High Penetration PV Initiative: Monitoring Deployment

BACKGROUND

The Sacramento Municipal Utility District (SMUD), in partnership with the Hawaiian Electric Company (HECO), is implementing a research and development project which targets testing and development of hardware and software for high-penetration PV. This effort is intended to address key grid integration and operational barriers that hinder larger-scale PV adoption into mainstream operations and onto the distribution grid. As two utilities managing grid integration of high-penetration PV,SMUD and HECO are coordinating research efforts at specific locations in California and Hawaii. These sites will serve as case studies for assessing solar forecasting needs and PV grid integration and visualization tools. This project received funding from the California Solar Initiative Research, Development, Demonstration and Deployment (CSI RD&D) Program's first grant solicitation. The CSI RD&D Program is administered by Itron, on behalf of the California Public Utilities Commission (CPUC).

SMUD and HECO are partners in this project. Both utilities share synergistic problems on the distribution system based on high penetration and the explosion of DG PV deployment to meet Renewable Portfolio Standard (RPS) and Energy Efficiency targets. Hawaii and CA both have aggressive RPS and solar/Distributed Generation (DG) goals (in CA 3000 MW of Solar PV, in Hawaii 4300GWh of distributed resources for energy efficiency). SMUD and HECO also share common issues:

- Lack of visibility on the system down to the distribution level, and
- Lack of reliable forecasting capability for solar and DG resources for effective operations especially during variable weather days and peak loads.

In addition, SMUD and the Hawaii utility share similar planning and operations tools for control of DG systems. Both systems have high penetration of variable renewable generation. Hawaii is already "seeing" the high penetration level of DG on the system where as many mainland grids are just now concerned about potential impacts

In both the California Intermittency Analysis (IAP) study and Hawaii's current Clean Energy Initiative (HCEI) renewable integration efforts, there is a lack of high quality, high resolution, field measured PV data to inform adequate modeling of high-penetration PV on the electrical system. This condition is a prevailing integration barrier not only for the solar community but also for wind, storage and other renewable efforts. Envisioned as part of this effort, SMUD and the Hawaiian Utilities are collaborating in the development of a High-Penetration PV Initiative (HiP-PV) focused on development of distributed PV visualization tools supported by on-going field monitoring and data analysis at sites of interest; development and testing of hardware and software for enabling HiP-PV; and transfer of lessons learned.

Project Description

With circuits throughout both CA & Hawaii already experiencing high levels of PV penetration, and others on the near horizon, immediate case studies have been identified by SMUD and HECO for field monitoring; data collection and analysis; system modeling and simulation; and software and hardware development and testing. The sites identified focus on cases of immediate interest (e.g. existing high penetrations or potential for high penetrations of PV), each requiring different monitoring and effort levels. These case studies will provide the necessary data for the development and integration of the HiP-PV Visualization tools (Planning, Operational and Forecasting) that will assist SMUD and HECO to identify optimal locations that can benefit and accommodate more distributed resources (e.g. PV), visually track and trend changes within their respective distribution systems . These tools and research will be useful to other utilities to better plan and utilize HiP-PV to improve their distribution systems.

This effort has five tasks:

1. Project Management, Technology Transfer and Outreach
2. System Modeling
3. Field Monitoring and Analysis
4. System Integration and Visualization Tools Development
5. PV Production Forecasting

As part of Task 2 and 3 of this project, the SMUD and Hawaiian Utilities circuits were using SynerGEE including the upgrades to allow modeling of distributed PV generation units. SMUD has utilized BEW Engineering (BEW) to assist with the SynerGEE modeling and to transfer the data to Power World for further analysis. In Task 3, specific cases including substations, circuits and existing renewable generation are being studied. Monitoring equipment is being deployed and data are being collected. This document describes the cases that are being studied in this project.

Task 3 Deployment Plan

In Task 2, SMUD and HECO is modeling several existing circuits in the distribution system of SMUD and the Hawaiian Utilities. BEW Engineering (BEW) is working with SMUD and HECO personnel to do this work. Both SMUD and HECO currently use the software modeling tool SynerGEE for the distribution system. SynerGEE can model various types of distribution circuits and distributed generation, but it is limited to steady-state analysis. Power World, PSS/E and PSLF perform dynamic analyses for both distribution and transmission systems. BEW are taking these SynerGEE circuit models and then transferring the data to a format that is compatible with PowerWorld to do dynamic circuit analysis. The Case Description report under the Task 2 describes the cases/sites being studied. In Task 3, SMUD and HECO are deploying monitoring and associated equipment to collect load and generation data. This plan describes the deployment activities.

MODELING AND ANALYSIS METHODOLOGY

The deployment of monitoring devices is resulting in data that is being used in the modeling and analysis work. This work consists of modeling the circuit(s) at each site under steady state conditions, with and without existing PV and higher PV penetrations by adding prospective PV, and assessing whether any problems (backflow, under/over voltage, overloaded lines) could occur on the feeder. The condition of interest that will be mostly simulated is a minimum daytime peak period that normally occurs on an April Sunday. The analysis evaluates power flows, voltage, current, backflow, line segment loading and other factors.

A preliminary list of the modeling, analytical and validation steps for SMUD and HECO is shown below:

- Identify high penetration analytical requirements (load flow, characteristics of the load, protection and coordination, voltage regulation, and islanding) for the distribution feeders being analyzed.
- Identify additional data parameters to be collected and locations of data collection along the high penetration distribution feeder to place additional high-fidelity monitoring equipment, if necessary.
- Record and collect a minimum of 6 to 12 months' worth of high-fidelity load data from the newly installed high-fidelity monitoring equipment.
- Collect the following electrical equipment nameplate data from the distribution system being analyzed: distributed generation on the feeder, inverters, any energy storage, feeder size, feeder length, feeder loading, switchgear, and transformers.
- Investigate varying incremental levels of PV penetration at the distribution capacity level and iterate with an existing system level model to understand to what degree higher PV levels will adversely affect the grids.
- Validate the models against the collected high fidelity load data.
- Develop a methodology for extending the findings using the simulation tools
- to inform and expedite interconnections studies at higher penetration levels.

DEPLOYMENT

SMUD and HECO selected 9 sites to study within their utility systems. The feeders selected for detailed analysis have distinctive characteristics that make them of particular interest.

Site 1: SMUD A-C Feeder

SMUD initiated a "SolarSmart Homes" Program where SMUD partners with developers to build a development consisting of homes with building-integrated PV systems and a package of energy-efficiency features resulting in substantial energy savings relative to a typical development. The Anatolia subdivision consists of 170 Solar Smart Homes, each with a 2 kW PV system.

This case feeder (Site 1) supplies the Anatolia III subdivision in Sacramento County. The solar penetration level on this circuit is currently 13 % under lightly loaded conditions. In this case, load is a combination of commercial and residential. BEW will develop the baseline model. Also, BEW will determine PV penetration levels resulting in adverse conditions and include possible corresponding mitigating solutions. Of particular interest is to determine when reverse power flow in the secondary distribution system could occur, validate distribution models with real data, analyze the impacts of this level of PV penetration and formulate mitigation measures to ensure reliable operation.

The graph shows the kilowatt flow on Feeder 1 from the substation to the entry point into the subdivision for various penetrations of roof top solar installations. These profiles indicate that solar sensors and power quality meters should be installed at the beginning and end of the modeled area for validating the feeder flows under base line conditions. Instead of installing another monitor in the middle of the feeder, the utility may want to take an instantaneous reading on a projected maximum and minimum daytime peak demand to validate the line flow and voltages on the line. Since the feeder demand is continuously recorded, the instantaneous readings in the middle of the feeder provide another level of validation.

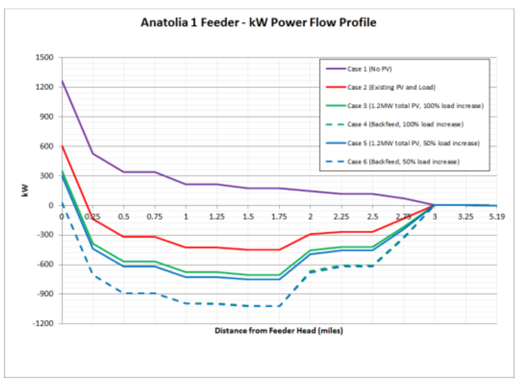


Figure 1: Feeder A-C Power Flow Profile

For Site 1, SMUD needs to separately monitor the load on the Solar Smart Homes subdivision. SMUD is deploying equipment in an underground enclosure located just outside of the subdivision. In the underground enclosure, the voltage and current are measured via current transformer (CT) and potential transformer (PT), Remote Terminal Unit (RTU) and a serial server. The information is transmitted by fiber to the SMUD Energy Management System (EMS). The feeder at the substation is already connected to the EMS.

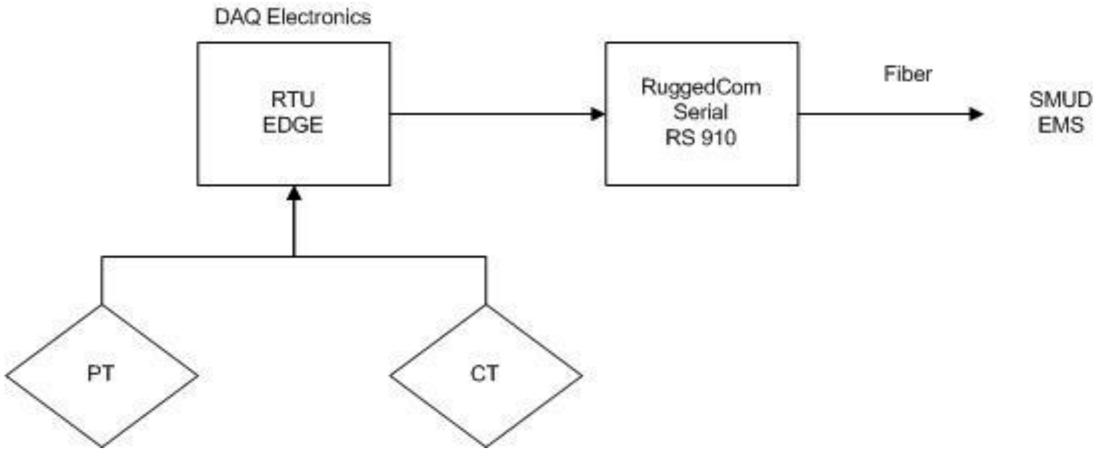


Figure 2: Site 1 Schematic

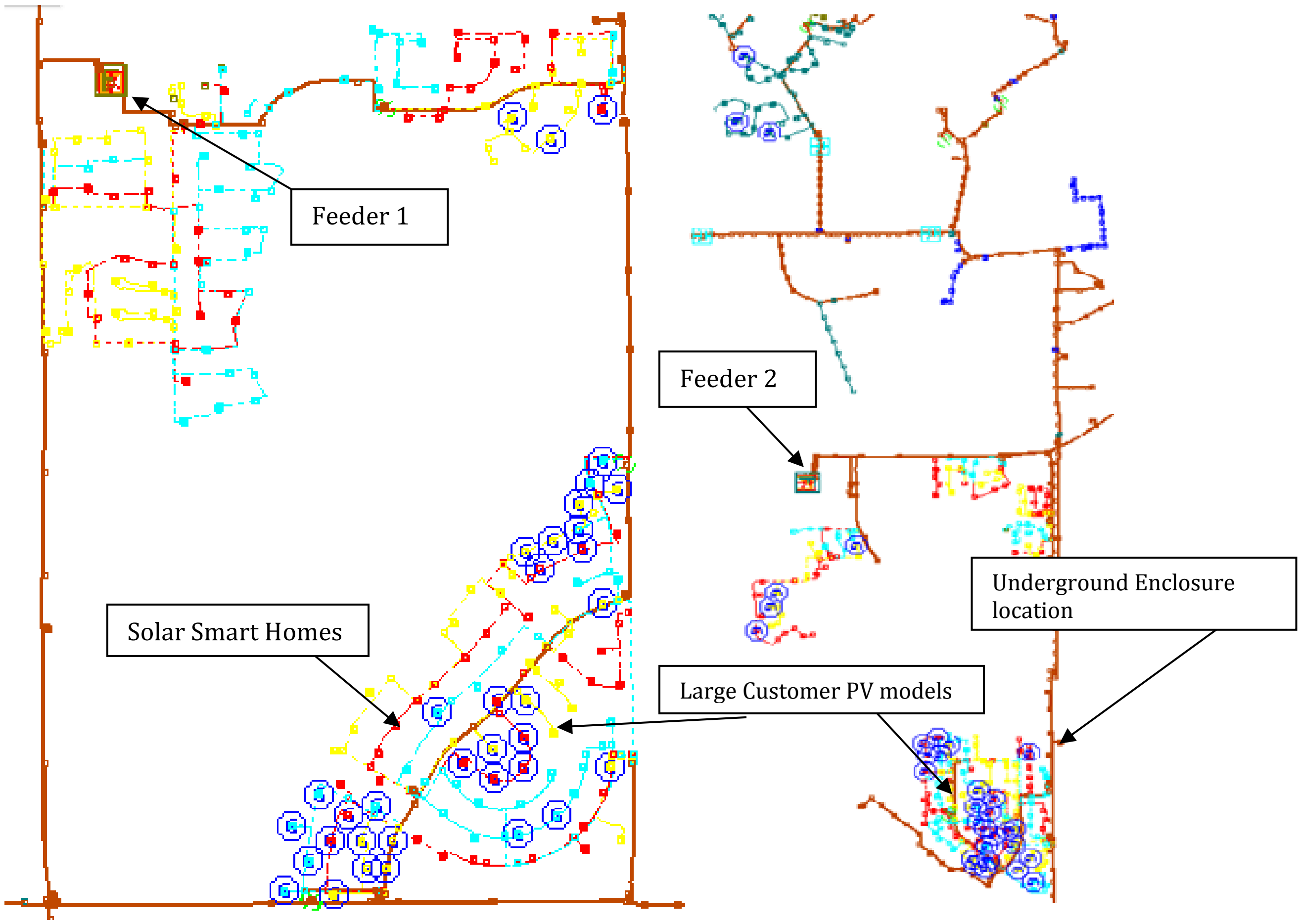


Figure 3. Locations of Existing PV within the A-C Feeder

Site 2: SMUD C-T Feeder

This feeder supplies SMUD's Rancho Seco facility as well as a small rural load. About 3 MW of installed solar PV capacity is located on the property, although only 1 to 2 MW of generation is realized due to the age of most of the PV modules. SMUD is developing alternative plans to repower the installation by possibly replacing panels, increasing the generation to capacity.

For Site 2, two transformer banks are in this substation, one equipped so that it is connected to SMUD's Energy Management System (EMS) and the other is not. Unfortunately, the C-T feeder is connected to the transformer that is not connected to the EMS. SMUD chose to reconnect the C-T feeder to the transformer bank with connection to the EMS. Below is the existing RTU and Router. At the PV Systems, the data is being collected by BEW Engineering.

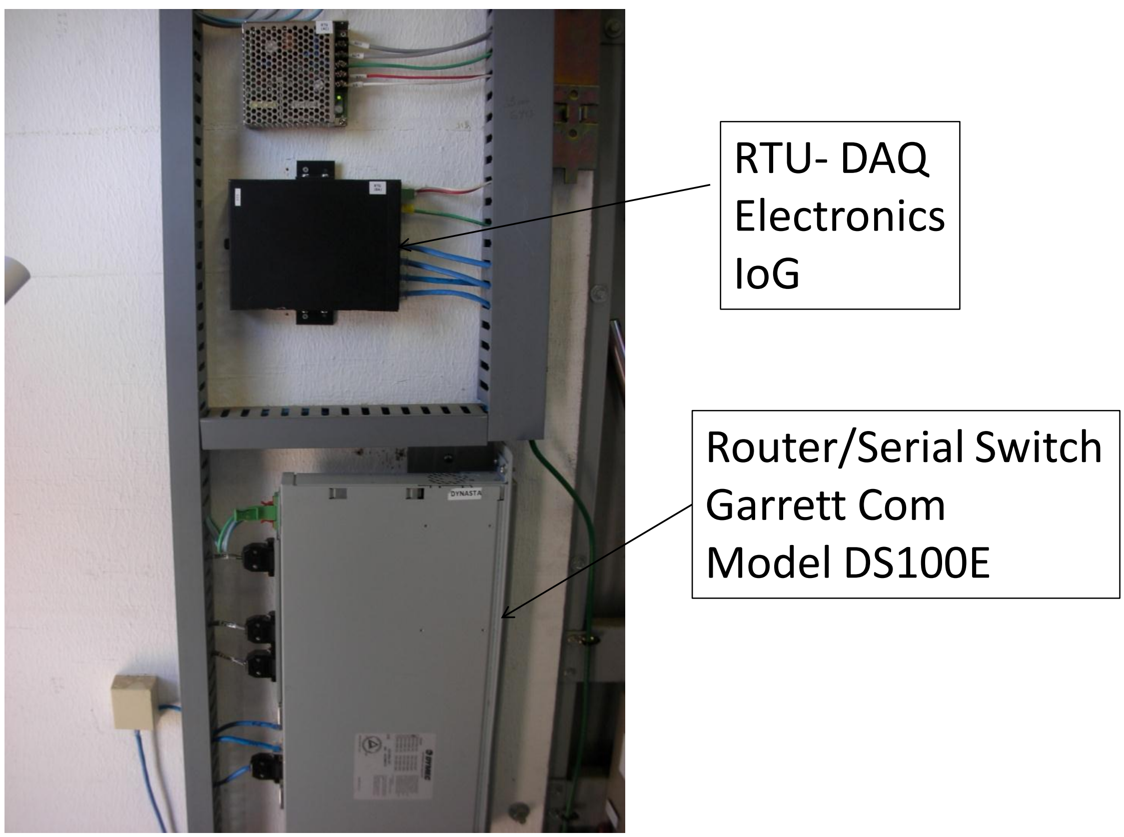


Figure 4: Site 2 Substation RTU and Router

Site 3: SMUD E Substation Bank 1
The feeders in this bank supply a combination of residential and rural loads. There are currently 48 MW of PV systems on these feeders installed as part of SMUD's Feed-In Tariff program.

Voltage and current data from the feeders at the substation are already being collected and sent to the EMS. This data establishes the load characteristics of the feeders. The new PV systems are installed with the capability to provide voltage and current information to the EMS. At the substation, the voltage and current are monitored via CT and PT, transducers and a RTU. At the PV systems, voltage and current are monitored via JEMStar meters, RTU, Routers and connected to the EMS via telephone lines.

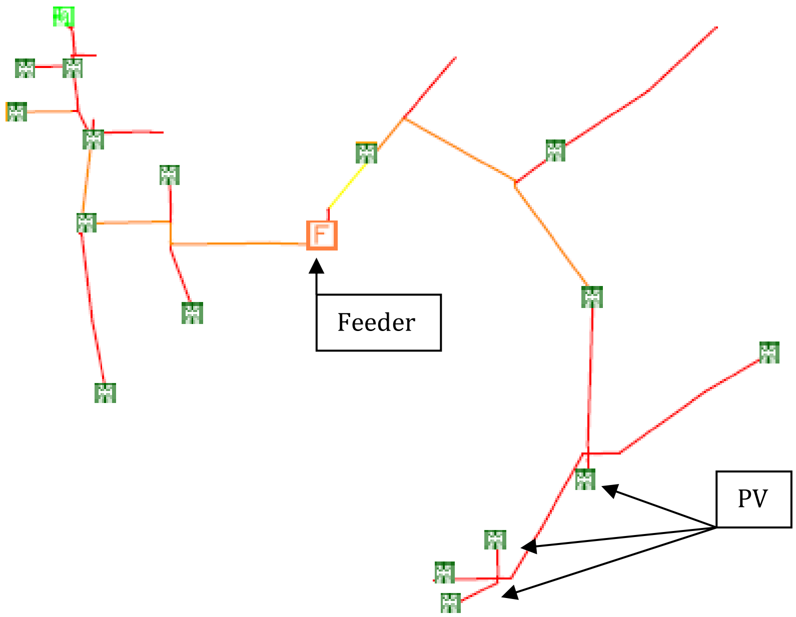


Figure 5. Bank E SynerGEE Model

Site 4: SMUD E-B Feeder
SMUD has worked with two local dairies to install anaerobic digesters (AD) that utilize cow manure to obtain biogas for electricity generation. This feeder supplies one of these dairies and other rural loads. This feeder is of particular interest because during the day the penetration (generation from digester gas at the dairy) is 10% and significantly larger during the night. SMUD wants a better understanding on how this

circuit operates with this distributed generation. In addition, a 1MW PV system is installed on this feeder. This case will allow us to see the interaction between the generation from an Anaerobic Digester and PV systems and their collective impact on the circuit.

This is a rural SMUD feeder with long lines and little load but with the dairy farm digester and one or more potential central distribution solar farms toward the end of the feeder. Since the feeder separates right outside of the substation into two vary long lines, it is difficult to determine where the additional monitors and sensors should be placed. There needs to be equipment installed at the substation and near the solar/digest installations to verify the reverse power flows and voltages. However, there needs to be monitors at the end of the other line segment or at least some installation readings to verify the voltages.

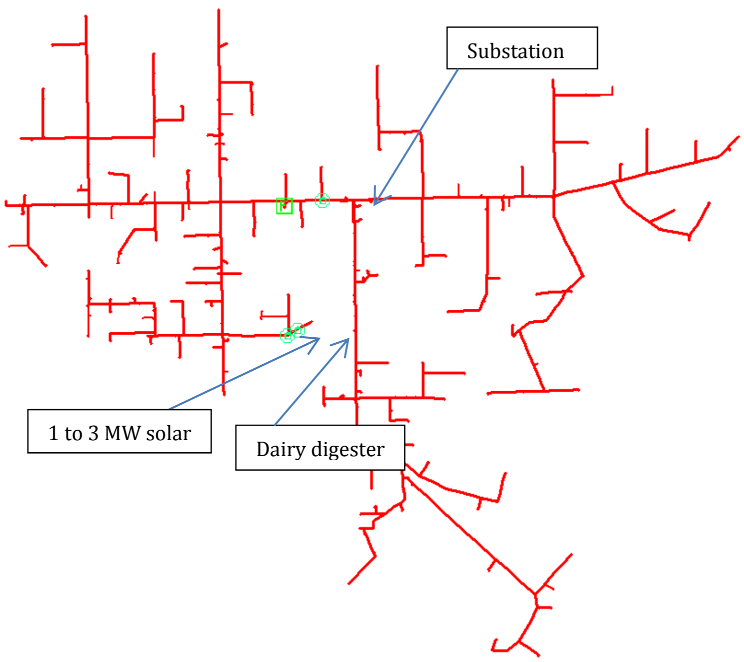


Figure 6: Synergee model of Feeder E-B

The two figures below show the maximum voltage and maximum flows on the distribution line for a minimum daytime peak hour which is normally modeled as an April Sunday noon where the load is low but the solar generation is high. The substation bus voltage was set at 123 volts. The objectives were to determine where the highest voltage and the highest reverse power flow were recorded on the feeder and the potential durations of each occurrence.

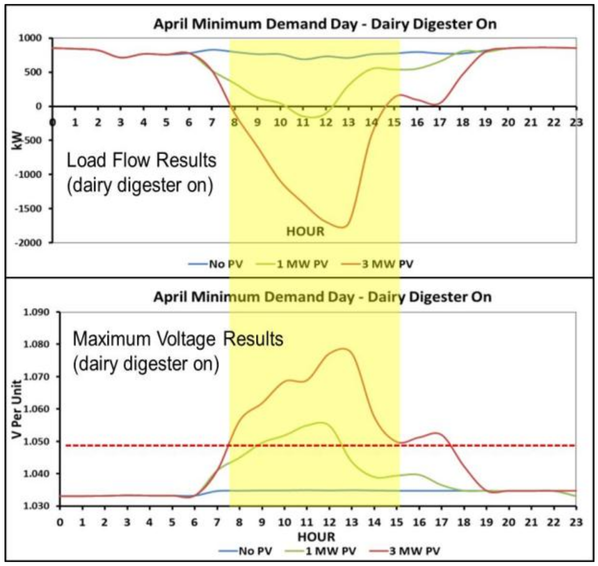


Figure 7: Preliminary Results at Feeder E-B

Site 4 is particularly challenging to monitor because of the age of the existing equipment. In this substation, the existing equipment is one of the oldest in SMUD territory. Monitoring equipments is installed at the substation. In order to not disturb, the existing equipment at the substation, SMUD used the LineTracker Intelligent Grid Monitoring LT40 product as displayed in Figure 8. Voltage and current data is collected. At the PV system, voltage and current data monitored via a JEMStar meter, RTU, Cooper Relay, and router and connected to the EMS via the telephone lines. See Figure 9.

Figure 8: Line Tracker Installed

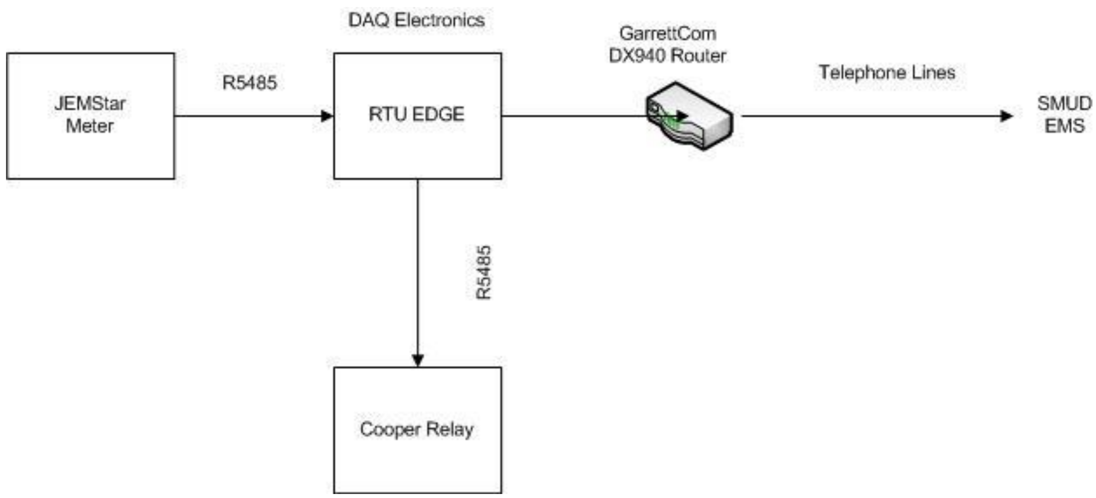


Figure 9: Site 4 Telemetry Schematic

Site 5: SMUD N-A/L7 Feeder

This large SMUD customer has installed a total of 5.2 MW of PV at two locations on their campus. This site is of particular interest because it is currently the largest PV installation in SMUD's service territory for a "Net-Meter" customer. A 69kV circuit is currently supplying the customer's facility. At Site 5, monitoring equipment will be installed at the substation and the two PV generation sites. The feeder supplies commercial and industrial load. The equipment will collect voltage and current data.

This site was particularly challenging because the PV systems and the substation are located on a customer's site. The customer did not want SMUD to utilize their internal communication network to data transfer. So radio transmitters were used for data transfer. At the two solar installations, the existing meters are exchanged out with JEMStar meters that are capable of communicating via the DNP3 protocol. These new meters are connected to a RTU and router/serial switch via a radio transmitter. See Figure 10.

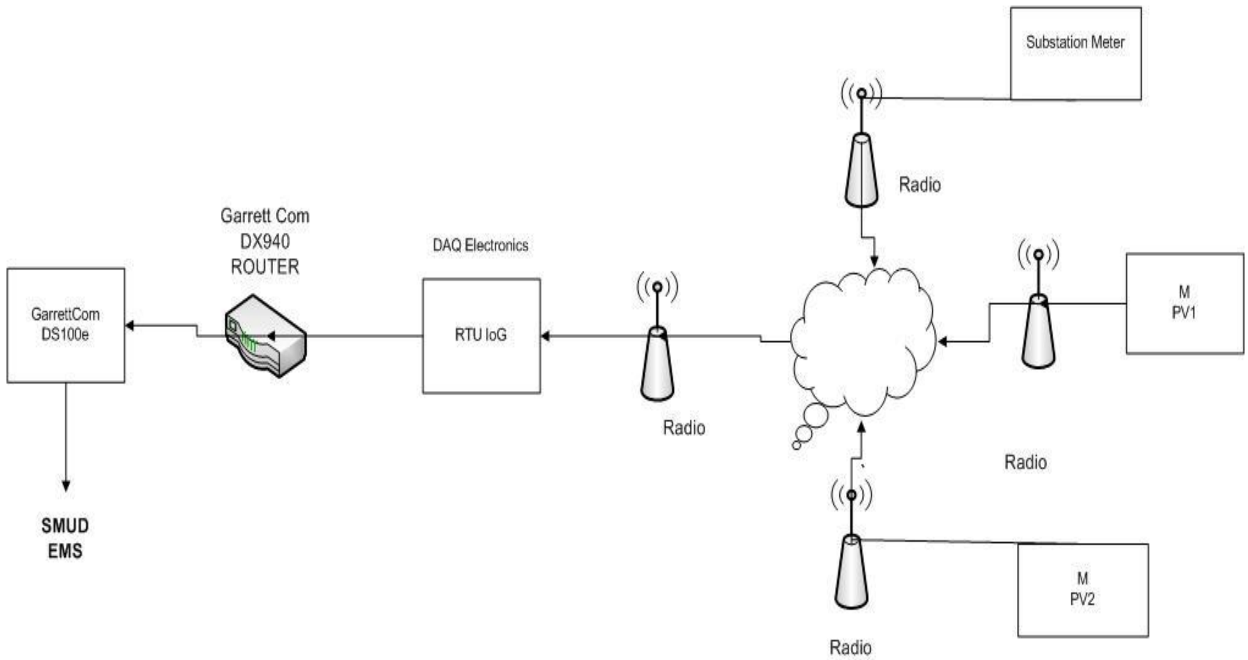


Figure 10: Site 5 Telemetry Schematic

Site 6: SMUD R-F Feeder

This large SMUD customer has currently installed approximately 1.9 MW of PV within their facilities in Sacramento, combined roof-top and parking lot cover installations. See Figure 11. The R-F Feeder serves both commercial and residential load.

In 2012, the substation was fully equipped with SCADA and connected to the EMS under a Department of Energy (DOE) Smartgrid grant. At the PV systems, voltage and current are monitored with JEMStar meters, RTU and Router and connected to the EMS via telephone lines. See Figure 12.

Figure 11: Site 6 Customer Roof-Top System

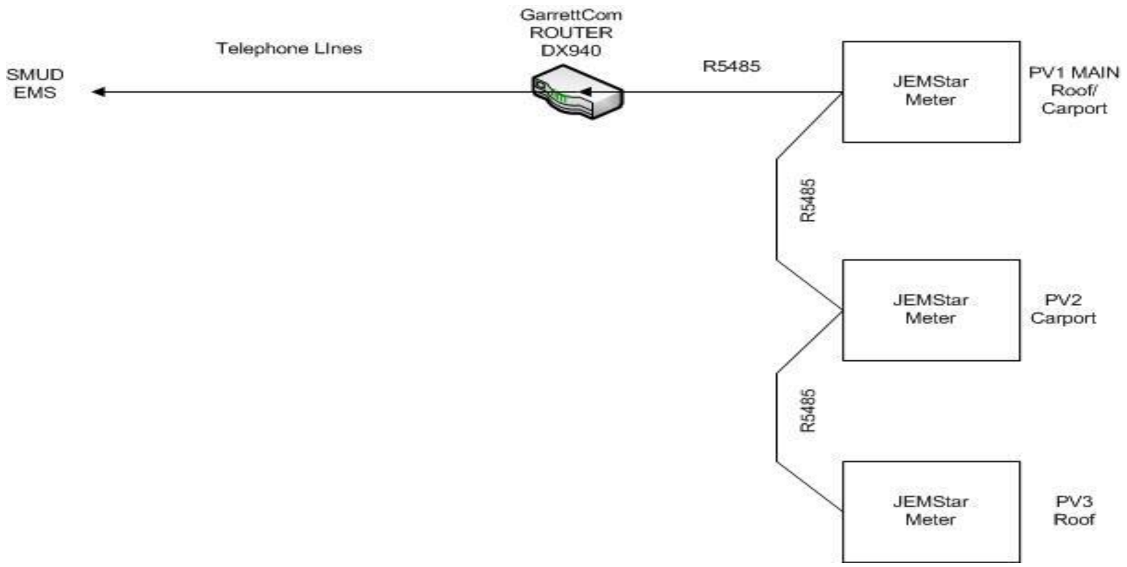


Figure 12: Site 6 Telemetry Schematic

Site 7: HECO Site 1 – Circuit Level Study

Site 7 has a penetration level of 24.50% of peak load with almost 800 kW of PV during the study. The PV installations on this circuit are comprised of a mix of industrial and residential customers over a relatively long distribution feeder.

Solar irradiance monitors, load monitors both at the substation and the customer site (end of the circuit) and a small PV panel (LM-1) to determine solar availability are installed to validate the 12kV distribution model. The load monitors collects circuit data such as voltage, amps, power factor, transformer tap position and count, VAR, real power and total power.

Data collected from this circuit is provided to BEW to populate/validate a SynerGEE 12kV model to study the effects of the distributed PV. Also, BEW is developing increasing PV penetration level scenarios to determine at what level(s) adverse circuit conditions would occur.

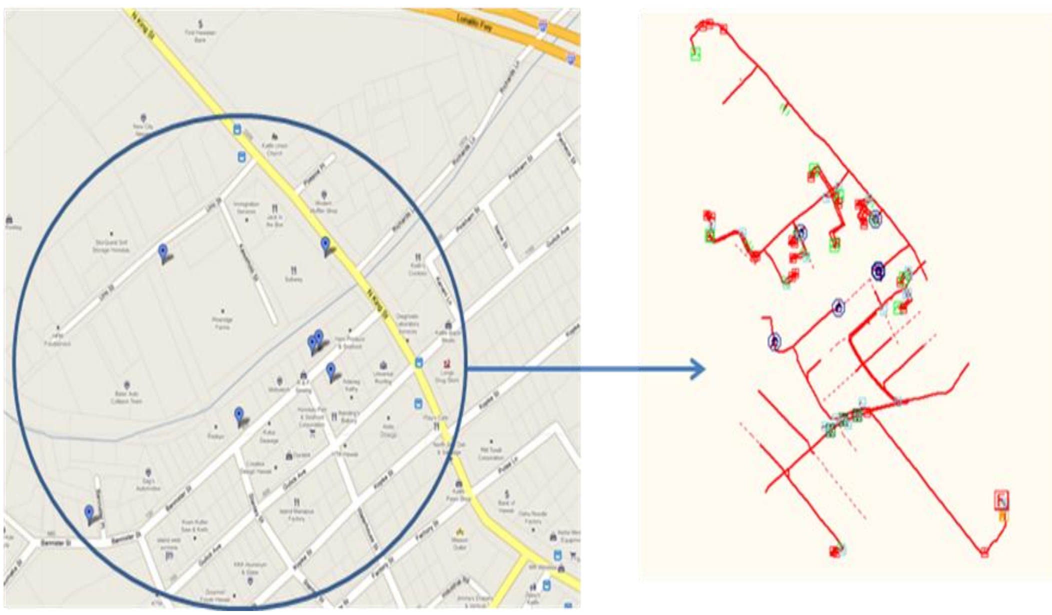


Figure 13: HECO Feeder 3 Geography of PV Locations

Load and solar resource monitors are used to capture data for model validation, and to identify events of interest to investigate further. Load monitors are located at both the substation and end of the circuit at the vault of a commercial customer with 500kW of rooftop PV.

A Shark monitor is installed at the substation and connected into the substation RTU, sending the data back to System Operations through the SCADA system. A PMI Revolution monitor is used to collect load data at the customer vault with data collected through a cellular data plan, as shown in Figure 14.

Figure 14: HECO load monitoring installation at customer vault

Solar resource is collected at the beginning of the circuit at the substation, in the middle of the circuit at an elementary school, and at the end of the circuit at a substation not electrically connected to the study circuit. At the substations, both the TJD-1 (Campbell Scientific irradiance kit) and LM-1 (PV Panel used to measure solar availability) are deployed, as shown in Figure 15.

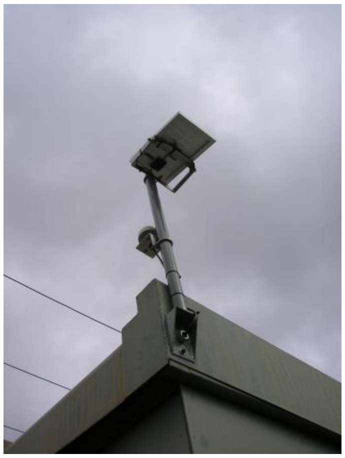


Figure 15: LM-1 deployed at substation

Figure 16: Solar irradiance kit (TJD-1) at the substation, HECO Site 1

With the LM-1 connected to the substation RTU, voltage and current are being brought back through the SCADA system. The TJD-1 solar irradiance kit is a standalone system with the data collected through a cellular data plan.

The solar irradiance kit is installed in a plastic enclosure due to substation safety guidelines not allowing an ungrounded metal tripod within the substation, shown in Figure 16. Along with eliminating the need for Substation Engineering to design a grounding scheme for the kit, the plastic enclosure also keeps the equipment from public view for security concerns.

A TJD-1 is also installed on an elementary school rooftop, and shared space with an already existing weather station kit, Figure 17.

Figure 17: TJD-1 installed on an elementary school rooftop

Equipment Summary

The LM-1 consists of a 20W PV panel with mounting bracket. The output of the panel is voltage and current, both serving as inputs into an Advantech ADAM-4017+ 8 Channel Differential Analog Input Module, than going into an RTU.

The TJD-1 includes a Campbell Scientific CR800 datalogger with access to the data through a cellular data plan via a Sierra Wireless Raven XT modem. The kit is powered with a battery kit including a PV panel and battery charger configuration. Solar irradiance kits are now being retrofitted with an ac adapter kit to remove the need for the battery kit to increase reliability and eliminate the need for battery disposal/purchases.

A LI-COR solar irradiance sensor, Garmin GPS, antenna and enclosure make up the remaining components of the kit.

Site 8: HECO Site 2 – Cluster Level Study

HECO Site 2 served to develop a methodology for a cluster level study. The definition of a cluster is a region of 46kV circuits and all electrically connected 12kV circuits. HECO site 2 consists of two 46kV circuits and five 12kV circuits as shown below and Figure 18.

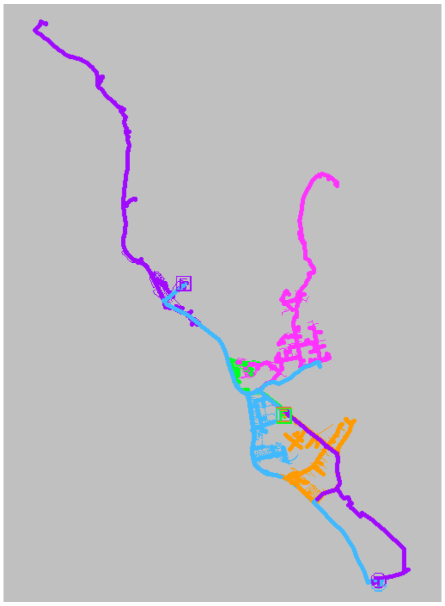


Figure 18: HECO Site 2 SynerGEE model

Summary of 12kV Circuits:
M1: 346 kW (9% of peak load) of PV installed/queued, residential & commercial loads
M2: 636 kW (11% of peak load) of PV installed/queued, residential & commercial loads
M3: 5000 kW (135% of peak load) of PV installed/queued, residential & commercial loads
M4: 1815 kW (57% of peak load) of PV installed/queued, residential & commercial loads
M5: 265 kW (5% of peak load) of PV installed/queued, residential & commercial loads

Load and solar monitors are installed at the substations and uses equipment identical to that of the circuit level study at HECO site 1, see Figure 19. Also, with the Sun Power for Schools program with HECO, solar irradiance data is collected at 3 schools in the area.

Figure 19: Solar irradiance kit (TJD-1) installed at HECO Site 2

Site 9: Hawaii Electric and Light Company (HELCO) Feeder – Cluster Level Study

The HELCO project models the M substation area where there are four circuits. M Circuit 1 has an existing penetration level of 8.6% with 260 kW of PV; M Circuit 3 has existing penetration level of 10% with 408 kW of PV. These two circuits serve the resort hotels and residential area of the M substation area. M Circuit 4 serves a large pumping load, with no PV. M Circuit 2 is designated to serve a new development that plans to include high levels of PV as it builds out. M Circuit 2 is not serving loads at this time. M substation is connected to the HELCO SCADA system and 15 minute load data has been collected for many years.

M Circuits 1 and 3 are long feeders and have had some fairly large PV systems in place since approximately 2004. More systems are coming on line at M substation due to good solar resource conditions at the location and lower costs for PV equipment. It is expected the circuits will be at 15% or higher peak load PV penetration soon.

Monitoring equipment used is identical to that of the HECO site 1 deployment and installed as shown in Figure 20.

Site 9 (M) is selected over other higher penetration circuits due to the long feeder length and the fairly high level of PV. The other circuits considered have more PV but the systems are located close to the substation resulting in less line impedance and less extreme conditions for voltage regulation requirements.

The M case allows a study of the pre and post conditions of high PV penetration.

Figure 20: HELCO TJD-1 installation

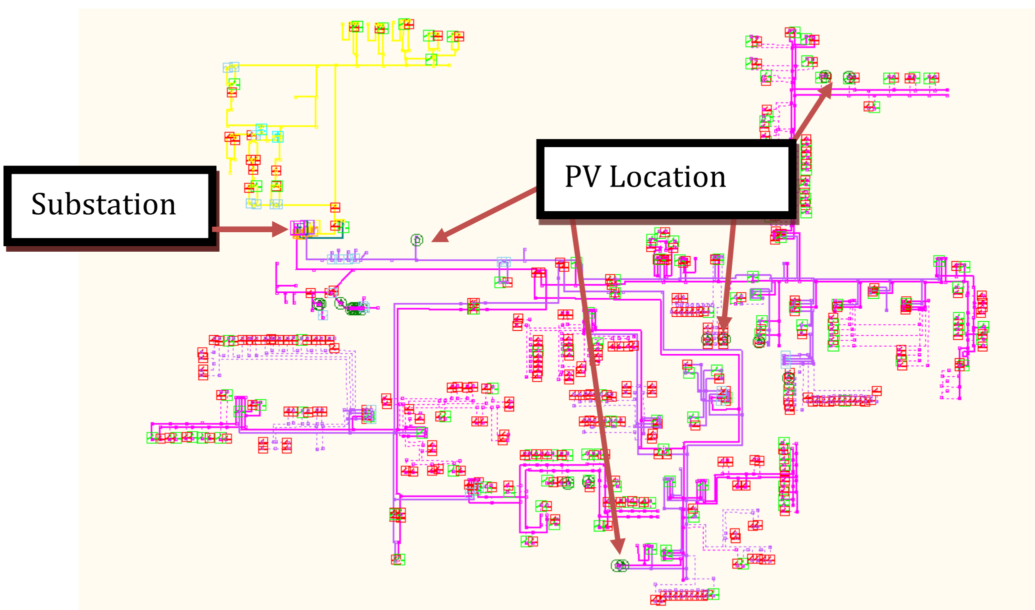


Figure 21: M Feeder Synergee model

Site 10: Maui Electric Company (MECO) Feeder – Cluster Level Study
This site was replaced with the Cluster Level Study of HECO Site 2.

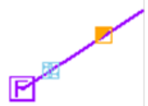
SUMMARY

The project team has selected several sites/cases from both the SMUD and HECO service areas. See table below. These case studies is providing the necessary data and modeling for the development and integration of the HiP-PV Visualization tools that will assist SMUD and HECO to provide visibility to the impact of higher penetrations of PV within their respective distribution systems.

Table 1: Feeders Selected for Analysis

Site	Feeder	Voltage	Location	Existing PV	Other existing DG
1	SMUD A-C (3 feeders)	12 kV	Residential	Yes - 0.6 MVA	No
2	SMUD C-T (2 feeders)	12 kV	Residential/Rural	Yes – 3 MVA	No
3	SMUD E Bank 1 (3 feeders)	69 kV	Residential/Commercial/Rural	Yes, 48 MW	No
4	SMUD E-B (1 feeder)	12 kV	Rural	Yes – 1 MW	Dairy Digester
5	SMUD N-A/L7 (1 Feeder)	69 kV	Industrial	Yes – 5.2 MW	No
6	SMUD RF (1 feeder)	12 kV	Commercial/Industrial	Yes- 1.9 MW	No
7	HECO 1 (4 feeders)	12 kV	Residential/Industrial	Yes – 800kW	No
8	HECO 2 (7 feeders)	69 kV & 12kV	Residential /Commercial	Yes – 8MW	No
9	HELCO (4 feeders)	4.16 kV	Commercial	Yes – 668kW	Yes – possibly out of service

Table 2: SYNERGEE MODEL KEY

	Fuse
	Transformer
	Open Switch
	Closed Switch
	Capacitor
	Start of a Feeder + Breaker + Meter
	Breaker
	Recloser
	Large Customer/Distributed Generator Model
	Synchronous Generator Model

Appendix A: Specifications