled conditions. Moreover, laboratory testing can also verify the SEM's various operating, protection, and maximum power point tracking (MPPT) functions, if required.
3. The availability of harmonic and flicker measurements should be confirmed during Part B.

5.0 COST/BENEFIT ANALYSIS

The evaluation of the costs and benefits of the PSM installations is presented in this section. This information was used in the NPV calculations in Section 6.0.

5.1 Costs

5.1.1 Purchase and Installation

The total cost of the pilot project was $258,660; this cost includes $225,000 for equipment and $33,660 for labour. 187 PSMs were installed, so the cost per unit was $1,383.21. Each PSM has a rated capacity of 240W, so the cost per Watt was $5.76/W.

According to Petra Solar, the unit costs have decreased and the power density of solar panels is expected to increase from 240W to 300W per panel in the future. According to Petra Solar and HHH, the cost for a 300W unit will be $1,071 in 2014, including installation. Assuming the cost per Watt is the same for a 300W unit or a 240W unit, the expected cost for a 240W unit in 2014 would be $887, including installation.

The NPV calculation for the pilot project uses the actual pilot project costs. The NPV calculation for future installations uses a cost of $887 for each 240W unit and $1,071 for each 300W unit.

5.1.2 Maintenance

According to Petra and HHH, the units do not require scheduled maintenance. The PV panels are treated with a coating that self-cleans with rain. The panels may need to be washed if there are extended periods without precipitation, but this is unlikely in Ontario's climate.

The PV panels are covered by a 20-year warranty and the SEMs are covered by a 10-year warranty. There are some indications that the SEMs will be covered by a 15-year warranty in the future, although this has not yet occurred. Although Petra Solar indicates that the expected failure rate for PSM installations is less than 1% per year, it has been assumed that the PSM installations will have a 30-year useful lifespan on average; this assumption results in a failure rate of approximately 3.2%, which is more conservative than the manufacturer's estimates, but is justified because the historical information relating to this technology is limited.

The NPV calculations assume that no maintenance is required for the first 10 years because all equipment is covered by warranty. In years 11 to 20, the SEMs are no longer covered by warranty and it is assumed that between one and six SEMs will require replacement each year at a cost of $150 each. After year 20, it is assumed that six complete PSM installations (PV panel and SEM) will require replacement per year. The replacement costs used in the NPV calculation were $150 per SEM, $737 per 240W PV panel for the pilot project, and $921 per 300W PV panel for future installations, including installation costs. These costs are subject to inflation, but like other new technologies, the costs are also expected to decrease as the technology matures. For the NPV calculations, it was assumed that these two effects would counteract one another, resulting in the replacement costs remaining constant over time.

Table 2 shows the estimated replacement schedule and associated costs.

Table 2: Estimated Replacement Schedule

Year	0-10	11	12	13	14	15	16	17	18	19	20	21+
SEM Replacement	0	1	1	2	2	3	3	4	4	5	5	6
PV Panel Replacement	0	0	0	0	0	0	0	0	0	0	0	6
Maintenance Cost Pilot Project – 240W units ($)	0	150	150	300	300	450	450	600	600	750	750	5,322
Maintenance Cost Future – 300W units ($)	0	150	150	300	300	450	450	600	600	750	750	6,246

5.2 Benefits

5.2.1 Power Production and Losses

The Distribution Solar System Integration pilot project has been in service since February 2013. The pilot project has not been in operation for sufficient time to provide historical annual power production information, but a previous installation site on 10th Line in Halton Hills near Ashgrove (Ashgrove) has been in operation for several years. The rated power output per unit at the Ashgrove site is 200 W, while the units used in the pilot project have a rated output of 240 W.

The Ashgrove site is an ideal site for PV installations and the PSMs installed in the pilot project are not expected to produce as much energy per installed Watt of capacity. The power output from the four units at the Ashgrove site was used to estimate the power production from the PSMs in the pilot project. To forecast the annual output of the PSMs in the pilot project, the average measured energy output from the Ashgrove PSMs was scaled to match the average measured output of the pilot project PSMs between March and June 2013. The forecasted annual pilot project PSM energy output was found by scaling the annual Ashgrove output by this scaling factor. Therefore, the forecasted energy output of the PSMs in the pilot project was based on the Ashgrove data, but adjusted to match the actual pilot project energy output measured between March 2013 and June 2013.

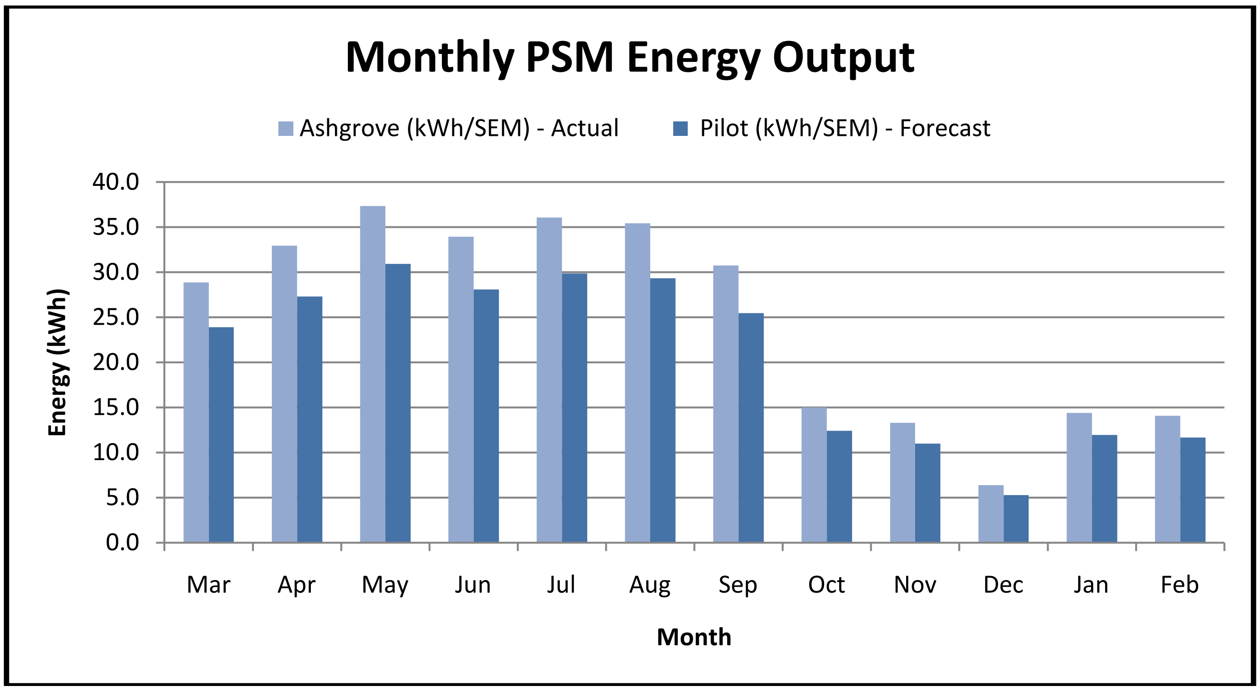

Figure 2: PSM monthly power output

Figure 2 shows the average measured monthly energy output of the PSM installations at the Ashgrove site from March 2012 to February 2013 and the forecasted monthly pilot project PSM energy output. Based on this prediction, the 187 PSMs in the pilot project are expected to produce approximately 46,214 kWh per year.

It is not uncommon to see a decrease in the power output of PV panels over time, however, and Petra projects that the productivity loss after 20 years will not exceed 15%. This decrease in productivity has been factored into the NPV calculation. According to a report by SANDIA National Laboratories, the mean annual decrease in the maximum power available from eleven different PV panels tested was 0.27% per year[3]. This annual decrease in energy output was used in the NPV calculations.

The power produced by the PSM installations will also have a beneficial impact on Halton Hills Hydro's losses. The power that is produced by the PV panels will be consumed locally and will therefore decrease the losses associated with transmitting this power through both the distribution and transmission systems.

Prior to the Distribution Solar System Integration Pilot Project, HHH's Total Loss Factor (TLF) was calculated to be 106.02%. This is comprised of HHH's Distribution Loss Factor (DLF) of 102.53% and an upstream Facilities Loss Factor (FLF) of 103.4%.

The impact of the Pilot Project PSM power production was calculated as follows. HHH's 5-year average DLF was calculated using the following equation:

$$DLF = \frac{W}{R} = \frac{490{,}073{,}766\ kWh}{477{,}985{,}841\ kWh} = 102.53\%$$

where W is the 5-year average net "wholesale" kWh delivered to the distributor and R is the 5-year average net "retail" kWh delivered by the distributor. Let E represent the annual kWh produced by the PSMs in the pilot project, then HHH's new DLF, considering the impact of the PSMs can be calculated to be:

$$DLF_{PSM} = W - DLF \cdot ER$$

because the energy produced by the PSMs will reduce both the net wholesale kWh delivered by the distributor and the losses on HHH's distribution system; therefore the difference in the net wholesale kWh delivered to the distributor is increased by the DLF. Solving for the new DLF_{PSM},

$$DLF_{PSM} = \frac{W}{R + E} = \frac{490{,}073{,}766\ kWh}{477{,}985{,}841\ kWh + 46{,}214\ kWh} = 102.52\%$$

Therefore the effect of the energy from the PSM pilot project being generated locally can be expected to decrease HHH's DLF by 0.01%. The savings associated with this loss reduction will be passed on to the customer. As an estimate for future PSM installations, the impact of 100 kW of PSMs (which would be expected to produce 102,972 kWh annually) on HHH's DLF would be a decrease of approximately 0.02%. It is also expected that PSM installations would have a different impact on losses for different utilities. For example, PSMs should reduce losses more for rural distributors than urban distributors. This is due to the reduced power flow along the lengthy feeders associated with rural utilities.

Considering the reduction of losses, the expected change in the average net wholesale kWh delivered to the distributor will be $E \cdot DLF_{PSM} = 46{,}214\ kWh\ \cdot 102.52\% = 47{,}378\ kWh$.

Because the PSMs only generate during daytime hours, which typically coincide with peak distribution system loading, the PSMs should reduce peak distribution system losses.

The PSMs reduce the net wholesale kWh delivered to HHH; therefore the rate paid to HHH is effectively the same rate as for energy delivered to the distributor. This rate is composed of the Hourly Ontario Energy Price (HOEP), the Global Adjustment (GA), the Transmission Network Charge, the Transmission

[3] Smith, R., Jordan, D., Kurtz, S, *Outdoor PV Module Degradation of Current-Voltage Parameters - Preprint*, 2012 World Renewable Energy Forum, 2012.

Connection Charge, the Wholesale Market Service Charge, the Low Voltage Charge, and the Rural and Remote Electricity Rate Protection. This rate is then multiplied by the FLF. The average hourly HOEP peak rate was used in the calculation because the PSMs only generate during daytime hours, which coincide with peak HOEP hours.

The rate for 2013 and future years was estimated by extrapolating the historical rates from 2008 to 2012; the average rate for 2012 was $0.0932/kWh and the trend shows an annual increase of $0.0035/kWh. The FLF is 3.4%, therefore the rate used in the NPV calculation was $0.0964/kWh in 2012 with an annual increase of $0.0036/kWh.

5.2.2 Smart Grid

The PSMs, in addition to the energy they produce, provide additional benefits that can be described as "smart grid" features. The PSMs measure and report system parameters, such as voltage and frequency, at regular intervals and are capable of raising alerts when these parameters fall outside of nominal ranges. The benefits associated with this smart grid functionality are described and their value is assessed in this section.

<u>Reliability & Fault Detection</u>

The PSMs monitor system voltage and frequency and can therefore report outages when configured to do so. HHH currently has them configured to raise an alert whenever the measured voltage is outside of the nominal range. Because many outages are only detected when customers report them, the automatic alert from the PSMs will allow HHH to detect and respond to outages more rapidly. This will reduce customer outage times and will have a positive impact on the utility's SAIDI and CAIDI statistics.

If it assumed that the alerts from the PSMs will provide HHH with notice of an outage 5 minutes earlier on average than the current reporting methods, the result would be a decrease in both of HHH's SAIDI and CAIDI statistics of 0.083. Considering the 2012 statistics, the resulting SAIDI and CAIDI statistics would be 1.45 hours and 0.72 hours, down from 1.53 hours and 0.80 hours respectively. No impact on the frequency of outages (SAIFI) is expected.

It is important to note, however, that the alerts from the PSMs are not currently actively communicated to utility personnel; the alerts are raised in the PSM's monitoring software program (IntelliView) and are only visible when someone logs into the system. Therefore, the positive impact of the PSM's smart grid functionality on reliability is not as significant as it could be if automated email or SMS alerts were to be incorporated into the system. It is recommended that HHH work with the equipment supplier to add this functionality to maximize the value of this system. However, it should also be noted that Halton Hills Hydro does not currently have a control room. This system could be integrated into a control room for ongoing monitoring.

<u>Power Quality Monitoring, and Troubleshooting</u>

The PSMs provide valuable data for diagnosing and troubleshooting power quality issues. As mentioned above, the PSMs measure the system voltage where they are connected. Using this information, HHH has found several locations along their feeders where the voltages were outside of the nominal range and the appropriate corrective action was taken. Correcting over/under-voltage conditions is generally expected to have a positive effect on utility and customer equipment. Without the data from the PSMs, it is likely that these over/under-voltage conditions would have gone unnoticed and would not have been corrected. Prior to the installation of the PSM units, over/under-voltages would only have been detected if the utility implemented a program to proactively measure voltages or if a customer measured their voltage and notified the utility that it was not at an acceptable level. Some over/under-voltages can stress utility and customer equipment and lead to increased failure rates.

Additionally, Petra has indicated that the next generation model of PSM will be capable of measuring system harmonics and flicker. Harmonic and flicker problems can be difficult to investigate and resolve and this capability will allow HHH to proactively address and resolve potential power quality problems. The model of PSM installed in the pilot project does not have the capability to measure harmonics or flicker.

Because the PSMs are single-phase devices, it is not possible for them to measure unbalance.

It is recommended that HHH require harmonic and flicker measurement capabilities for future PSM installations.

Voltage Regulation

The PSM system has the physical capability to perform active voltage regulation through dynamic VAR injection. This control mode would allow a utility to set a voltage set point and the PSMs would dynamically adjust their reactive power output to maintain the voltage at that set point. Although dynamic VAR injection is not yet available and the PSMs in the pilot project operate at a constant power factor (1.0 at full power output), future PSM models may be equipped with this functionality.

This control mode could provide a benefit to HHH, but it should be studied before implementation for several reasons. Firstly, active voltage regulation by distributed devices requires careful coordination to ensure that there are no conflicts with the utility's existing voltage regulating equipment. Secondly, the PSMs have a limited power output and any quantity of reactive power (VAR) produced would come at the expense of active power production (W). Since HHH receives financial compensation from the PSMs as a function of the active power produced (kWh), any reactive power production will decrease the savings from the active power production. Finally, due to the relatively low rated capacity of the PSMs (240 W – 320 W), the PSMs may not be physically capable of regulating the voltage. It is recommended that HHH study these issues before considering the implementation of active voltage regulation by the PSMs.

Smart Grid Valuation

Although there is clear value in the added smart grid functionality associated with the PSMs in the pilot project, and to a greater extent the next generation of PSMs, it is difficult to quantify this benefit in financial terms. Much of the information provided by the PSMs, such as system voltages and power quality measurements, provides a benefit to HHH and its customers by helping to diagnose and resolve problems that may have otherwise gone undetected and these benefits are difficult to quantify financially. Therefore, instead of attempting to quantify these benefits directly, the cost associated with installing an alternative smart grid system with similar functionality has been used.

The OptaNODE system, manufactured by Grid20/20, was selected as the alternative smart grid technology because it offers smart grid features comparable to those provided by the PSMs. The OptaNODE units measure system parameters, such as voltage, current, power, and energy and have built-in communications. A future version of the OptaNODE unit is expected to be capable of measure harmonics and flicker as well. Unlike the PSMs, the OptaNODE units do not produce energy.

According to the Grid20/20, the approximate cost for fewer than 1,000 OptaNODE units is roughly $600/unit. Therefore, the cost of installing 187 units, the number of PSMs installed in the pilot project, was estimated to be $112,200. It was also assumed that there would be ongoing maintenance costs associated with the OptaNODE units, estimated at $3,600 per year after twenty years. This is based on the following assumptions: the units have a 20-year warranty, 6 units would need to be replaced annually, and each replacement unit would cost $600. The cost for this alternative smart grid system was deducted from the installation and maintenance costs of the Distribution Solar System Integration pilot in the relevant NPV calculations.

It should be noted that the benefit of any smart grid system will be maximized when the utility achieves visibility of every circuit. After this has been achieved, there is little value in the installation of additional devices, as far as smart grid functionality is concerned. For a distributor, this maximum smart grid value will occur when a smart grid device is installed on each phase of every circuit in the system, where a circuit is defined as a section of line that is separated by a transformer or a section of line that can be sectionalized from the rest of the grid.

5.2.3 Renewable Energy

The PSMs provide a benefit in that the solar energy they produce is green and renewable. In addition to the obvious environmental benefits of renewable energy production, the PSMs also provide a benefit to HHH's reputation and the reputation of the communities within which it operates; this is because the PV panel installations are prominently mounted on utility poles and clearly visible to the public.

However, similarly to the smart grid benefits discussed in Section 5.2.2, the financial benefit of green/renewable energy production is difficult to quantify. HHH is not receiving any premium for the renewable energy produced by the panels, and there is therefore no direct financial benefit to HHH or its customers. However, there is clearly value in the renewable nature of the energy produced by the PSMs and this should be captured in the NPV calculations.

There is an energy provider that operates in Ontario (and other areas of Canada), Bullfrog Power[4], that sells electricity from renewable sources to its customers for a premium. This company has been operating successfully in Ontario since 2005 and, therefore, the premium they charge to customers for renewable electricity was used to represent a reasonable valuation for the renewable energy produced by the PSMs. The premium charged by Bullfrog Power is $0.03/kWh and this rate has been used in the relevant NPV calculations in Section 5.3.

It should also be noted that the installation of PSMs may be eligible for carbon credits. According to the United States Environmental Protection Agency, electricity generation in the US produces 1,222.29 lb/MWh of equivalent carbon emissions[5]. Using this number, it is estimated that the Distribution System Solar Integration pilot project would offset approximately 26 metric tons of equivalent carbon emissions annually. This is equivalent to 0.58 metric tons per installed kW. Carbon credits were not considered in this analysis, but should be investigated to determine if PSM installations are eligible.

[4] http://www.bullfrogpower.com/index.cfm, May 30, 2013.
[5] *eGRID2012 Version 1.0 Year 2009 Summary Tables*, EPA, April 2012
http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012V1_0_year09_SummaryTables.pdf

5.3 NPV Calculation

The 30-year cost/benefit Net Present Value (NPV) calculation was performed for the following eight cases:

A) Pilot Project - Actual: this case represents the actual NPV for the pilot project. The revenue from power production and loss reduction was estimated and neither the benefit of smart grid nor renewable energy was considered.

B) Pilot Project - Smart Grid: this case represents the NPV for the pilot project when the smart grid benefit is considered.

C) Pilot Project - Renewable: this case represents the NPV for the pilot project when the renewable energy benefit is considered.

D) Pilot Project - Smart Grid and Renewable: this case represents the NPV for the pilot project when both the smart grid and renewable energy benefits are considered.

E) Future PSMs: this case represents the NPV for future PSM installations, with the estimated future installation cost of $1,071 for a 300W PSM, or $3.57/W.

F) Future PSMs - Smart Grid: this case represents the NPV for future PSM installations when the smart grid benefit is considered.

G) Future PSMs - Renewable: this case represents the NPV for future PSM installations when the renewable energy benefit is considered.

H) Future PSMs - Smart Grid and Renewable: this case represents the NPV for future PSM installations when both the smart grid and renewable energy benefits are considered.

The following assumptions were used in the NPV calculations for all cases:

- The discount rate used was 6.09%[6]
- NPV is calculated in 2012 Canadian dollars.
- The installation costs are described in Section 5.1.1.
- The maintenance costs are described in Section 5.1.2.
- The energy production, losses, and revenue received for energy produced by the PSMs is described in Section 5.2.1.
- The added benefit of the smart grid functionality is described in Section 5.2.2.
- The added benefit of the renewable energy produced by the PSMs is described in Section 5.2.3.

[6] The Regulated Rate of Return from Halton Hills Hydro's 2012 COS Rate Application

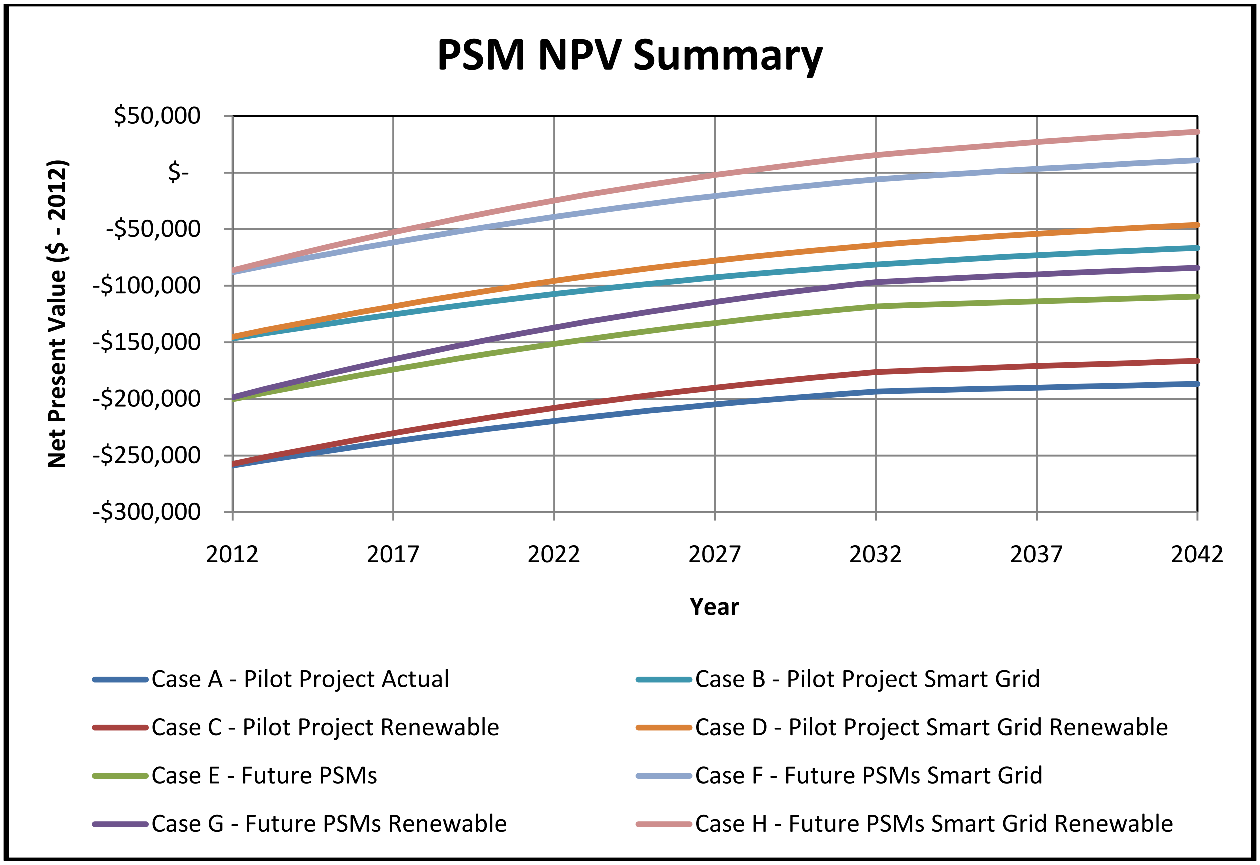

Figure 3: 30-year Cost/Benefit NPV Summary

Figure 3 shows the results of the NPV calculations for the eight cases. The results indicate that the Distribution Solar System Integration pilot project will not be revenue-positive, even when considering the added benefits of smart grid and renewable energy. Table 3 shows a summary of the 30-year NPV for the pilot project both with and without the benefits of smart grid and renewable energy.

Table 3: Pilot Project NPV Summary

Cost/Benefit Scenario	NPV (2012 $)
Smart Grid and Renewable Benefits	-$46,186
Renewable Benefits (no smart grid benefit)	-$166,474
Smart Grid Benefits (no renewable benefit)	-$66,474
Actual Benefits (no smart grid or renewable benefit)	-$186,762

However, due to the predicted increase in energy output and decrease in installation costs, future PSM installations are predicted to have a positive NPV. Table 4 shows a summary of the 30-year NPV for the future PSM installations, both with and without the benefits of smart grid and renewable energy.

Table 4: Future PSM NPV Summary

Cost/Benefit Scenario	NPV (2012 $)
Smart Grid and Renewable Benefits	$36,174
Renewable Benefits (no smart grid benefit)	-$84,114
Smart Grid Benefits (no renewable benefit)	$10,814
Actual Benefits (no smart grid or renewable benefit)	-$109,474

When the benefit of smart grid is considered, future PSM installations are expected to break even in 24 years and provide a modest positive value of approximately $11,000 over 30-years. When the added benefit of renewable energy is also considered, future PSM installations are expected to break even in approximately 16 years and a positive NPV of approximately $36,000 over 30 years is predicted.

It is important to note that the NPV analysis is dependent on the data used in the calculations and the results can change significantly when variables such as capital costs, maintenance, and energy prices are changed.

5.3.1 Break Even Cost Calculations

Additional NPV calculations were performed to find the necessary installation costs, in $/W, for a PSM installation to be revenue neutral over 30 years for four different scenarios:

1. Actual: the only financial benefit considered was the expected reduction in 5-year average net "wholesale" kWh delivered to the distributor, valued at $0.0964/kWh in 2012 and increasing by $0.0036/kWh annually.

2. Smart Grid: in addition to the financial benefit considered in 1, the benefit of the smart grid functionality was added. This was valued at $112,200 in 2012 with annual maintenance costs of $3,600 per year after year 20.

3. Renewable: in addition to the financial benefit considered in 1, the benefit of the renewable nature of the energy produced by the PSMs was added. This was valued at $0.03/kWh.

4. Smart Grid and Renewable: in addition to the financial benefit considered in 1, the benefits of smart grid and renewable energy were added. They were valued per 2 and 3 above.

These "break even" costs represent the maximum installation cost per Watt required for the PSMs to be financially profitable. Table 5 shows the calculated break even costs.

Table 5: Break Even Costs

Cost/Benefit Scenario	Cost
Smart Grid and Renewable Benefits	$4.17
Renewable Benefits (no smart grid benefit)	$2.17
Smart Grid Benefits (no renewable benefit)	$3.75
Actual Benefits (no smart grid or renewable benefit)	$1.75

Without considering the added benefits of renewable energy or smart grid functionality, the maximum installation cost per Watt required for the PSMs to be financially profitable was found to be $1.75/W. In contrast, when the benefits of both smart grid and renewable energy are considered, this cost was found to be $4.17/W.

6.0 SAFETY

The PSM installations are not expected to have a significant impact on safety, either positive or negative. The PSMs are unlikely to reduce safety hazards, nor should they pose any additional risk to utility staff or the general public because they are certified to UL1741/IEEE 1547.1 and have been inspected and approved by the Ontario Electrical Safety Authority (ESA). However, it is strongly recommended that all utility safe-work practices, including checking for voltage and the application of safety grounds, are followed at all times.

There currently is some concern in the utility industry around the anti-islanding protections associated with certified inverters. It is uncertain whether all inverter anti-islanding protections will be effective when other inverter and/or non-inverter generation is operating on the same circuit. Because of this, some utilities are currently limiting the distributed generator penetration. For example, Hydro One is currently limiting the penetration of MicroFIT generators to 7% and 10% of peak feeder loading on F- and M-class feeders respectively[7]. It is likely that future PSM installations will be restricted by this Hydro One limit.

It is recommended that Halton Hills Hydro confirm the effectiveness of the PSM anti-islanding protections for multiple PSM installations connected in close proximity to one another before installing large numbers of PSMs. It is also recommended that Halton Hills Hydro works with Hydro One to ensure that Hydro One is aware of the PSM installations.

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[7] Wrathall, Cress, Tsimberg, *Technical Review of Hydro One's Anti-Islanding Criteria for MicroFIT PV Generators*, Kinectrics Inc K-418086-RA-001-R00, November 22, 2011

7.0 CONCLUSIONS

The following are the significant finding of this study:

1. The PSM measurements are sufficiently accurate for practical utility engineering applications, such as reliability assessment, voltage regulation analysis, losses studies, fault detection, and general troubleshooting.

2. The PSMs do not currently measure harmonics or flicker.

3. The benefits associated with the PSMs can be grouped into three categories: Power Production and Losses, Smart Grid, and Renewable Energy.

    a. Power Production and Losses - the PSMs installed in the pilot project have an estimated annual output of 46,214 kWh and will reduce Halton Hills Hydro's (HHH) Distribution Loss Factor by 0.01%, from 102.53% to 102.52%. The expected loss reduction would be approximately 0.02% per 100 kW of installed PSMs. This reduction in losses will benefit HHH's customers. Because PSM generation typically coincides with peak loading (daytime hours), a reduction in peak losses would be expected.

    b. Smart Grid - PSMs provide the following smart grid benefits:
        i. The measurements and alerts provided by the PSMs will allow HHH to detect and respond to outages faster, which will have a positive effect on HHH's reliability statistics.
        ii. The voltage measurements provided by the PSMs have allowed HHH to diagnose over- and under-voltage problems on their feeders. These problems would most likely have gone undetected had the PSMs not been installed. Additionally, future PSM models will have the capability to measure harmonics and flicker, providing HHH additional tools to detect and troubleshoot power quality problems.

    c. Renewable Energy – the PV solar power produced by the PSMs has a positive environmental benefit and, because the PSMs are highly visible, will add to Halton Hills Hydro's reputation as an environmentally conscious organization. The energy output from the Distribution System Solar Integration pilot project is estimated to offset approximately 26 metric tons of equivalent carbon emissions annually. This is equivalent to 0.58 metric tons per installed kW.

4. The Net Present Value (NPV) analysis resulted in the following conclusions:

    a. Although the pilot project will not provide a net positive value when all costs and benefits are considered, future PSM installations, because of decreasing equipment costs, are expected to provide a net positive value when the benefit of smart grid is considered. The 30-year NPV of the pilot project and future PSM installations, with and without the added benefit of smart grid and renewable energy, are summarized in Table 6. This table also shows the number of years required for the PSM installations to achieve neutral value for each scenario.

Table 6: Pilot Project and Future PSM 30-Year Cost/Benefit NPV Summary

Cost/Benefit Scenario	Pilot Project		Future PSMs	
	NPV (2012 $)	Years to Break Even	NPV (2012 $)	Years to Break Even
Smart Grid and Renewable Benefits	-$46,186	>30	$36,174	16
Renewable Benefits (no smart grid benefit)	-$166,474	>30	-$84,114	>30
Smart Grid Benefits (no renewable benefit)	-$66,474	>30	$10,814	24
Actual Benefits (no smart grid or renewable benefit)	-$186,762	>30	-$109,474	>30

b. The maximum total installation costs per Watt required for a PSM installation to achieve a neutral net present value after 30 years was calculated for each scenario. When the actual installation costs are less than these "break even" costs, PSM installations will provide a net positive value within a 30-year time period.
   i. When only the benefits associated with energy production and loss reduction are considered, the break even cost was calculated to be $1.75/W.
   ii. When the benefit of the smart grid functionality is also considered, the break even cost was $3.75/W.
   iii. Similarly, when the benefits of energy production and loss reduction are considered with the value of renewable energy, the break even cost was found to be $2.17/W.
   iv. Finally, when all benefits are considered together, the break even cost was $4.17/W.
   v. For comparison, the costs associated with the pilot project were $5.76/W and the expected cost for PSM installations in 2014 is $3.57/W.

c. The NPV analysis indicates that, of the three primary benefits associated with the PSMs (energy and loss reduction, smart grid, and renewable energy), the smart grid features provide the greatest benefit to HHH.

8.0 RECOMMENDATIONS

Based on the results of this study, Kinectrics recommends the following:

1. Provided the costs and power densities of future PSMs are less than $3.75/W, as they are predicted to be, HHH may wish to consider expanding the PSM program up to the point where the smart grid benefits are maximized. The maximum smart grid benefit would be achieved by having one PSM connected to each phase of each circuit. The installation of more than one PSM unit on one phase of a given circuit will not provide additional smart grid benefits and therefore would not be cost effective.

2. HHH should install the new versions of the PSM, once available, to take advantage of the additional smart grid features, such as improved power quality monitoring and automated alerts. If technically possible and cost-effective, existing PSM units should also be upgraded with this functionality.

3. Should the total installation price for PSM installations fall below $1.75/W, HHH should consider installing PSM units beyond the point where the maximum smart grid benefit is achieved. When the installation price is below this level, the PSMs will provide a direct financial benefit to HHH's customers.

4. It is recommended that Halton Hills Hydro confirm the effectiveness of the PSM anti-islanding protections for multiple PSM installations connected in close proximity to one another before installing large numbers of PSMs. It is also recommended that Halton Hills Hydro work with Hydro One to ensure that Hydro One is aware of the PSM installations.

Smart Energy Module Measurements rev. 1

For Halton Hills Hydro *April 24, 2013*

Kinectrics Project: K-418480

Overview

The following is a summary of the results of *Part A: Measurement Validation* for Kinectrics project K-418480, *Smart Energy Module Validation*. Measurements were recorded at the AC outputs of two Smart Energy Modules (SEMs) and the data were compared to the measurements reported by the SEMs through the IntelliView system. The two SEMs measured were SN236121109P012 and SN236121109P014, on poles 706 and 3362 respectively.

Measurements

Kinectrics' measurements were recorded using a calibrated Fluke 435 Power Quality Analyzer (Fluke). Measurements were recorded every second on two different days; the SEM at pole 706 was measured over a three-hour period on February 21, 2013 and the SEM at pole 3362 was measured over a six-hour period on April 17, 2013. The following quantities were measured: frequency, RMS voltage, RMS current, active power, reactive power, energy, voltage THD, current THD, and voltage flicker (P_{st} and P_{lt}).

Measurements from the SEMs were reported at approximately 15-minute intervals. The following quantities reported by the SEMs were available in the IntelliView System: frequency, RMS voltage, RMS current, active power, reactive power, and energy. SEM measurements for voltage THD, current THD, and flicker could not be found in the IntelliView system and were therefore not compared against the Fluke measurements.

Time-Synchronization

The measurement time stamps of the SEMs and the Fluke were not synchronized. Synchronization of the data was performed by maximizing the sum of the correlations of the voltage and frequency measurements between the SEMs and the Fluke.

Results

Table 7 shows a summary of the measurement comparison. It shows the average magnitudes and percentages of the errors between the SEM and Fluke measurements for each measured quantity.

Charts showing the measurement comparisons of each quantity for the two SEMs, including the accuracy range of the Fluke 435 Power Quality Analyzer, can be found in the Appendix.

Table 7: Measurement analysis summary

Smart Energy Module (SEM) Measurement Analysis					
Quantity	Unit	Pole 706 SEM		Pole 3362 SEM	
		Average Error Magnitude	Average % Error Magnitude	Average Error Magnitude	Average % Error Magnitude
Frequency	Hz	0.01	0.02%	0.01	0.02%
Voltage	V	0.13	0.11%	0.50	0.41%
Current	A	0.01	1.68%	0.01	0.89%
Active Power	W	2.50	7.04%	3.11	1.50%
Reactive Power	VAR	1.67	0.50%	8.12	36.33%
Energy	Wh	3.43	2.03%	4.90	1.45%

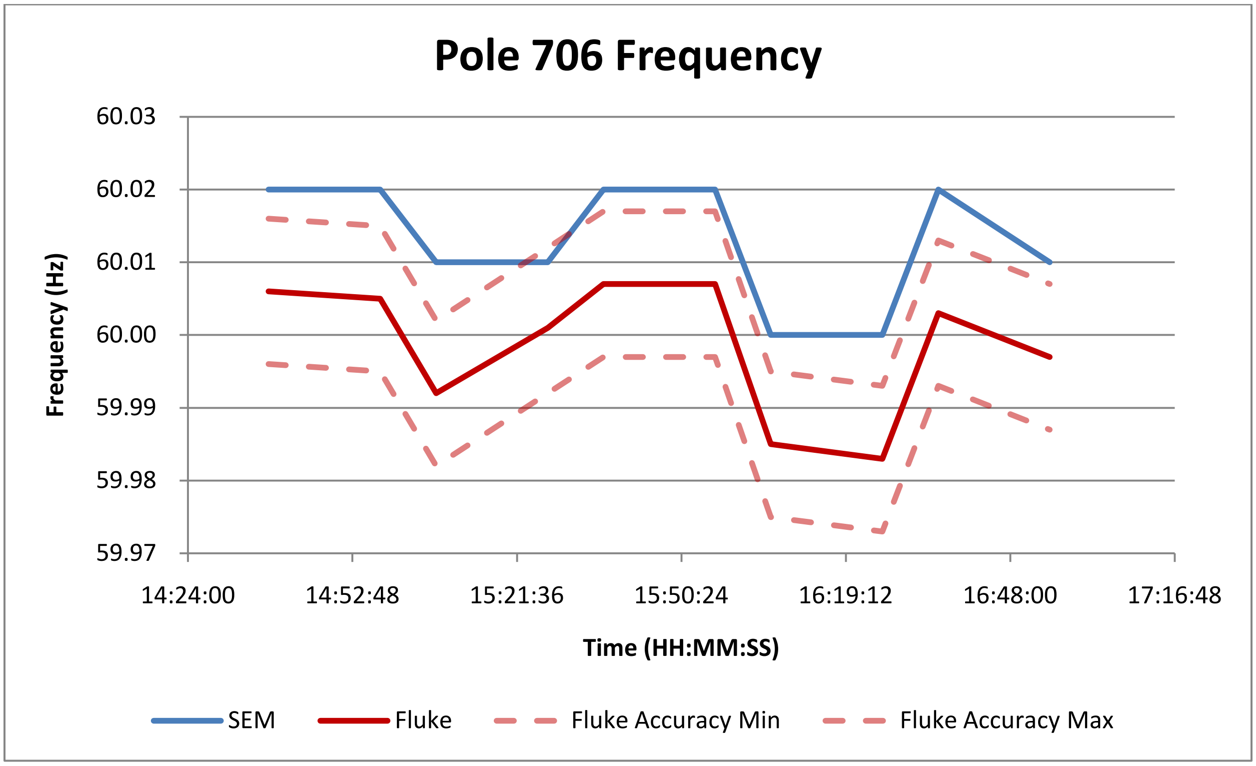
Conclusions

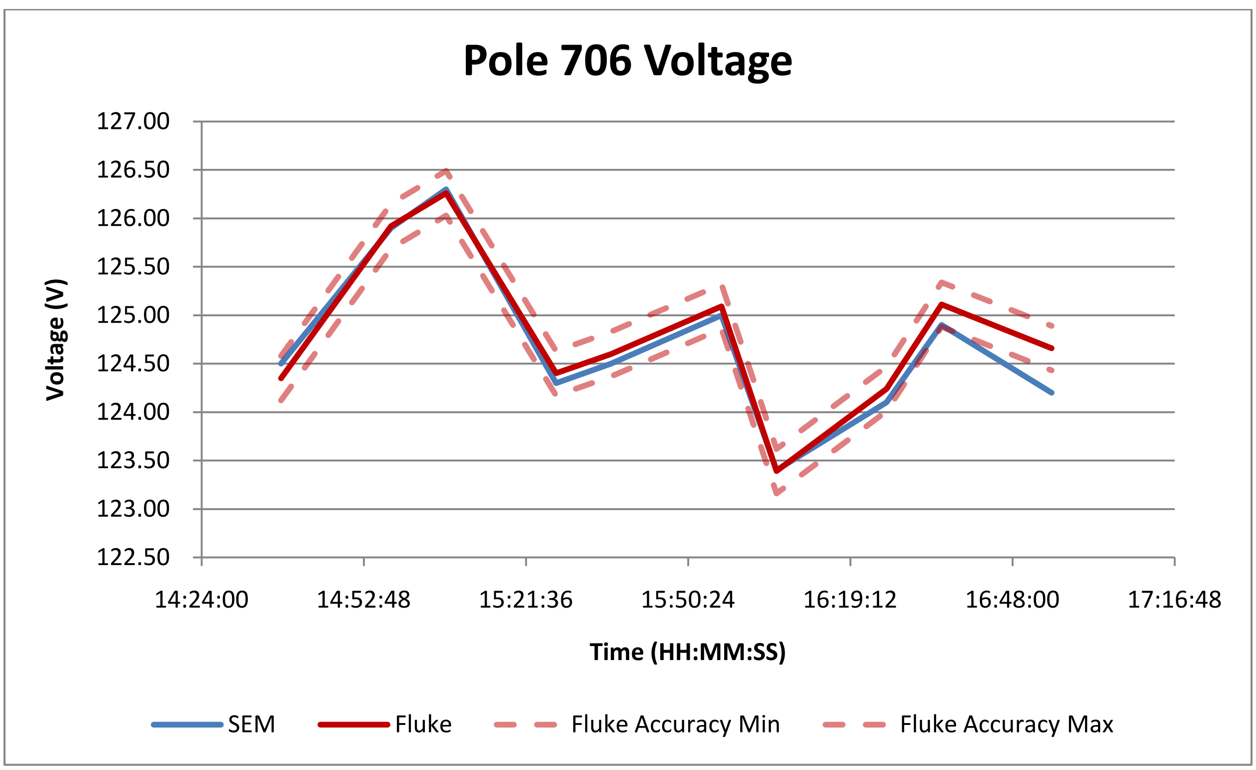
1. The measurements recorded by the SEMs are sufficiently accurate for practical applications, including: reliability assessment, voltage regulation analysis, losses studies, fault detection, and general troubleshooting.
2. The measurements recorded by the SEMs may not be sufficiently accurate to be used as a substitute for field or laboratory measurements with calibrated instruments. However, the practical applications for which the SEM measurements would typically be used by a utility do not generally require highly accurate measurements.
3. SEM harmonic and flicker measurements were not available in the IntelliView system and could not be compared with the Fluke measurements. The availability of harmonic and flicker measurements should be confirmed during Part B.

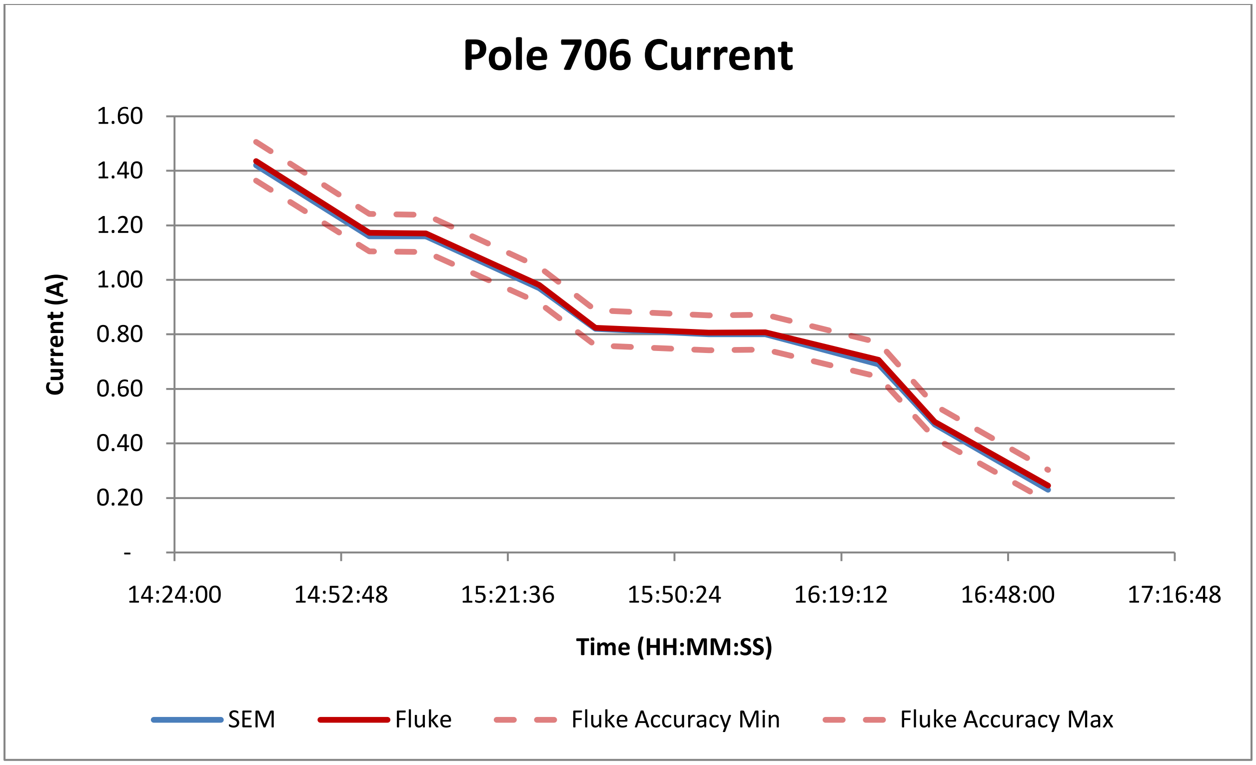
Recommendations

1. The measurement data recorded by the SEMs was found to be sufficiently accurate for practical applications, including Part B of this project. Therefore, it is recommended that Part B – Cost/Benefit Analysis proceed.
2. A SEM should be tested in a controlled laboratory environment to determine the accuracy of the active power, reactive power, and energy measurements under controlled conditions. Moreover, laboratory testing can also verify the SEM's various operating, protection, and maximum power point tracking (MPPT) functions, if required.
3. The availability of harmonic and flicker measurements should be confirmed during Part B.

Appendix : Measurement Figures



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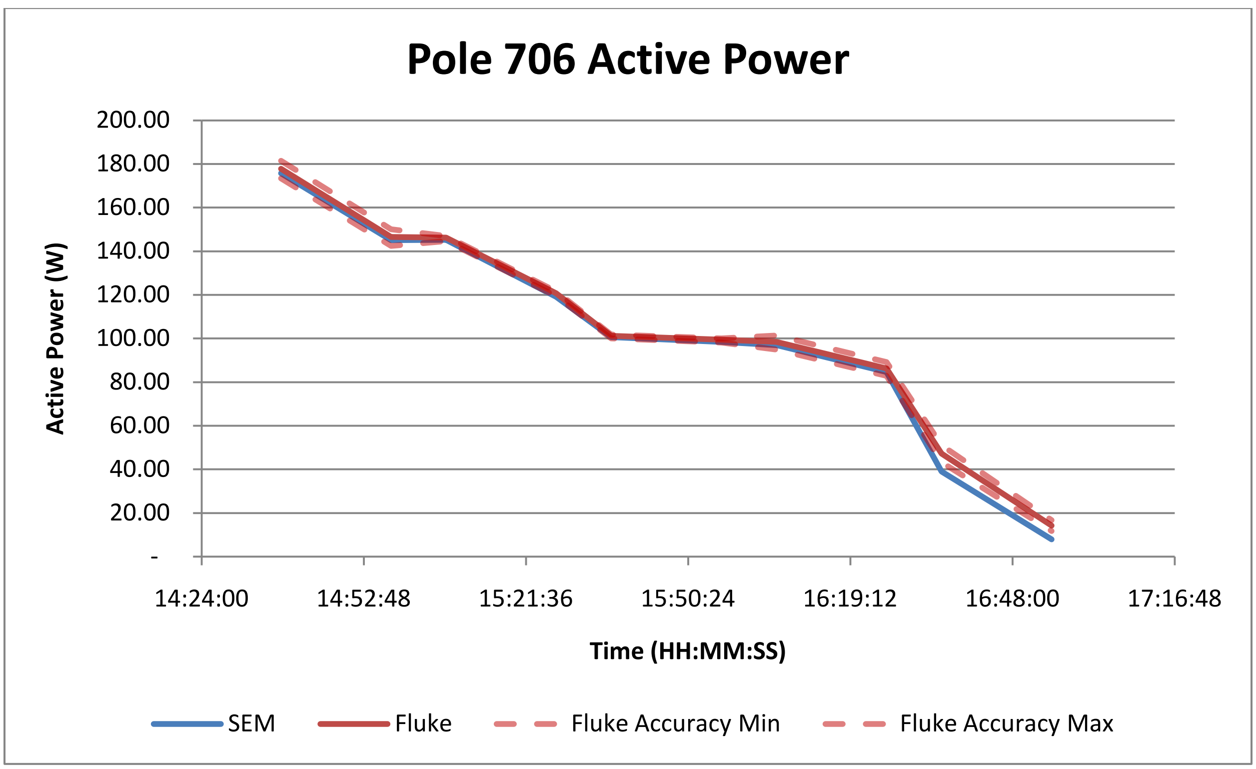
1.40
1.20
1.00
0.80
0.60
0.40
0.20
-
Current (A)
14:24:00
14:52:48
15:21:36
15:50:24
16:19:12
16:48:00
17:16:48
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Min
Fluke Accuracy Max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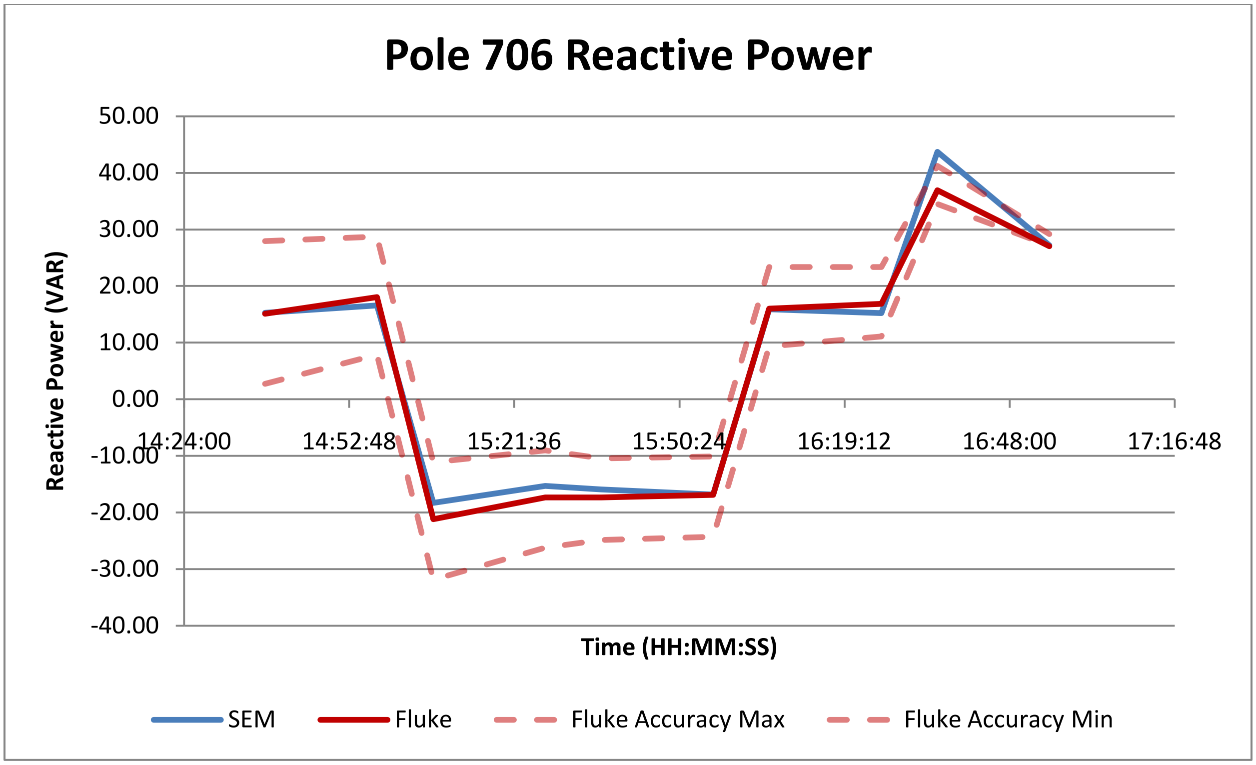
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
-
Active Power (W)
14:24:00
14:52:48
15:21:36
15:50:24
16:19:12
16:48:00
17:16:48
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Min
Fluke Accuracy Max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40.00
30.00
20.00
10.00
0.00
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-20.00
-30.00
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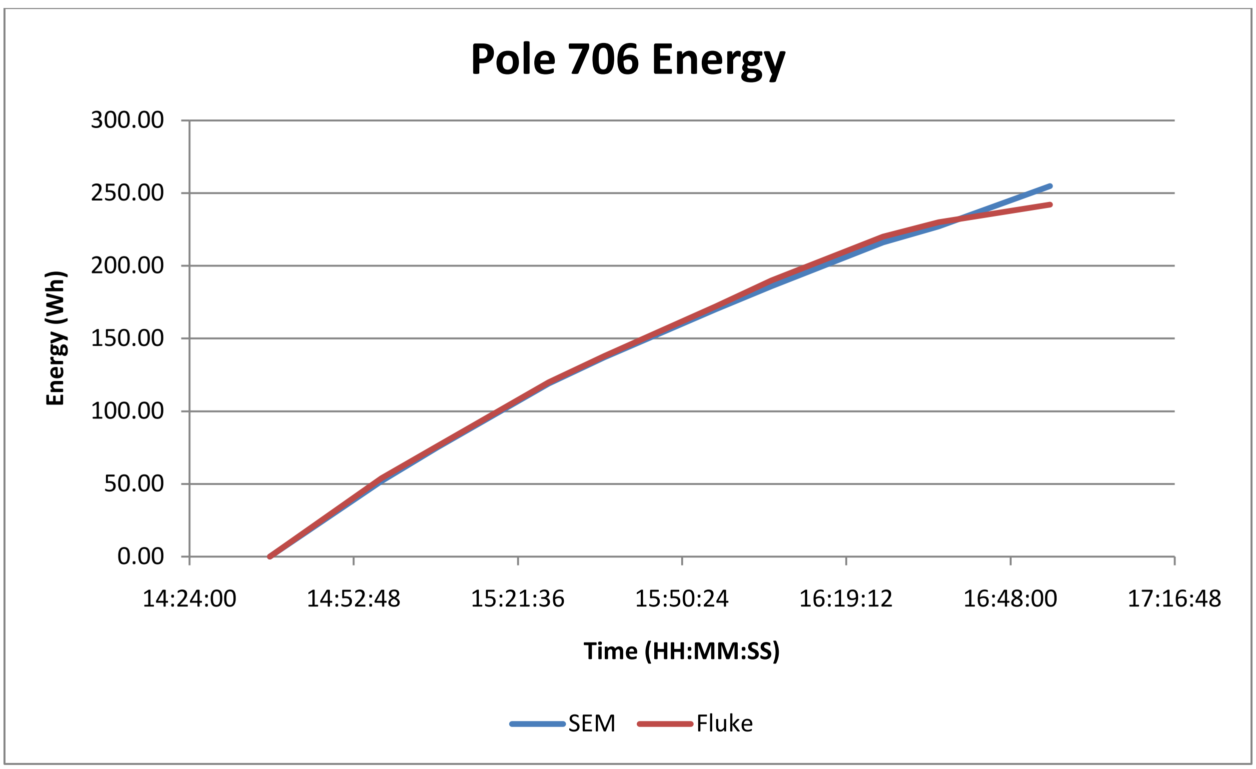
14:52:48
15:21:36
15:50:24
16:19:12
16:48:00
17:16:48
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Max
Fluke Accuracy Min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250.00
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150.00
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0.00
Energy (Wh)
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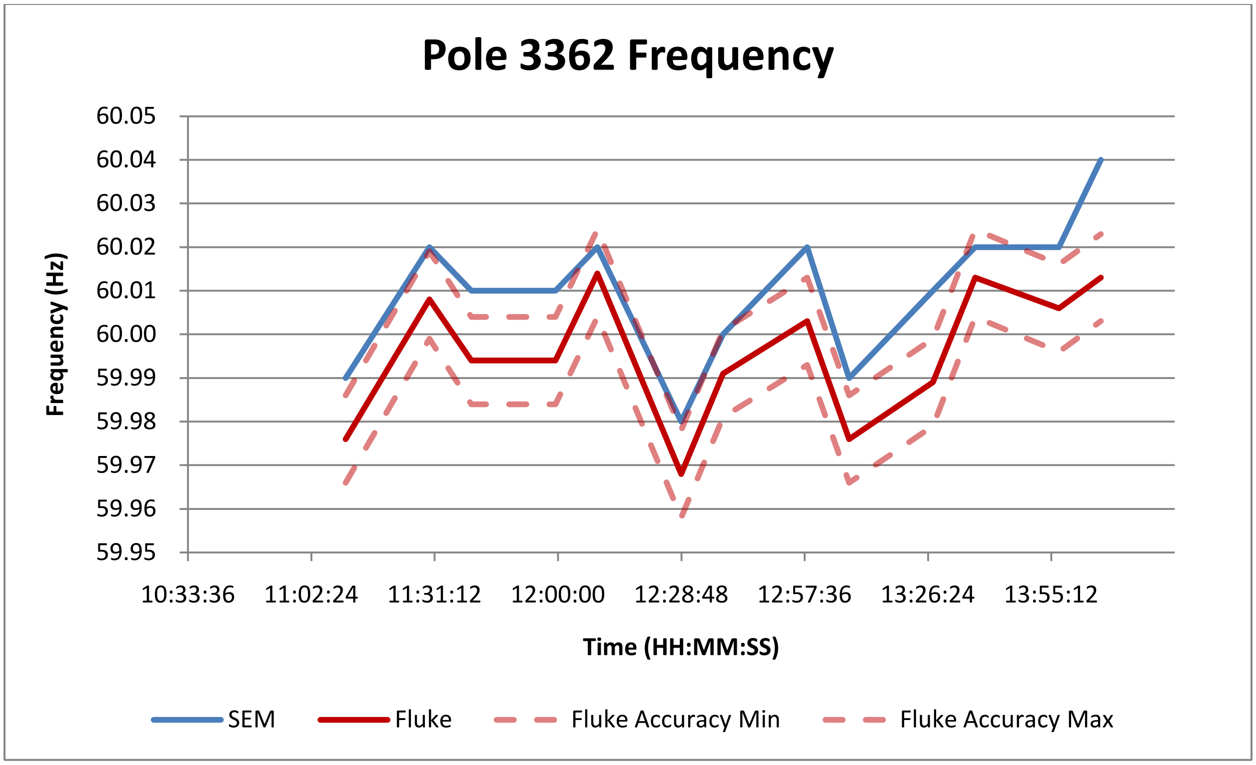
Time (HH:MM:SS)
SEM
Fluke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Frequency (Hz)
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59.95
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12:00:00
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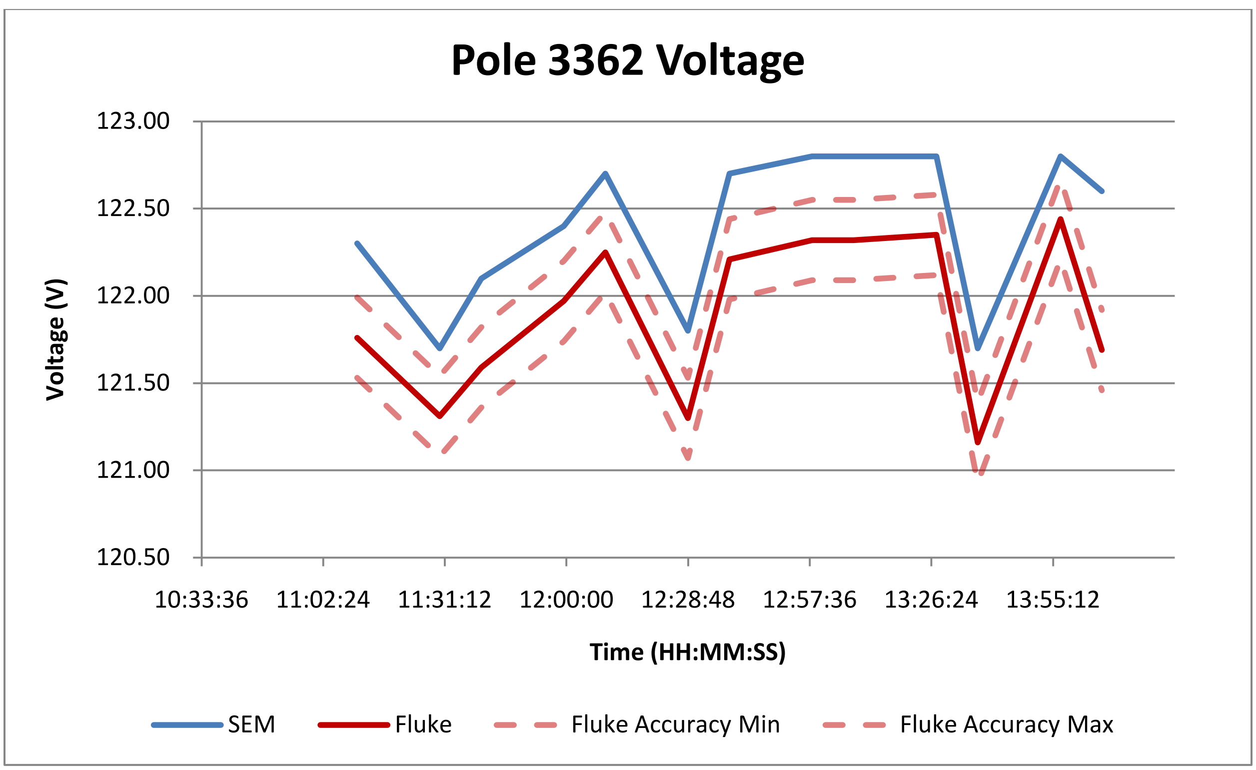
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Min
Fluke Accuracy Max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121.00
120.50
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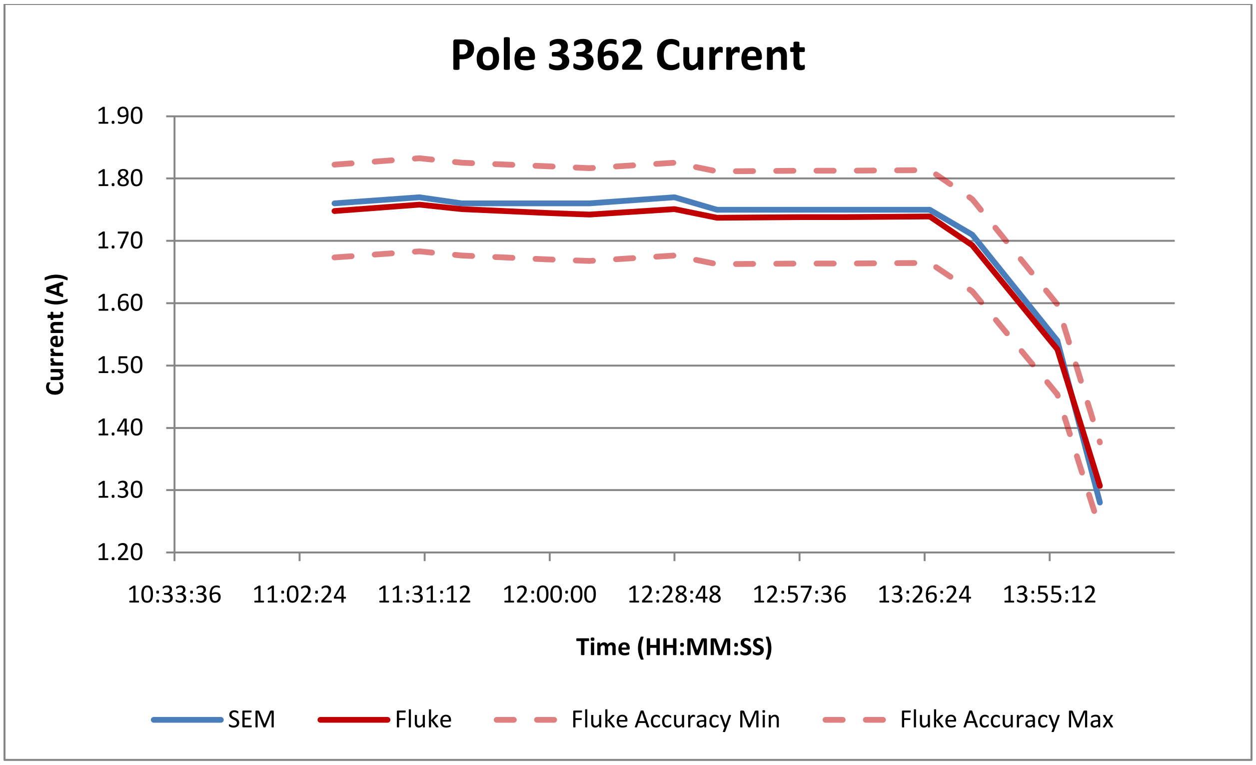
12:00:00
12:28:48
12:57:36
13:26:24
13:55:12
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Min
Fluke Accuracy Max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1.30
1.20
Current (A)
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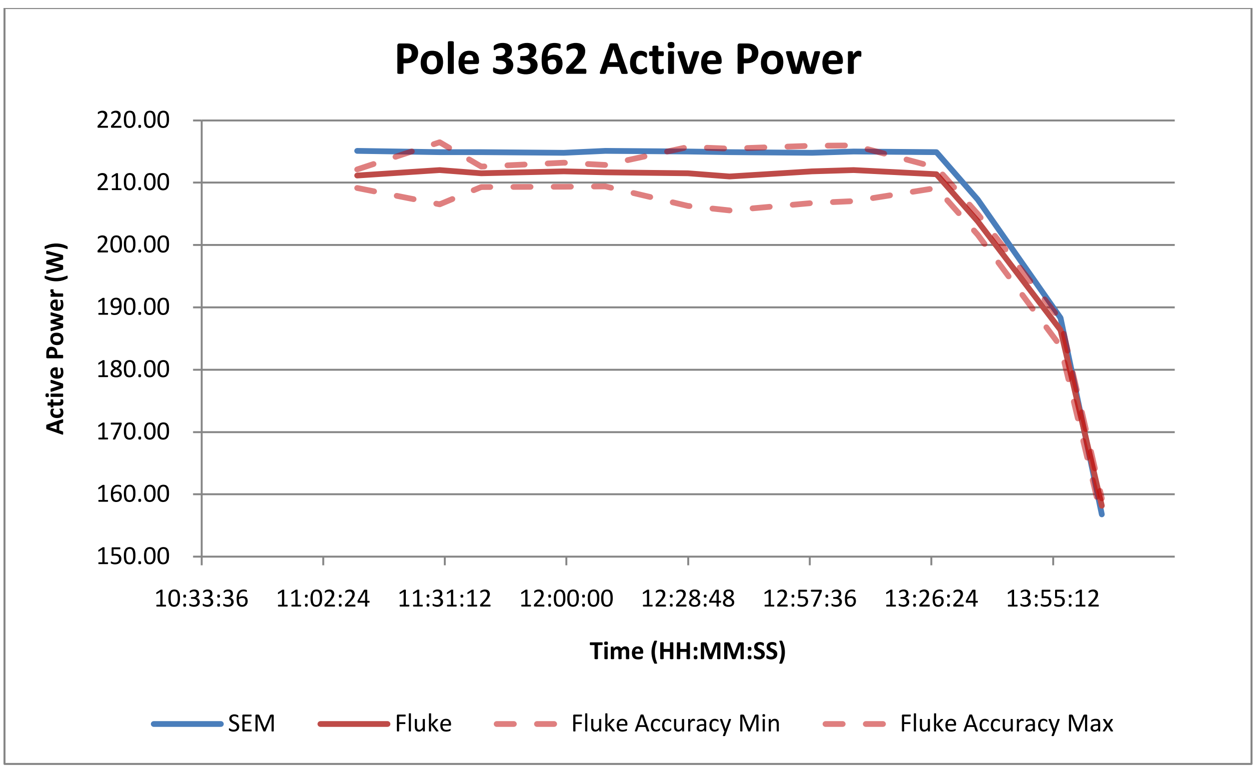
12:00:00
12:28:48
12:57:36
13:26:24
13:55:12
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Min
Fluke Accuracy Max


Pole 3362 Active Power
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210.00
200.00
190.00
180.00
170.00
160.00
150.00
Active Power (W)
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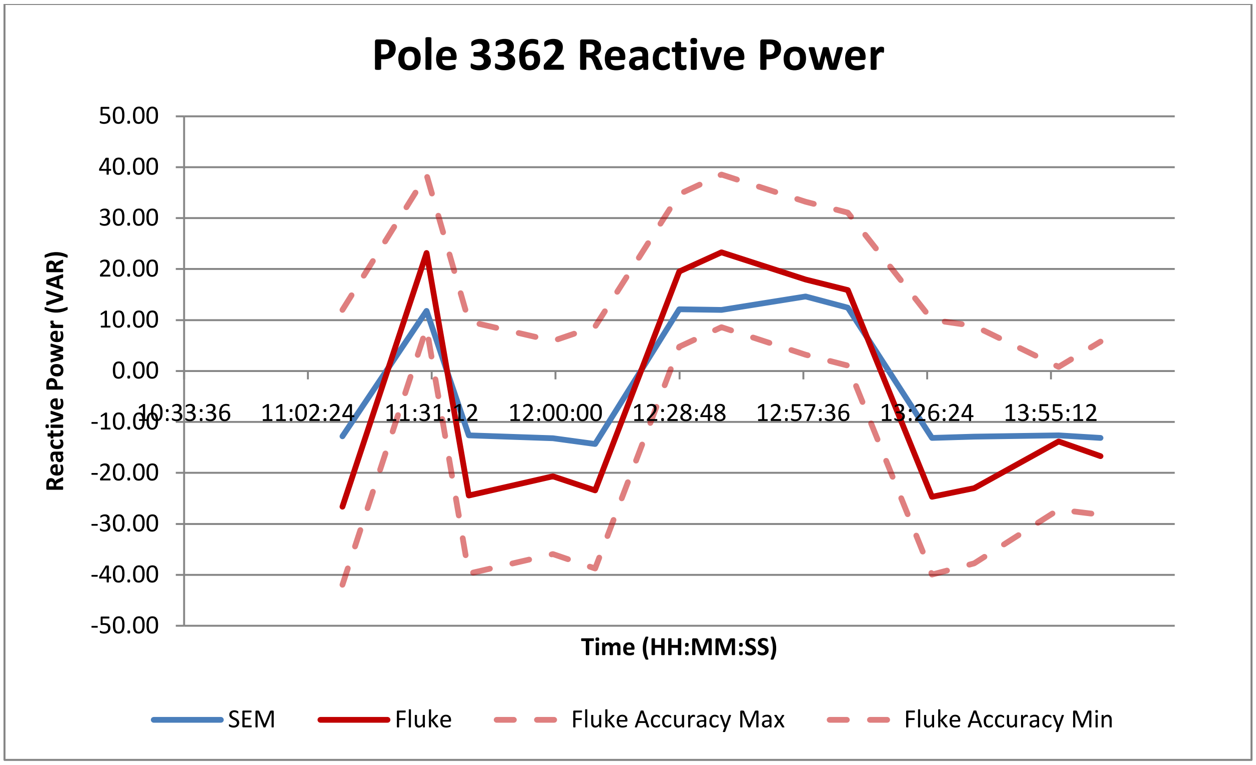
12:00:00
12:28:48
12:57:36
13:26:24
13:55:12
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Min
Fluke Accuracy Max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40.00
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Reactive Power (VAR)
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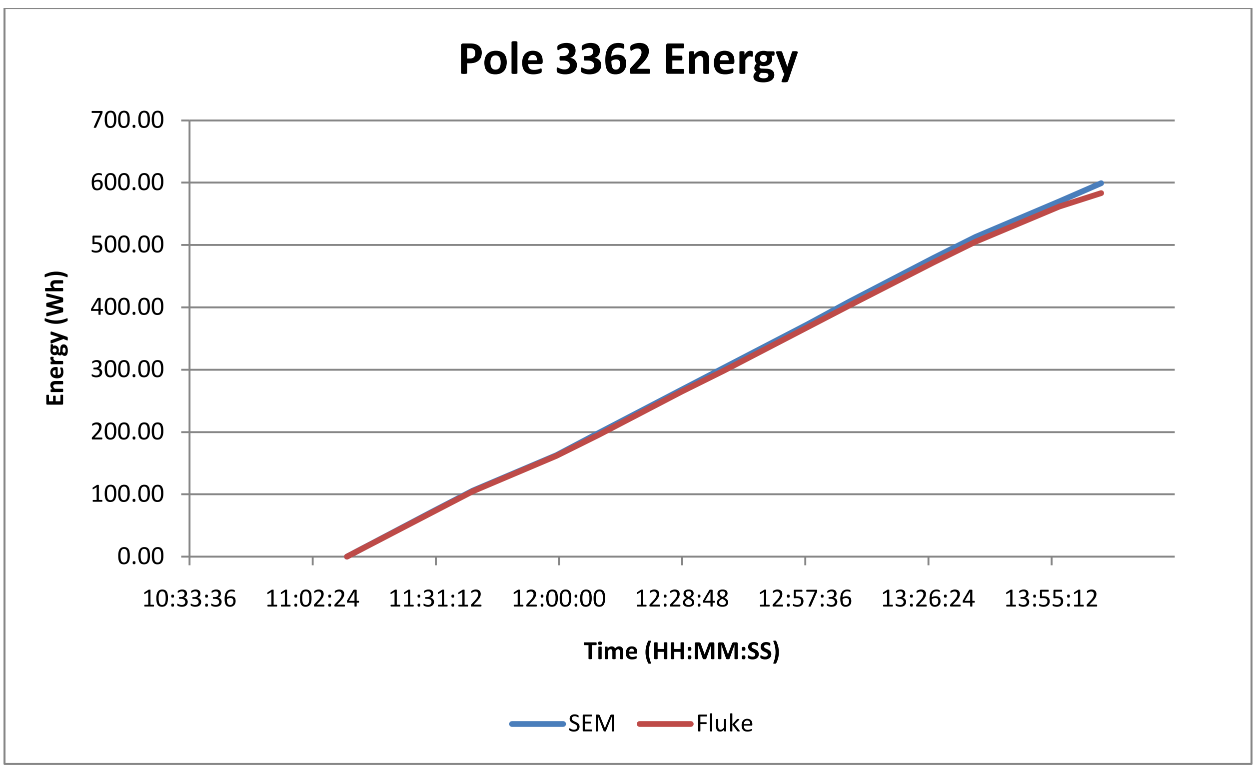
12:00:00
12:28:48
12:57:36
13:26:24
13:55:12
Time (HH:MM:SS)
SEM
Fluke
Fluke Accuracy Max
Fluke Accuracy Min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400.00
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200.00
100.00
0.00
Energy (Wh)
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11:31:12
12:00:00
12:28:48
12:57:36
13:26:24
13:55:12
Time (HH:MM:SS)
SEM
Fluke