# PV Distribution Interconnection Study Analysis

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## Introduction

Deployment of distributed PV systems is increasing rapidly. High penetration scenarios, which are becoming increasingly common, have the potential to affect the distribution feeder equipment [1] and the operation of the distribution system in general. Interconnection study processes are developed to identify possible system impacts and, in the case of negative impacts, design mitigation alternatives [2]. In the majority of cases, system impacts can be ruled out or mitigation strategies can be identified without an involved study by using a screening process or a simple supplemental review study [3]. For proposed projects that require a closer evaluation, the existing methods, data, and simulation tools may not be adequate to fully characterize the potential system impacts. Enhanced system impact studies are required to identify the potential electrical impacts associated with the integration of PV on the distribution system [4, 5]. This report demonstrates how time series simulation and high time-resolution data can be used to assess the potential PV system impacts in a comprehensive manner.

## Interconnection Impact Studies

To examine the impact of PV on the distribution system, many different types of studies and analyses can be performed. Commercial circuit analysis tools have historically provided the capability to perform steady state power flows to analyze the distribution system at specific snapshots in time, but PV output is highly variable and the potential interaction with control systems may not be adequately analyzed with traditional snapshot tools and methods. Highly detailed and accurate interconnection impact studies require a time series simulation with large amounts of data. The time-resolution of the data must be high enough to show the interaction of the devices in the distribution system. Time series simulations require the availability of historical time series load data for the feeder and coincident solar irradiance data measurements for the same time period and location.

## Analysis Results

Many of the results and analyses from this section are presented in the Sandia report "Time Series Power Flow Analysis for Distributed Connected PV Generation" [6]. See the report for a full detailed discussion on performing PV interconnection studies and additional analysis examples.

Two interconnection analyses are shown here for the feeder in Figure 1. The feeder has a substation LTC with LDC and two switched capacitors. The substation transformer serves a total of four feeders, and the other three feeders were simulated as lumped loads. EPRI's open-source distribution system power flow solver OpenDSS was used for all analyses.

The first analysis investigates operations of voltage regulation equipment during a 9-month simulation with the central PV system connected at the furthest three-phase point on the feeder that could thermally support the PV plant. Coincident feeder load data and local high resolution irradiance measurements are used for the simulation. The hypothetical PV plant has a nominal capacity of 7.5 MVA output at unity PF, which is equal to 100% of feeder peak load. The simulation was run at 1-second resolution from January 1, 2011 through September 30, 2011. Table 1 shows a comparison of the base case and PV case with regard to LTC and switched capacitor operations for the 9-month simulation.

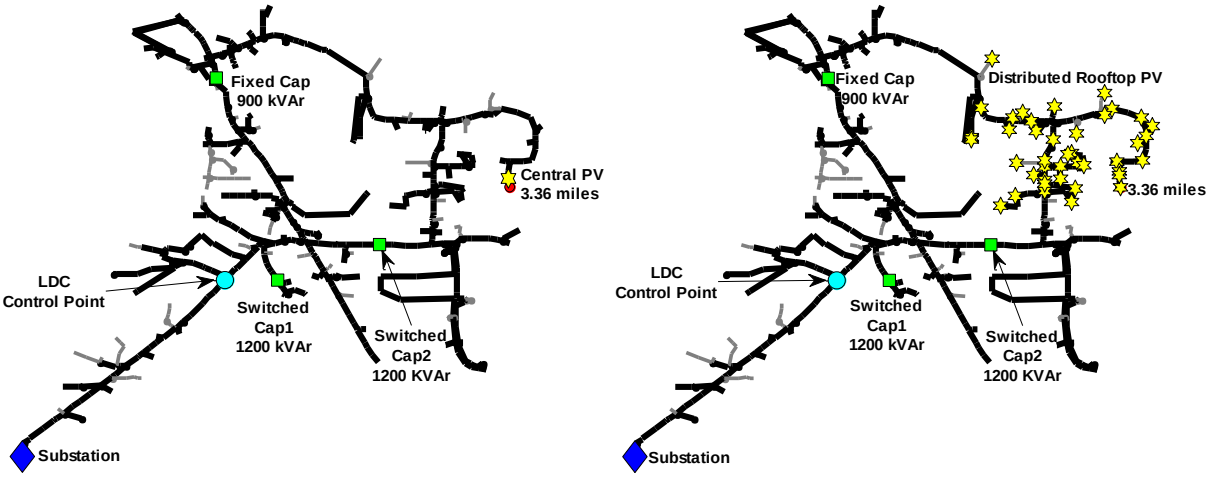


**Figure 1. Distribution feeder with one central plant or distributed rooftop PV**

**Table 1. Device Operation Comparisons, Base Case and PV case, 9-month Simulation.**

| Device | Operations Base Case | Operations With PV (Differential) | Percent Change |
|---|---|---|---|
| LTC | 459 | 394 (-65) | -14% |
| Cap 1 | 12 | 6 (-6) | -50% |
| Cap 2 | 16 | 28 (+12) | +75% |

The addition of PV resulted in a net reduction in operations observed over the 9 months for the LTC and Cap 1 (nearest the substation) and an increase in the operations for Cap 2. The substation LTC is a ±8 step device, unlike the more common ±16 step devices, which means that each tap change results in twice the voltage change per step and fewer operations. Figure 2 shows a column plot with the total LTC operations by month for the 9-month simulation of both the base case and PV case. The differences shown in Figure 2 highlight the periods where PV causes the greatest decrease in operations, which is during the summer months, and a small amount of additional operations, which occurs in the winter months.

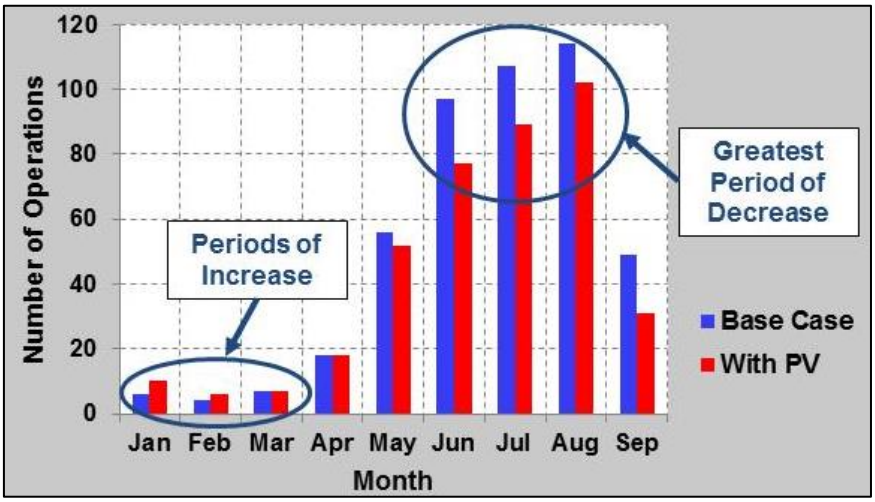


**Figure 2. LTC Operations by Month, Base Case and With PV, 9-Month Simulation**

Note that the distribution system is connected to a stiff 115 kV transmission system. This means the number of LTC operations will be lower than an LTC connected to either a weaker grid (low SCC) or a lower voltage. The LTC is connected to three additional distribution feeders, so a high penetration of PV on one feeder may not considerably affect the substation current or the number of LTC operations. PV variability can have a more significant impact on distribution system LTC's for a weaker grid when the substation voltage fluctuates more with changes to the load and when there are fewer feeders on the transformer.

The second example uses the distributed rooftop PV shown in Figure 1 to analyze the PV's impact to the distribution system voltages. The simulation was run for a week surrounding Saturday, April 23, 2011, at 1-second resolution. The total nominal output of the distributed rooftop PV is 7.5 MW, and each PV system is connected on the secondary system. Figure 3 shows the total aggregate power output of the distributed rooftop PV systems at the end of the feeder in comparison to the substation and feeder real power. A check for voltage issues was performed as part of the analysis to verify the highest and lowest voltage found at any location on

the feeder at each iteration. This allows for a thorough check to determine if further study is necessary and to identify the location of the highest and lowest voltages, both with and without PV. Figure 4 shows the plot of the highest and lowest voltages for the PV case during the study week.

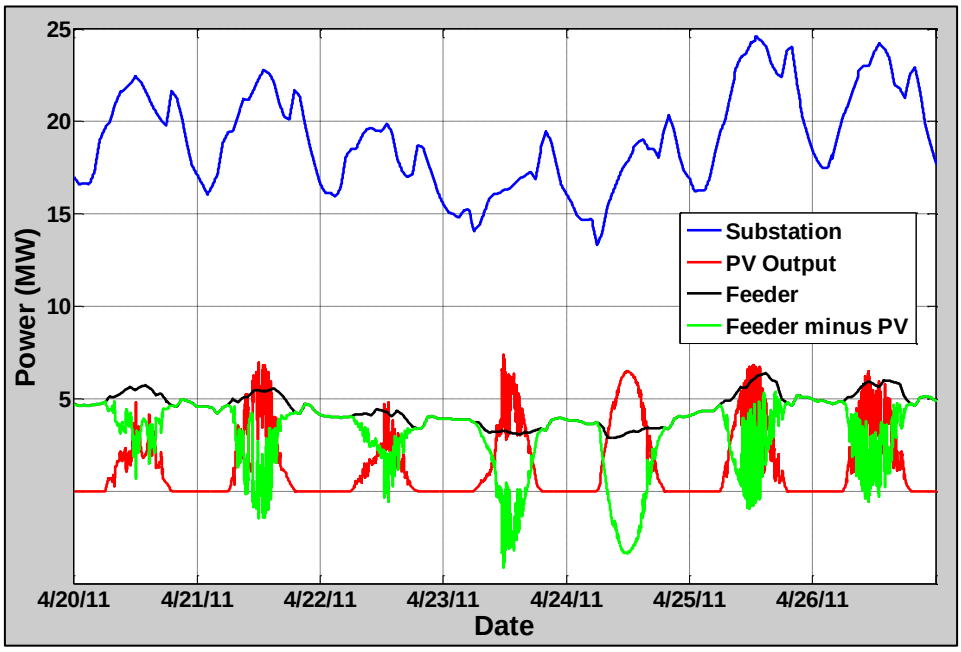


**Figure 3. Power profiles for April 20th through 26th**

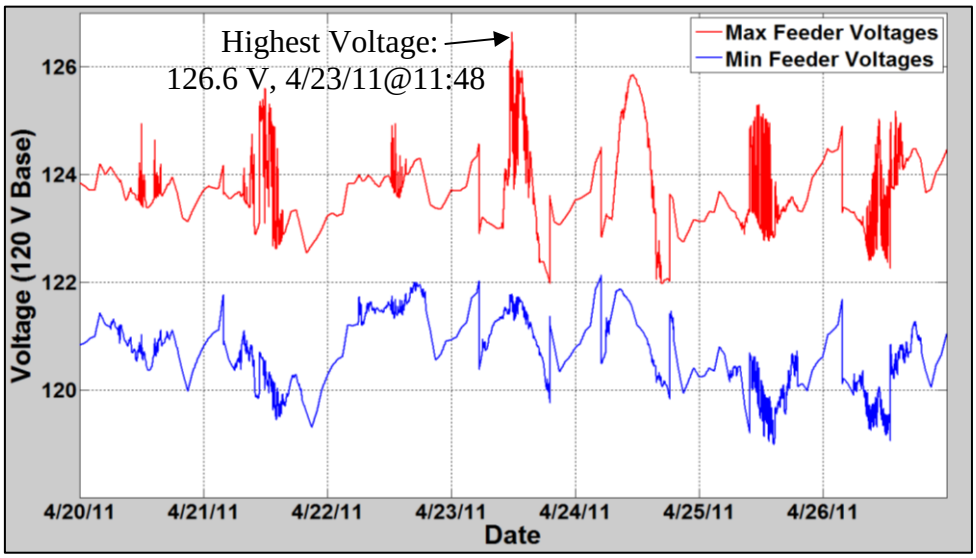


**Figure 4. Maximum and Minimum Voltages with PV for Study Week**

Figure 5 shows the feeder voltage profile at the time of highest voltage identified. Figure 5 shows all phases and lines on the feeder, with secondary services shown as dashed lines. This illustrates the extreme voltage rise observed

on the secondary with PV and the location of the highest voltage. This example illustrates the importance of considering secondary voltage rise to PV systems.

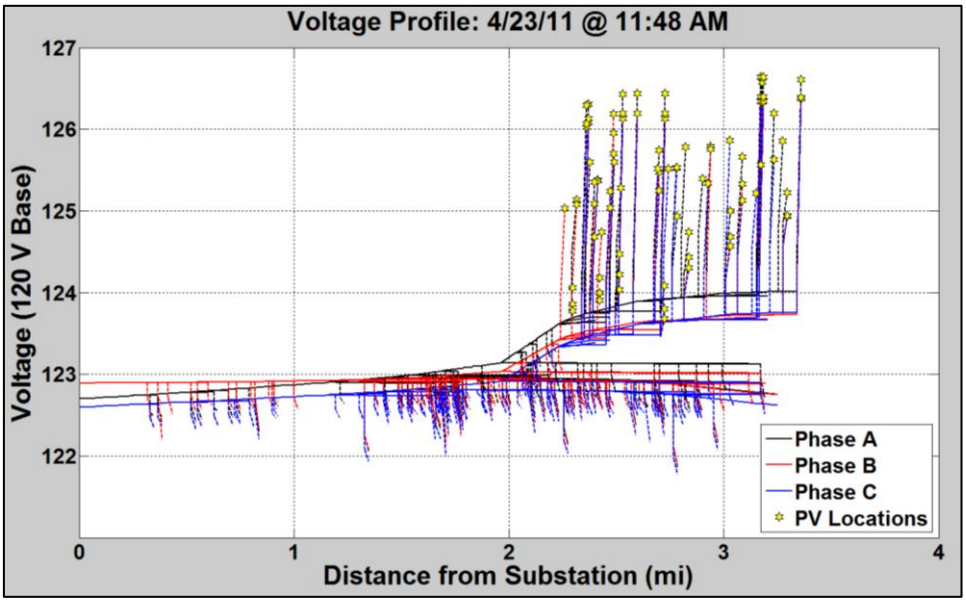


**Figure 5. Voltage profile for the feeder during the highest voltage time**

## Analysis Tools

Performing detailed distributed PV interconnection studies can be very time-consuming and complex. To improve the accuracy of such studies, clearly defined methodology and tools are needed. A collaborative website www.gridintegration.org will be available online soon for researchers, government labs, utilities, and universities to work together to continue to develop these abilities. Some tools will be available on the website that demonstrate using MATLAB and OpenDSS for distribution studies. These tools help to streamline the process with visualizations such as the voltage contour plots in Figure 6 and the interface in Figure 7.

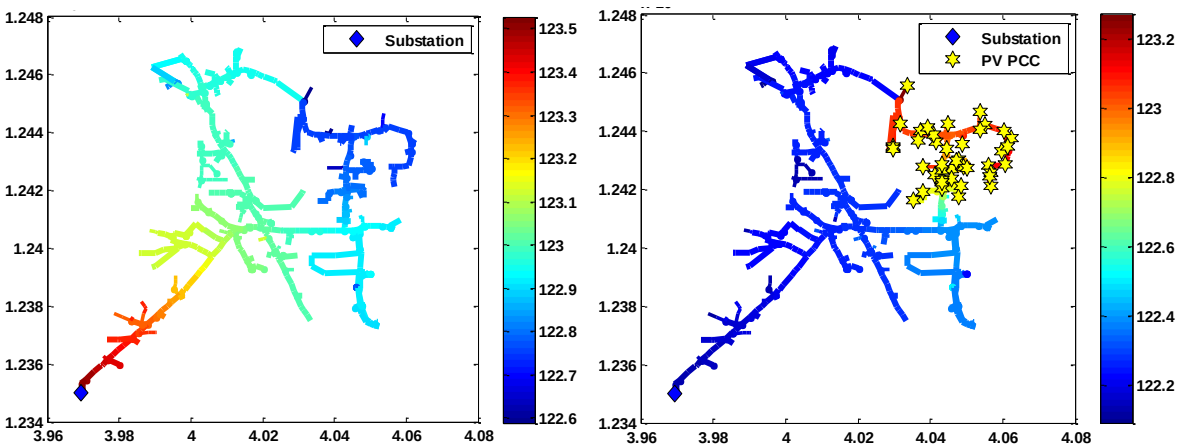


**Figure 6. Feeder circuit plots colored by voltage (120 V base) without PV and with distributed rooftop PV**

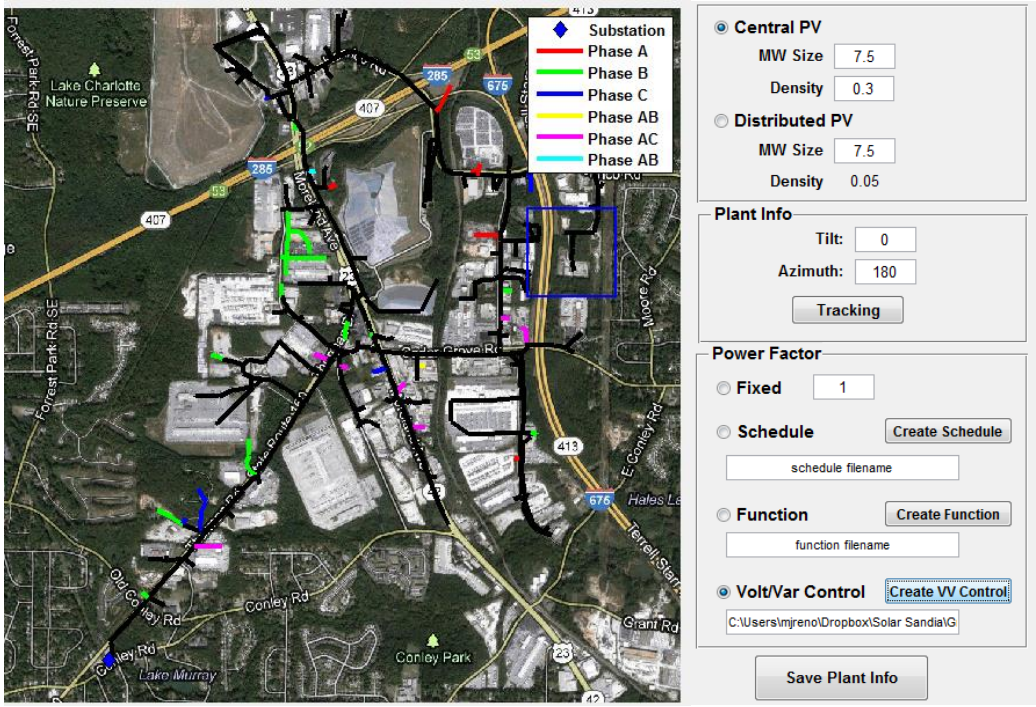


**Figure 7. Interface window for setting up a PV plant**

## Conclusions

Distributed PV interconnection studies using time series simulation and high time-resolution data can better characterize the specific impacts of high deployment levels of PV systems on the distribution system. Because PV output is highly variable, the potential interaction with control systems is not adequately analyzed with traditional snapshot tools and methods, which only provide an assessment of the distribution system at one instant in time. Some brief examples were shown and the full details and methodology can be found in the Sandia report in reference [6].

## References

[1] J. Quiroz and M. J. Reno, "Detailed Grid Integration Analysis of Distributed PV," in *IEEE Photovoltaic Specialists Conference*, Austin, TX, 2012.
[2] A. Ellis, B. Karlson, and J. Williams, "Utility-Scale Photovoltaic Procedures and Interconnection Requirements," Sandia National Laboratories SAND2012-2090, 2012.
[3] R. J. Broderick and A. Ellis, "Evaluation of alternatives to the FERC SGIP screens for PV interconnection studies," in *IEEE Photovoltaic Specialists Conference*, Austin, TX, 2012.
[4] J. E. Quiroz and C. P. Cameron, "Technical Analysis of Prospective Photovoltaic Systems in Utah," Sandia National Laboratories SAND2012-1366, 2012.
[5] M. J. Reno, A. Ellis, J. Quiroz, and S. Grijalva, "Modeling Distribution System Impacts of Solar Variability and Interconnection Location," in *World Renewable Energy Forum*, 2012.
[6] R. J. Broderick, J. E. Quiroz, M. J. Reno, A. Ellis, J. Smith, and R. Dugan, "Time Series Power Flow Analysis for Distribution Connected PV Generation," Sandia National Laboratories SAND2013-0537, 2013.

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