Photovoltaic (PV) Impact Analysis

A Sample Case Study

Electrical Distribution Design
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Table of Contents

List of Figure

Introduction

PV Impact Analysis studies can provide utilities with information needed to address new dynamics occurring on the distribution grid as a result of increasing size and adoption levels of solar generation. Two sample studies presented here, performed on representative utility company feeders (Midat_1 and Midat_2), investigate potential impact scenarios to the distribution grid due to the introduction of photovoltaic generation (PV generation). To show the impact, the analysis performed considers the following:

- Compare the impact on customer voltage before and after PV installation
- Compare the impact on customer voltage using two different sources of time varying PV data, data provided from an available regional data center (ARDC) and data from the National Renewable Energy Lab (NREL)
- Compare the impact on customer voltages using PV control strategies that adjust the inverter operating power factor.

An additional study assessing customer voltage levels is presented here on a heavily loaded feeder, Midat_3, which does not contain any PV generation.

For the PV analysis performed for Midat_1 and Midat_2 feeders, six curves are presented in this sample report[1]. The six curves presented for each PV impact study are:

- Two curves showing impacts on customer level voltage as a function of PV generation inverter power factor, one curve based upon available regional data center solar data, and the other curve based upon National Renewable Energy Lab solar data
- Four curves showing PV generator output (two curves for each PV site, where one curve uses available regional data center data and the other curve uses National Renewable Lab data).

Also for each PV impact study a circuit schematic is presented that illustrates the extent of reverse power flow at peak solar generation.

Case Studies

Feeders analyzed are Midat_1, Midat_2, and Midat_3. The Midat_1 feeder has two 855 kW PV sites and one 1300 kW PV site. The Midat_2 feeder has one 475 kW PV site and one 1000 kW PV site. The Midat_3 circuit does not have any PV sites, but is a heavily loaded feeder. A single loading condition was provided for each of the three feeders. For the Midat_2 feeder the native load on the feeder (part of model interface provided by the client) was used. In cases where the maximum voltage fluctuations due to loss of PV generation were calculated, the rated values of the PV generators were used.

For the Midat_1 feeder the native load on the feeder was modified by power factor and current measurements taken at the substation so that the power flow results matched the measurements

[1] ***For the actual client study, additional data was presented in supporting documentation.***

(with no PV generation). The loads on the Midat_1 feeder were then held constant so that all PV generation cases analyzed used the same loading condition. The Midat_1 feeder measurements provided were 543.6 amps and a power factor of 0.971 lagging for each phase.

For the Midat_3 feeder the native load on the feeder was modified by using current measurements taken at the substation so that the power flow results matched the current measurements. The Midat_3 measurements provided were 681.0 amps per phase.

There are two ways to attach PV measurements in DEW. One is to attach the PV measurements using an interface to a database containing the measured PV output. In the analysis performed here the database was used to interface normalized available regional data center (ARDC) solar generation measurements. The generation used in the analysis was obtained by using the normalized ARDC solar data to scale each individual PV generator rating according to the time point being analyzed. The ARDC solar data used came from the July 2010 data set provided by the client where the solar generation measurement sample time was one minute.

The other approach to interfacing PV generation measurements in DEW is to use an interface to the National Renewable Energy Lab (NREL). This interface allows users to download time varying solar generation data from NREL, where the solar generation data downloaded is a function of such parameters as the geographical location and the size of the PV generator. From the NREL interface time varying PV generation estimates were obtained for each PV generator for July.

To show the impact of PV, the customer voltage before introduction of the PV generation into the feeder was calculated to establish a baseline condition. The studies then compared the effects of various PV power factor control strategies, where inverter operating power factors analyzed came from the set { -0.90, -0.95, 1.0, 0.95, 0.90 }. The unity power factor (1.0) case supplies only real power to the circuit from the PV. The lagging power factor (0.9, 0.95) case supplies real and reactive power to the circuit from the PV. The leading power factor case (-0.90,-.95) supplies real but consumes reactive power.

Results

A summary of the analysis results for each of the three feeders is presented in this section. More detailed results from the analyses were provided in supporting documentation to the client. Included in the supporting documentation were:

- Graphical models of the three feeders along with calculated results at selected points along each feeder.
- Detailed results from the analysis of the Midat_1 and Midat_2 feeders, both using time varying solar data from the National Renewable Energy Lab and the normalized time varying solar measurements from the available regional data center.

Midat_1 Feeder Results

Figures 1 and 2 illustrate the effect that the different PV control strategies have on the customer voltage at the closest automatic line equipment (voltage regulator) in the Midat_1 feeder. Figure 1 shows analysis results where the ARDC solar data is used, and Figure 2 shows analysis results where the NREL solar data is used. Since there is only a single load condition modeled, the customer voltage is constant across time for the No PV case. The results show that inverter lagging and unity power factor control raise the customer voltage, and that inverter leading power factor control results in a decreasing customer voltage. From Figures 1 and 2 it may be observed that the NREL and ARDC time varying solar generation data sets provide similar results.

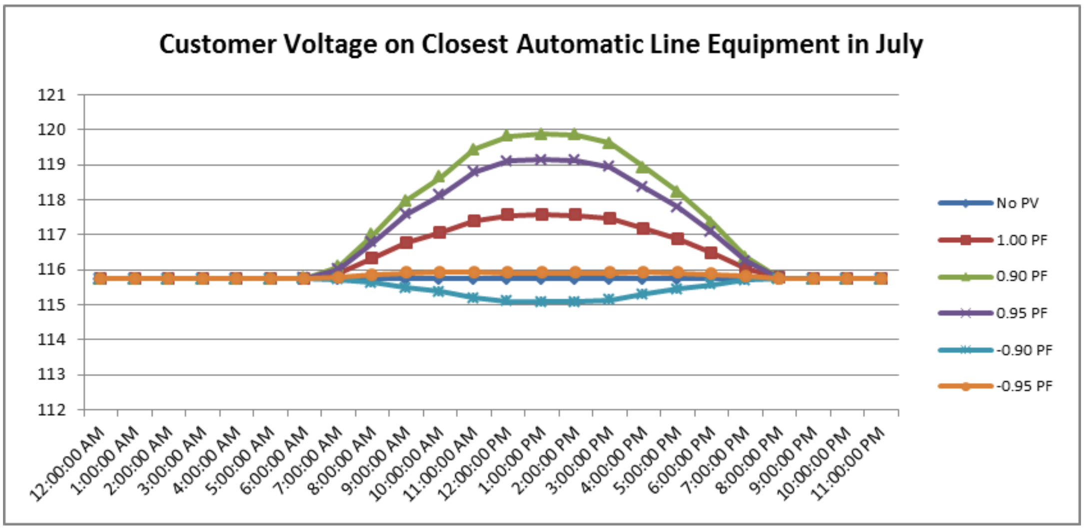

Figure 1: Customer Voltage on Closest Automatic Line Equipment in July for Midat_1 Feeder, ARDC case

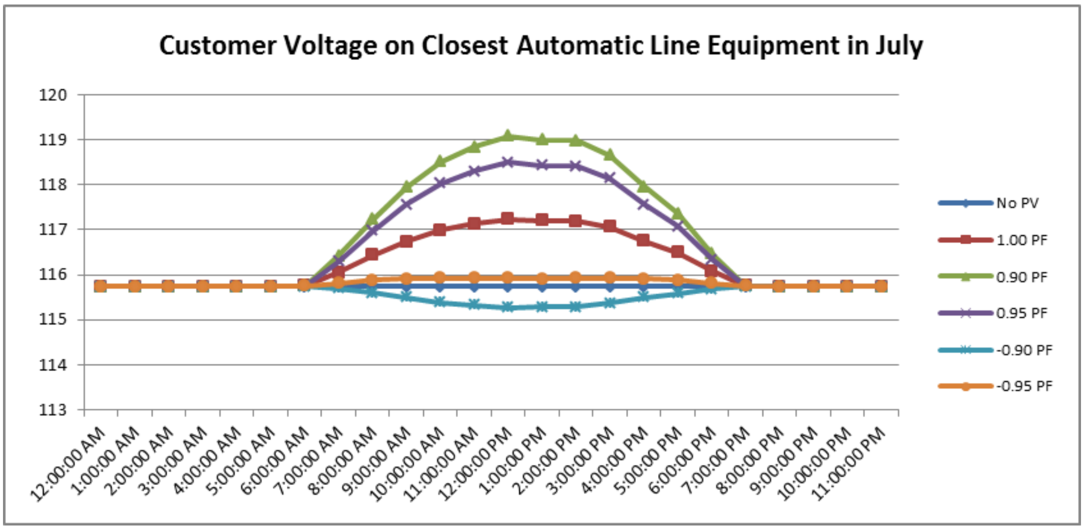

Figure 2: Customer Voltage on Closest Automatic Line Equipment in July for Midat_1 Feeder, NREL case

Figures 3 and 4 show the phase A generation for the Midat_1 PV sites based upon the available regional data center data.

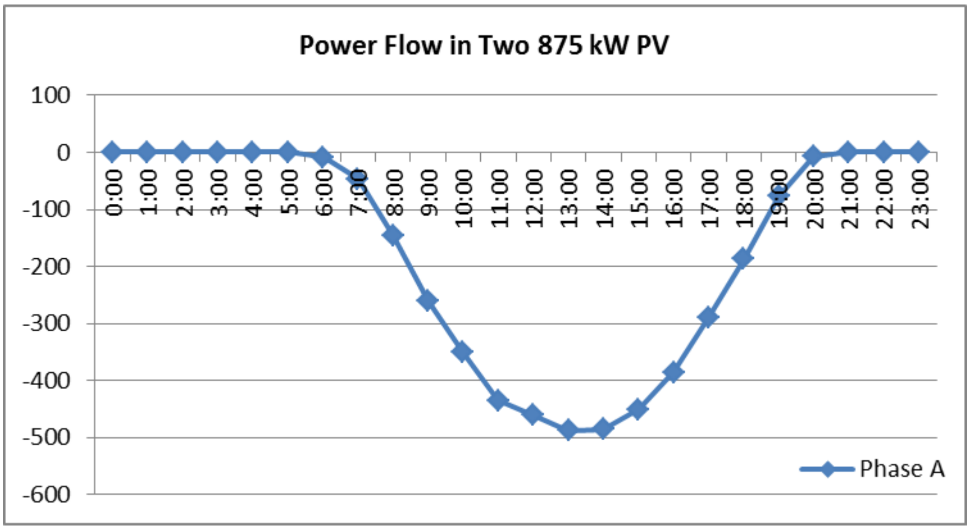

Figure 3: PV Generation (kW) from Two 875 kW PV Generators in July for Midat_1 Feeder, ARDC case

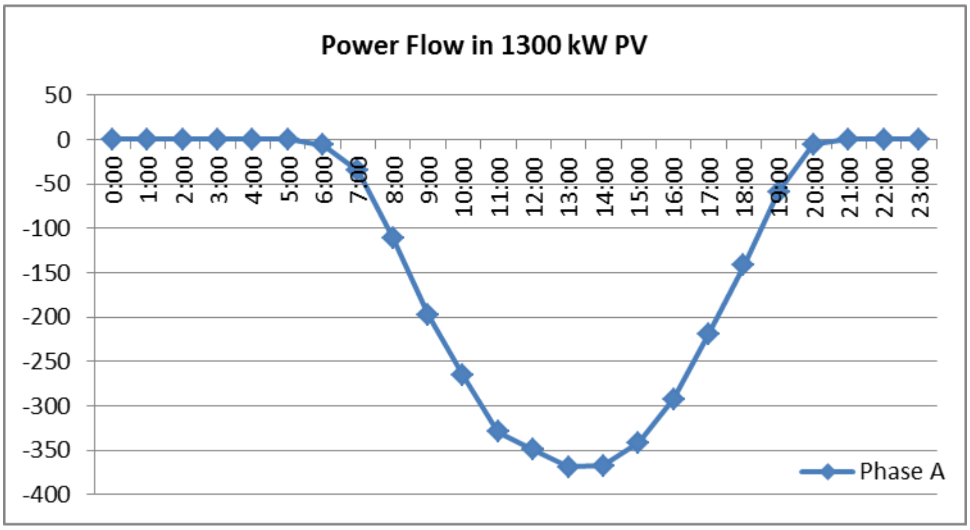

Figure 4: PV Generation (kW) from 1300 kW PV Generator in July for Midat_1 Feeder, ARDC case

Figures 5 and 6 show the phase A generation for the Midat_1 PV sites based upon the National Renewable Energy Lab data.

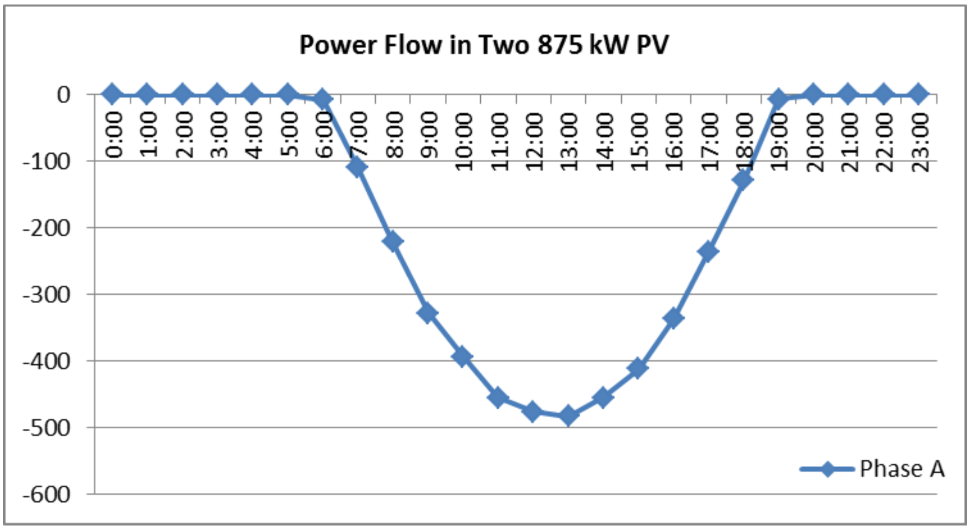

Figure 5: PV Generation (kW) from Two 875 kW PV Generators in July for Midat_1 Feeder, NREL case

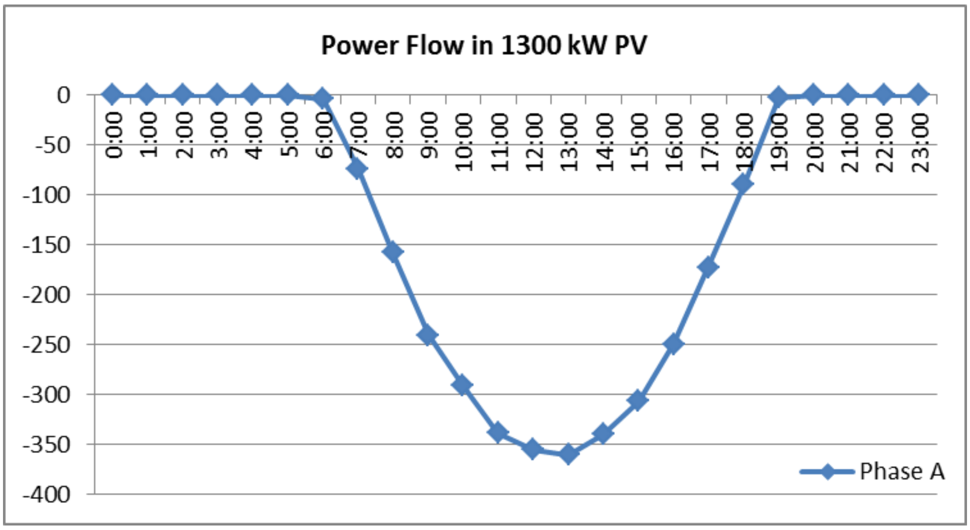

Figure 6: PV Generation (kW) from 1300 kW PV Generator in July for Midat_1 Feeder, NREL case

Comparing Figure 3 with Figure 5 shows the predicted generation from the two different data sets is very similar for the generation from the two 875 kW PV generators. Likewise, comparing Figure 4 with Figure 6 shows the generation predicted from the two different data sets is very similar for the 1300 kV site.

Figure 7 illustrates the portion of the feeder experiencing reverse power flow (shown in red) predicted for the Midat_1 feeder at peak solar generation based upon the available regional data center solar data.

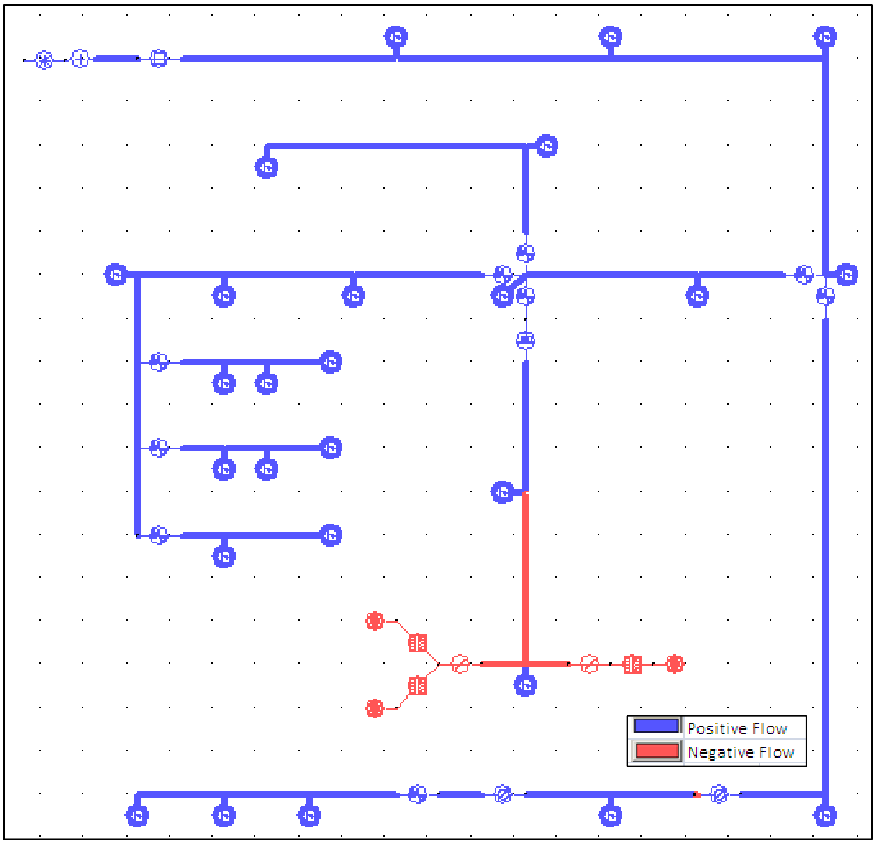

Figure 7: Portion of Midat_1 Feeder (with Reverse Power Flow in Red) for July at Peak Solar Generation

Midat_2 Feeder Results

Similar to the Midat_1 feeder, Figures 8 and 9 show the effect of the time varying solar generation on the customer voltage at the closest automatic line equipment (switched capacitor) in the Midat_2 feeder. Figure 8 shows analysis results where the ARDC solar data is used, and Figure 9 shows analysis results where the NREL solar data is used. Since there is only a single load condition modeled, the customer voltage is constant across time for the No PV case. The results show that inverter lagging and unity power factor control raise the customer voltage, and that inverter leading power factor control results in a decreasing customer voltage. From Figures 8 and 9 it may be observed that the NREL and ARDC time varying solar generation data sets provide similar results.

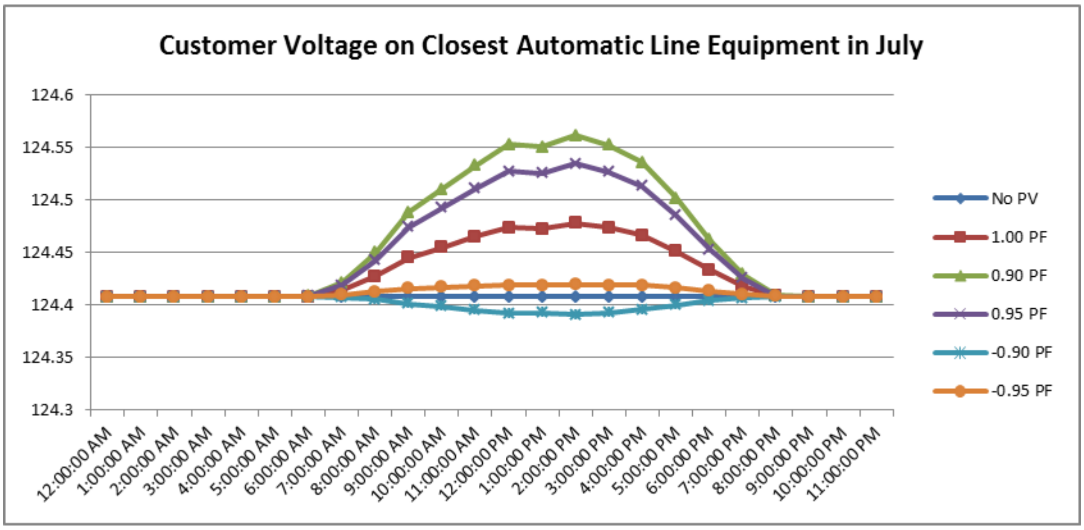

Figure 8: Customer Voltage on Closest Automatic Line Equipment in July for Midat_2 Feeder, ARDC case

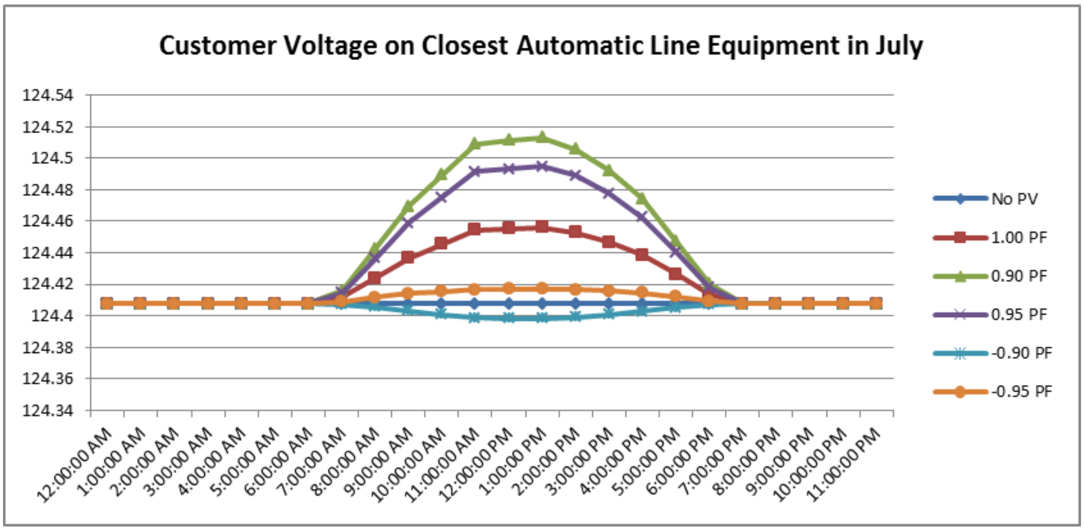

Figure 9: Customer Voltage on Closest Automatic Line Equipment in July for Midat_2 Feeder, NREL case

Figures 10 and 11 show the phase A generation for the Midat_2 PV sites based upon the available regional data center data.

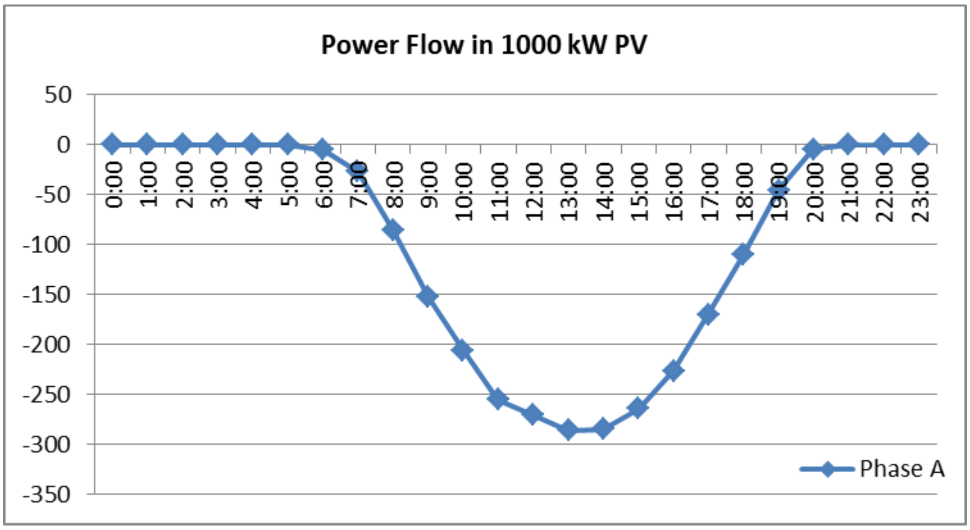

Figure 10: Power Flow (kW) from 1000 kW PV Generator in July for Midat_2 Feeder, ARDC case

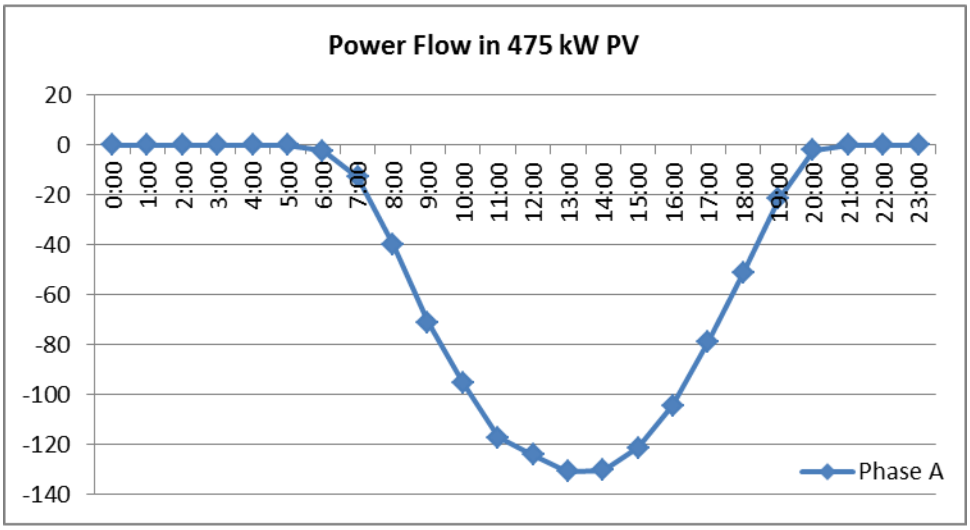

Figure 11: Power Flow (kW) from 475 kW PV Generator for Midat_2 Feeder, ARDC case

Figures 12 and 13 show the phase A generation for the Midat_2 PV sites based upon the National Renewable Energy Lab data.

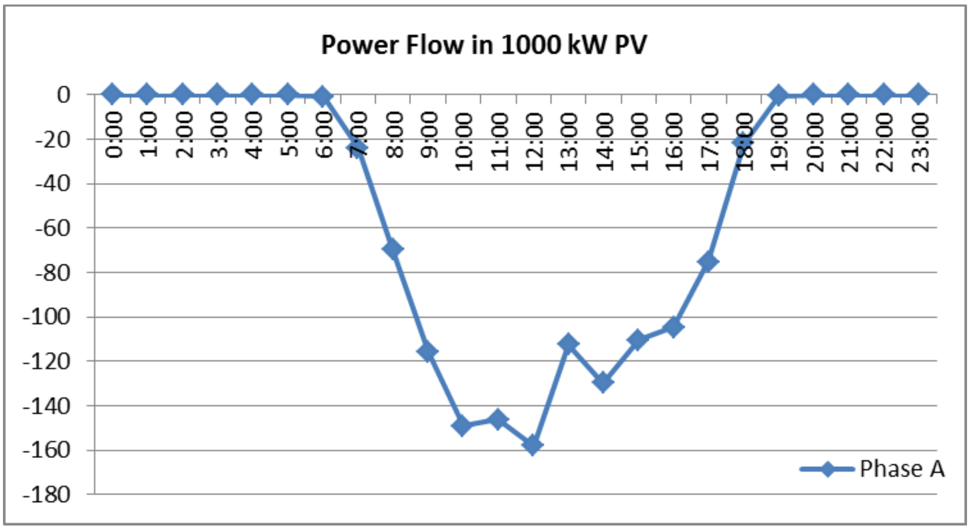

Figure 12: Power Flow (kW) from 1000 kW PV Generator in July for Midat_2 Feeder, NREL case

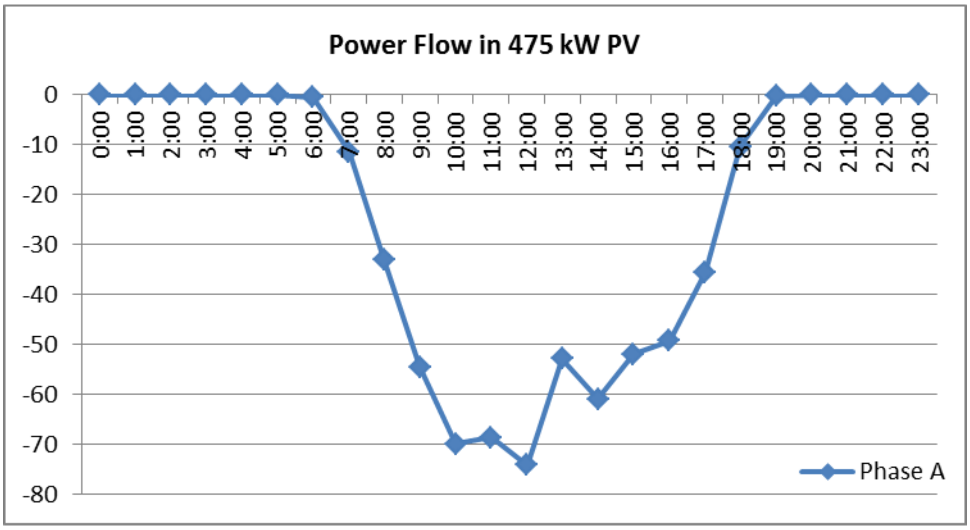

Figure 13: Power Flow (kW) from 475 kW PV Generator for Midat_2 Feeder, NREL case

Comparing Figure 10 with Figure 12 shows the generation predicted by the NREL data is significantly less than that predicted by the ARDC data for the 1000 kW PV site. Likewise, comparing Figure 11 with Figure 13 shows the generation predicted by the NREL data is significantly less than that predicted by the ARDC data.

Figure 14 illustrates the portion of the feeder experiencing reverse power flow (shown in red) predicted for the Midat_2 feeder at peak solar generation based upon the available regional data center solar data.

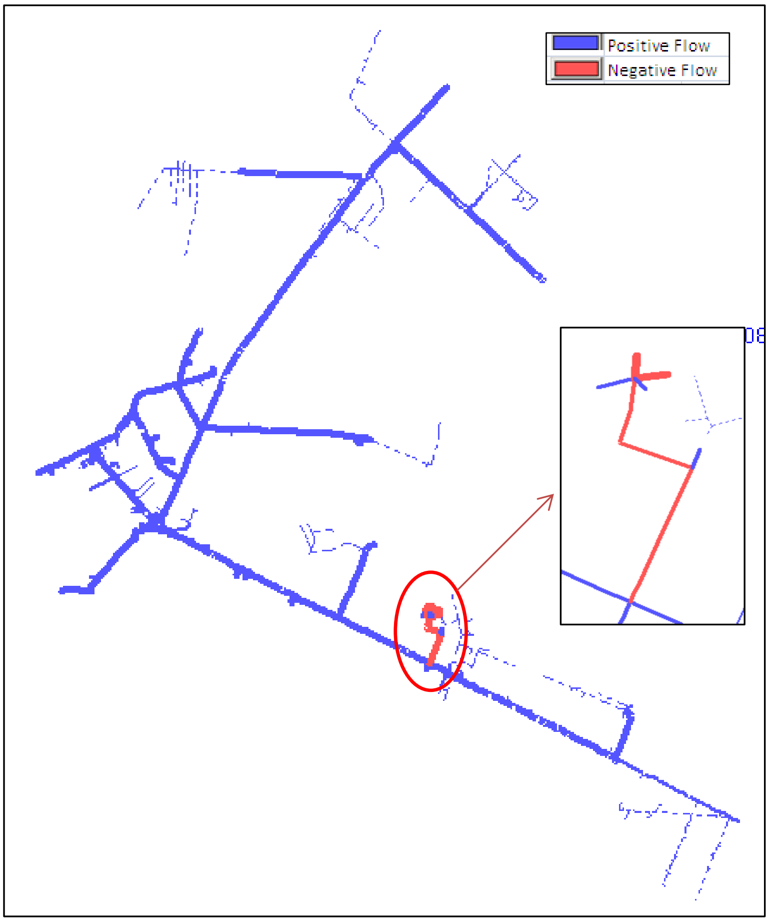

Figure 14: Portion of Midat_2 Feeder (with Reverse Power Flow in Red) for July at Peak Solar Generation

Midat_3 Feeder Results

Customer level voltages of approximately 111 volts were calculated for the Midat_3 feeder. Detailed analysis results and plots of customer level voltage versus distance were provided to client in supporting documentation, which included graphical depictions of the analyzed circuits showing specific locations for equipment of interest.

Conclusions and Recommendations

The customer voltage analysis results obtained from using the National Renewable Energy (NREL) Lab time varying solar generation data agreed fairly well with the results obtained from using the normalized time varying solar data from the available regional data center (ARDC). The NREL PV generation data agreed very closely with the ARDC PV generation data for the Midat_1 feeder, where as the NREL PV generation was significantly lower than the ARDC PV generation for the Midat_2 feeder.

For the Midat_2 feeder the maximum quasi-static voltage fluctuations were very small across all inverter control strategies.

For the Midat_1 feeder the maximum quasi-static voltage fluctuations were significant for inverter lagging power factors and also with a unity power factor, where at unity power factor the voltage fluctuation was 2.25 volts and at 0.9 lagging power factor the voltage fluctuation was 5.1 volts. The voltage fluctuation was smaller at leading power factors.

For the Midat_3 feeder low customer voltages were observed, with the lowest voltage being approximately 111 volts.

Only one loading condition was supplied for each of the three feeders analyzed in this study. Follow-up recommendations are that the analysis also be performed for at least minimum load conditions, and if possible, through the use of SCADA measurements, over a time varying load pattern. Also recommended was that protection and coordination be evaluated, especially for the feeder components that experience reverse power flow.