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High Penetration PV Initiative: Case Descriptions

Elaine Sison-Lebrilla

Sacramento Municipal Utility District

Dora Nakafuji

Hawaiian Electric Company

Hawaiian Electric Company

SMUD™

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Elaine Sison-Lebrilla (SMUD)
Dora Yen Nakafuji (HECO)
Project Leads

Thomas Aukai (HECO)
David Brown (SMUD)
Ronald Davis (BEW)
Billy Quach (BEW)
Emma Stuart (BEW)
Contributing Authors and Project Team Members

DISCLAIMER:
This project is receiving funding under the California Solar Initiative (CSI) Research, Development, Demonstration and Deployment (RD&D) Program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the CPUC, Itron, Inc. or the CSI RD&D Program.

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).

These R&D activities aim to address key integration barriers in visualizing, monitoring and controlling high-penetration PV on the grid, including:

- Smart siting of renewable distributed generation involves fully understanding the solar resource, its potential deployment, and interaction with the existing distribution infrastructure. A key task of this project is to develop a software visualization tool to enable identification of high value locations for distributed PV on the distribution system, and to identify problem areas that will require reinforcement or modification to enable higher penetrations of PV. Case studies have been identified that include residential, commercial and greenfield sites overlaid throughout the electrical system in order to assess interconnection benefits (cost and locational value) to the system.
- Development of a renewable generation operational tool that allow utilities to see how the renewable generation is functioning on their system. This tool also enables full use of distributed PV in displacing the need for distribution upgrades and natural gas peakers. It will also allow validation of forecasting software providing 3 hour-ahead and day-ahead PV output forecasts.
- Deployment of a solar irradiance sensor network and coordinated advance communication for controls [i.e. dedicated cellular, Advanced Metering Infrastructure (AMI) network, Supervisory Control and Data Acquisition (SCADA) system enabled condition monitoring, distribution remote terminal units (RTU).] shall also be investigated as part of this effort.

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.

As distributed PV and large-scale PV facilities continue to be planned and developed in both states, there is a need to implement quality field measurement campaigns and amass accurate data for improving electrical system models to include PV generators and integration control characteristics. Information developed can help inform PV manufacturer's development of new software, hardware, and communications approaches to respond to these needs.

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

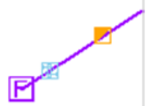
As part of Task 2 and 3 of this project, the SMUD and Hawaiian Utilities circuits were using SynerGEE including the upgrades to allow modeling of distributed PV generation units. SMUD has utilized BEW Engineering (BEW) to assist with the SynerGEE modeling and to transfer the data to Power World for further 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 2 DELIVERABLE: Description of Cases/Sites

In Task 2, SMUD and HECO are 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 has taken these SynerGEE circuit models transferred the data to a format that is compatible with PowerWorld to do dynamic circuit analysis. The following is a description of the cases/sites with their SynerGEE circuit representation (Figures 1-10). Table 1 is the legend that identifies the different symbols in the SynerGEE circuit representation. Table 2 at the end presents a summary of the different cases.

The models will be used to characterize the existing systems (identified cases) within SMUD and HECO to create the baseline for later high penetration scenarios. A baseline model of the distribution and existing grid-connected PV has been developed by BEW. These modeled results are intended to guide further field monitoring efforts and load studies as necessary during the project assuming high penetration PV with and without mitigation options. Validation of the models will be done as part of Task 3.

Table 1: 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**

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.

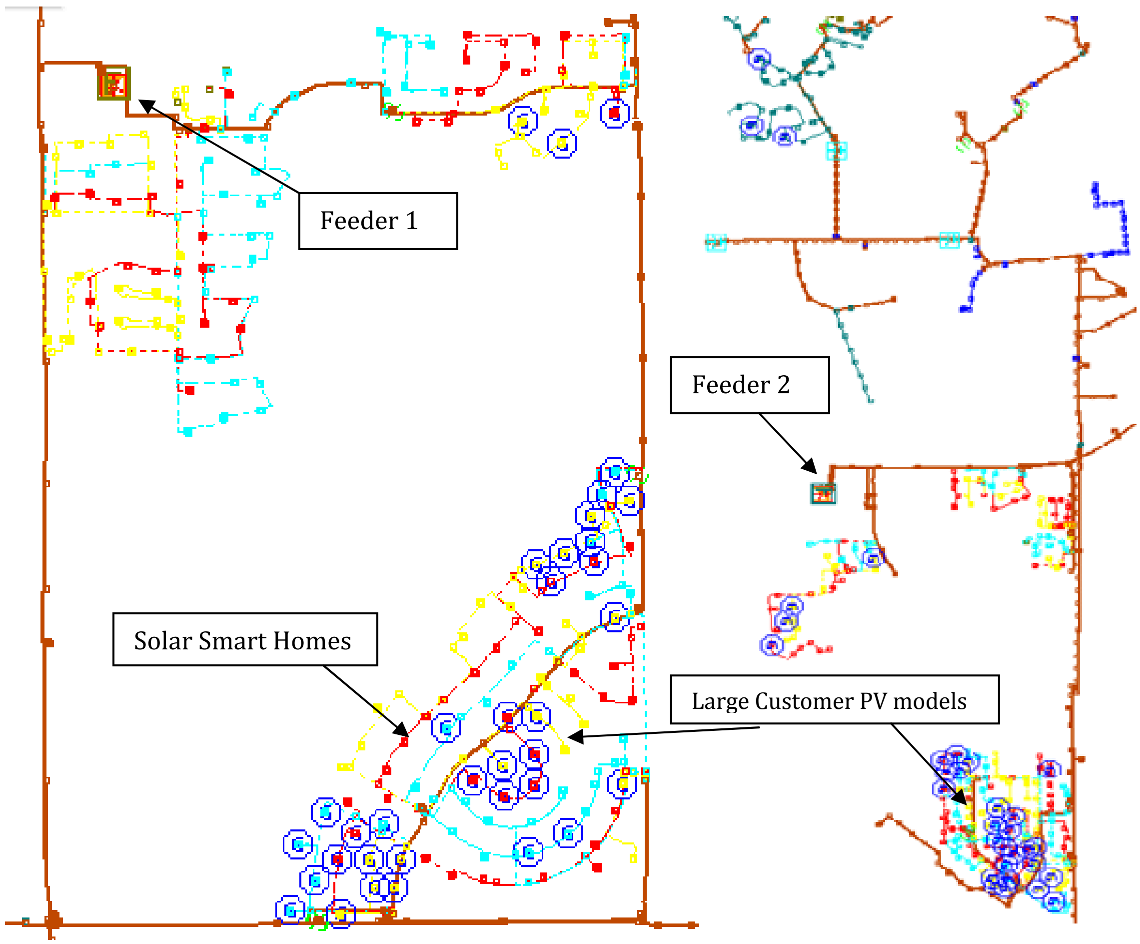


Figure 1. Locations of Existing PV within the A-C Feeder

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 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, monitoring equipment will be installed to supplement the SCADA system that currently collects and feeds data into the energy management system (EMS). Load and voltage data are currently being collected. Additional equipment to monitor for minor line faults or transients that trip inverters will be installed. Of particular interest at this case are voltage regulation, unintentional islanding prevention, and false inverter trips with transient evaluation.

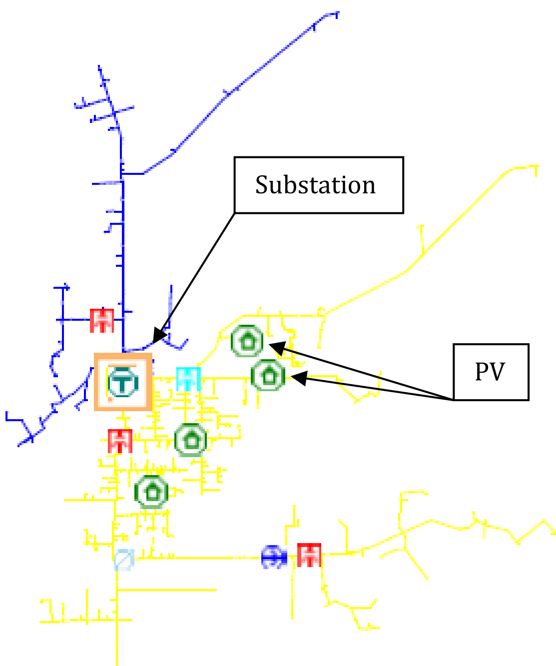


Figure 2. C- T Feeder SynerGEE Model

Site 3: SMUD E Substation Bank 1

The feeders in this bank supply a combination of residential and rural loads. There are currently no PV systems on these feeders. This bank is of particular interest because about 48 MW of PV will be installed along the feeders within 1-2 years as part of SMUD's Feed-In Tariff program.

At Site 3, data from the feeders are already being collected via the SCADA system. This data establishes the load characteristics of the feeders. The new PV systems will be installed with SCADA link to SMUD'S EMS. SMUD will be able to monitor the operations of the feeders and the PV systems with resolution in seconds. In this case, data from this bank will provide a clear picture on the impact of large amounts of PV generation on circuits.

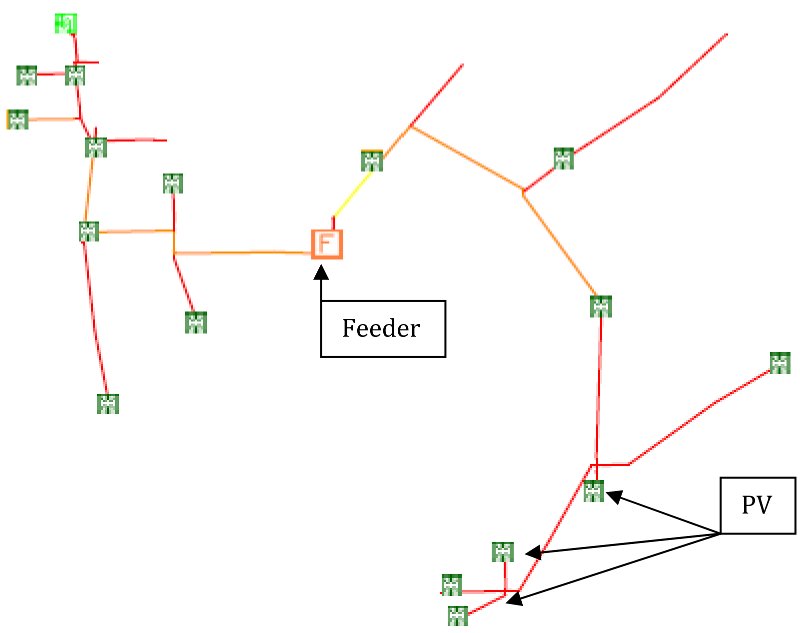


Figure 3. Bank E SynerGEE Model

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 will be installed on this feeder in the next year. 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.

Site 4 will be 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 will be installed at the substation and at the dairy. Load and voltage data will be collected. The ambient temperature data will also be collected to determine how it affects digester gas output and the relationship to generation from the units. When the expected PV system is installed, data will be collected from that generation.

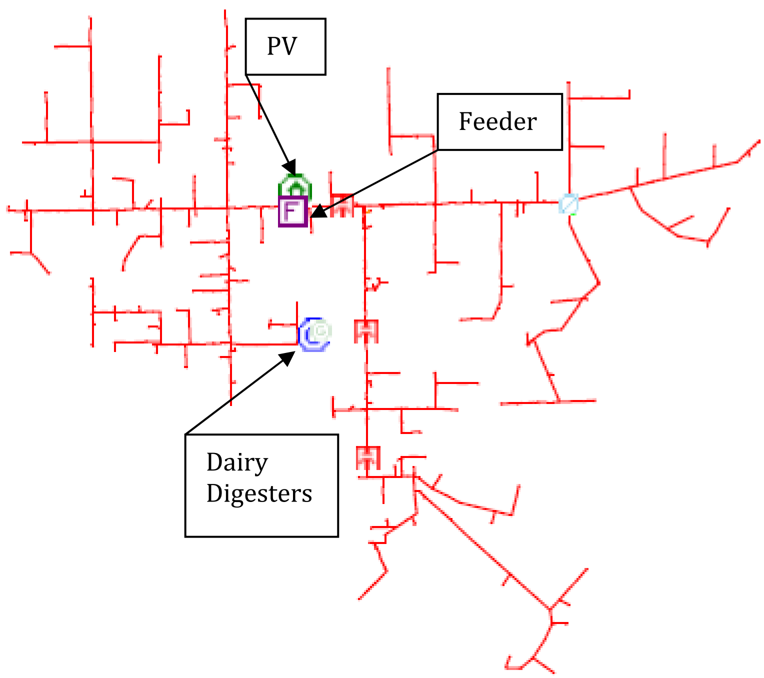


Figure 4. E-B Feeder SynerGEE Model

Site 5: SMUD N-A Feeder

This large SMUD customer has installed a total of 6 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. 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.

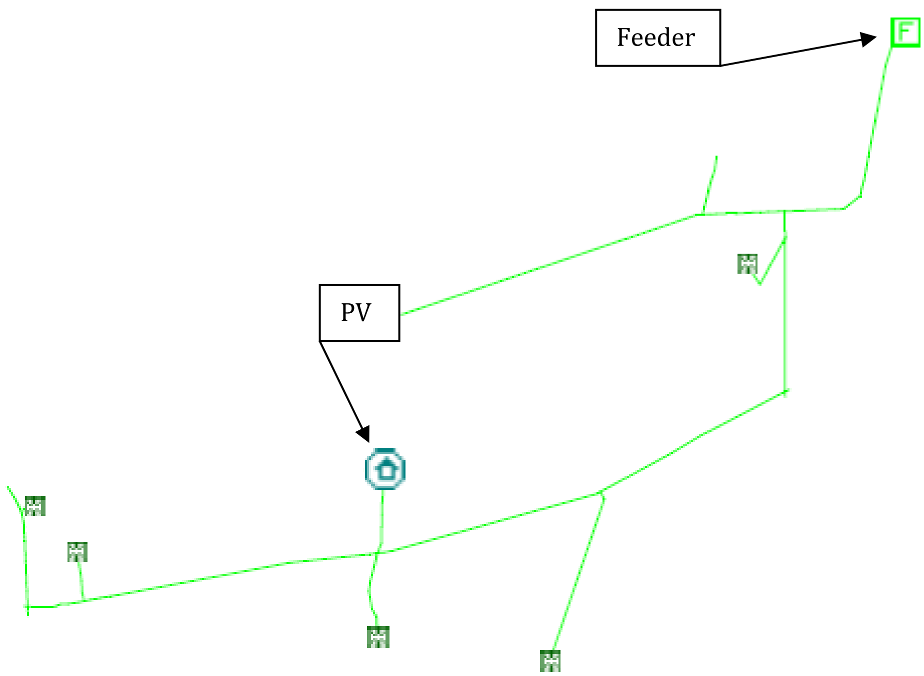


Figure 5. SynerGEE model for N-A Feeder

Site 6: SMUD R-F Feeder
This large SMUD customer has currently installed approximately 1 MW of PV and is constructing an additional MW of PV for a total capacity of approximately 2 MW at one of their facilities in Sacramento. This 2 MW installation is expected to result in a 30-40% penetration level on the feeder, and will likely exceed that level during low-load periods. A 12 kV distribution feeder currently supplies the facility and other loads.

At Site 6 monitoring equipment will be installed at the customer site, including the PV system and the transformer. Load and voltage data will be collected at the substation at or near the facility load. VAR data will also be collected to investigate the potential for future deployment of inverter technologies with VAR dispatchability.

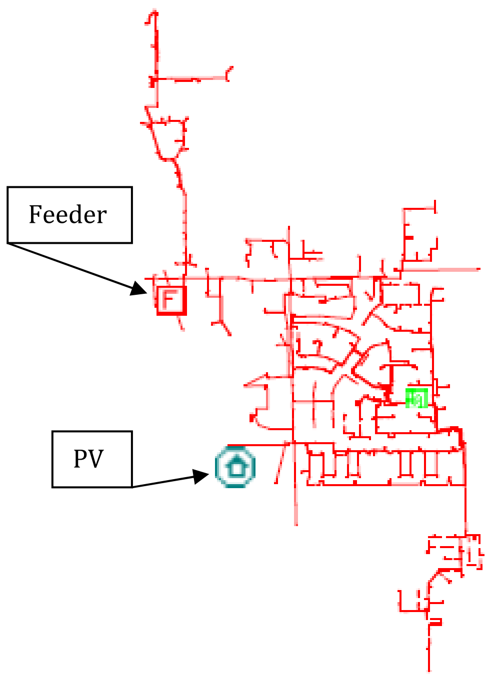


Figure 6. SynerGEE Model for R- F feeder

Site 7: HECO Site 1

Site 7 has a current penetration level of 24.50% of peak load with almost 900 kW of PV. 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 LM-1 (locational monitor) to collect solar availability data as a percentage of panel output and visual data are currently installed. The load monitors collect circuit data such as voltage, amps, power factor, transformer load tap changer position and count, VAR, real power and total power.

Data collected from this circuit is being provided to BEW to populate a SynerGEE 12 kV model to study the effects of the distributed PV. Also, BEW will determine PV penetration levels resulting in adverse conditions, inverter interactions and include the corresponding recommendations on mitigating options.

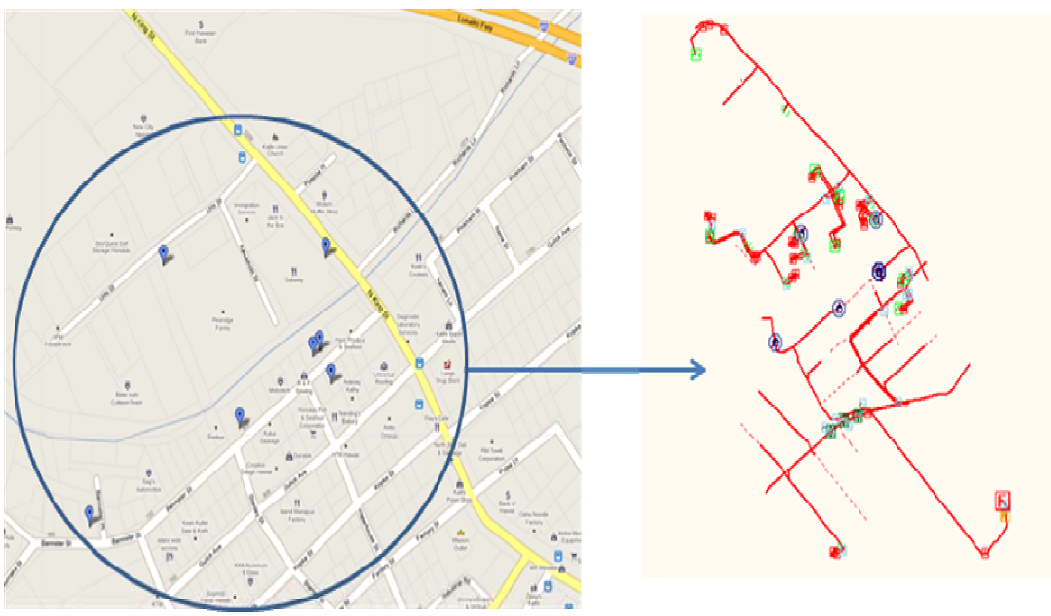


Figure 7. HECO Feeder 3 Geography of PV Locations

Site 8: HECO Site 2
Site 8 has a current penetration level of 21.90% of peak load with 1147 kW of PV. This circuit consists mainly of industrial customers. Due to the high peak load penetration value, with businesses active mainly during the day, the circuit penetration level during off-hours may be significantly higher, especially on weekends.

Similar to Site 7, Site 8 will include solar monitors, load monitors and small PV panels for system operator visualization. Data collected from this circuit is being provided BEW to populate the SynerGEE 12 kV model to study the effects of the distributed PV, and to provide solutions and penetration levels resulting in adverse effects.

Due to rapid changes on penetrations levels on the feeders and delays in getting monitoring devices out to this site, a backup Site 2 has also been identified. The Site 2 Backup consists mainly of industrial, agricultural loads and recently reached 83% of peak load penetration of PV. The SynerGEE model has already been completed by BEW for this site. HECO staff will investigate timing of getting monitoring devices out to Site 2 Backup for validation purposes. As it has higher priority at this time, it is likely that this site will replace the original site. This site is a prime candidate site to apply modeling methods developed in this project and for assessing impact of pre-PV and post-PV conditions on the feeder and the system.

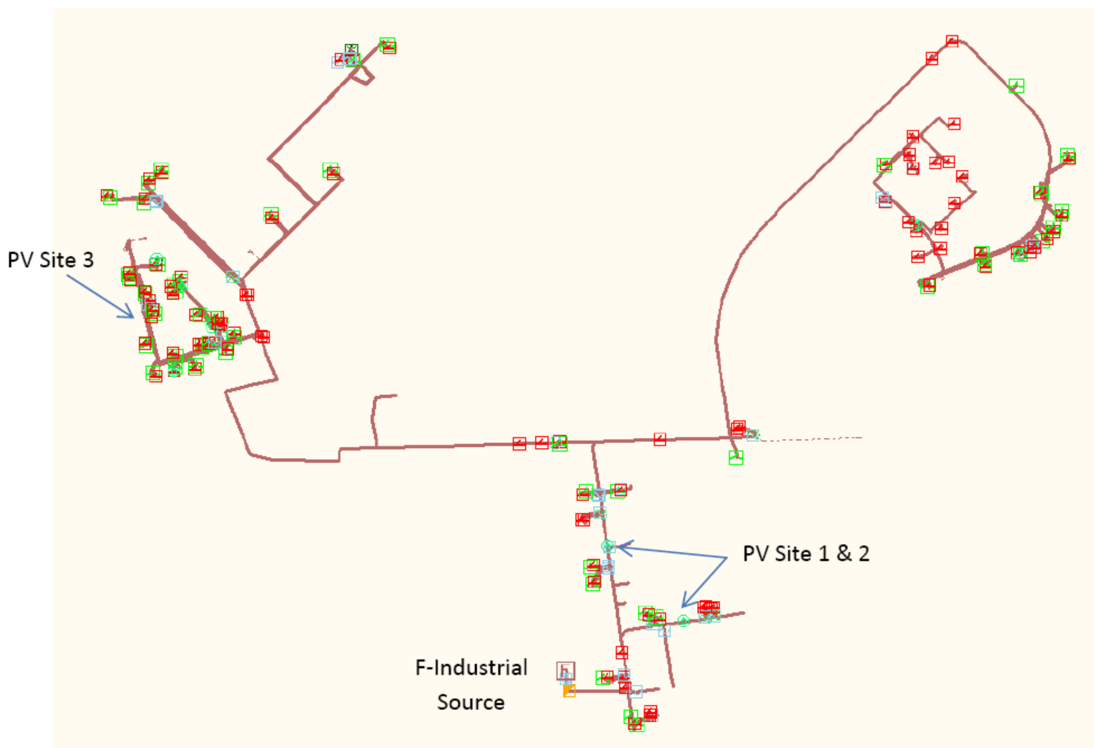


Figure -8. HECO Site 2 Feeder SynerGEE model

Site 9: Hawaii Electric and Light Company (HELCO) Feeder
The HELCO project will model the M substation area where there are four circuits. M Circuit 1 has an existing circuit penetration level of 8.6% with 260 kW of installed PV to circuit peak load. M Circuit 3 has an existing circuit 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.

Solar irradiance monitors, load monitors both at the substation and the customer site (end of the circuit) and small PV panel to collect visual data are either currently installed or being installed. The load monitors will collect circuit data such as voltage, amps, power factor, transformer tap position and count, VAR, real power and total power.

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

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

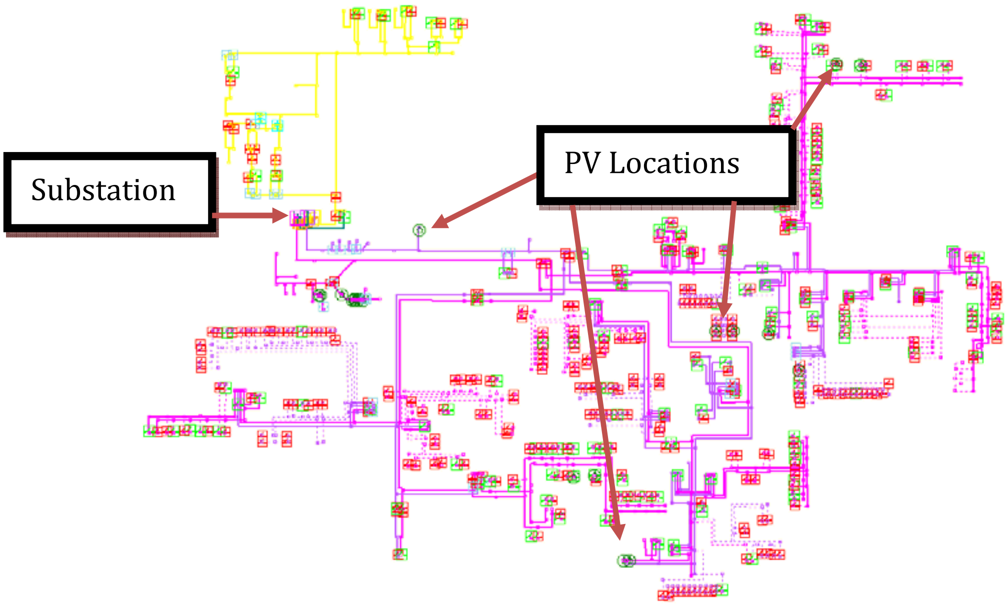


Figure -9. M Feeder SynerGEE model

Site 10: Maui Electric Company (MECO) Feeder

The MECO Site (Site 10) has a current penetration level of 6.34% of peak load with approximately 176 kW of PV. The PV installations on this circuit are comprised of a mix of commercial and residential customers over a relatively long distribution feeder.

Solar irradiance monitors and load monitoring from the MECO SCADA system at the substation are currently installed or being installed. Data from the EMS will include circuit data such as voltage and amps. Data collected from this circuit is being updated by BEW into the SynerGEE 12 kV model to study the effects of the distributed PV. Also, the BEW will determine PV penetration levels resulting in adverse conditions and include the corresponding mitigating solutions.

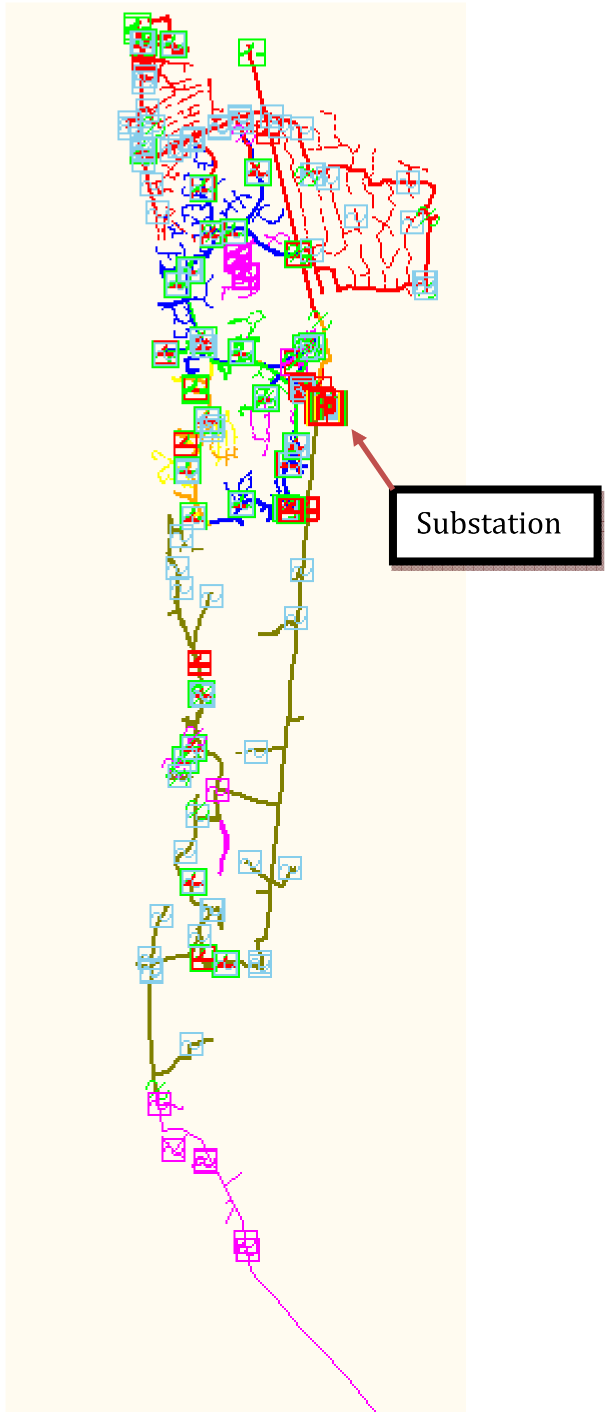


Figure-10. SynerGEE Electric model of MECO substation

Conclusion

The project team has selected several cases from both the SMUD and HECO service areas. These cases are summarized in Table 2 below. These case studies will provide the necessary data and modeling for the development and integration of the HiP-PV Visualization tools. The team will apply modeling techniques developed as part of this project and will assist SMUD and HECO to evaluate locations that can reliably benefit from and accommodate more PV distributed resources. Both utilities will also continue to visually track and trend changes within their respective distribution systems following lessons learned from these initial sites.

Table 2: Summary Table

Case/Circuit	Customer/Load Type	Existing Penetration at peak load/Existing Gen/Expected Gen	Comments
SMUD A-C Feeder	Commercial and Residential	13% at light load/725kW with planned upto1.2MW	Housing subdivision loads and rooftop installations
SMUD C-T Feeder	Rural	TBD/2MW with future planned reduction to decommission outdated systems	Pumping Load and PV generation, ground mounted
SMUD E Sub Bank 1	Residential and Rural	0/0/48MW	Planned 48 MW of Feed-In Tariff PV Generation, ground mounted
SMUD E-B Feeder	Dairy and Rural	0/0/1 MW	Existing Dairy AD generator
SMUD N-A Feeder	Industrial	TBD/6MW with additional PV generation planned	Ground mounted installations
SMDU R-F Feeder	Residential, Commercial and Industrial	TBD/2MW with potential additional PV planned	Rooftop and over parking installations
HECO 1	Residential, Commercial Mix load	24.5%/900 kW	Existing NEM and commercial SIA rooftop installations
HECO 2	Industrial	21.9%/1.15 MW	Industrial rooftop installations
HECO 2 Backup	Residential, Industrial - Agricultural Load	83%/Approx. 250kW installed with up to 3.5 MW planned	Existing NEMs and new FIT Tier 3 installations; candidate site for applying modeling work to assess pre-PV and post-PV conditions
HELCO Feeder(s)	Commercial	8.6-15%/Approx. 670 kW installed	Unique pumping loads and disproportionate demand on feeders
Maui Feeder	Commercial, Residential Mix	6.34%/176 kW installed with planned additions	Long feeder expected to have market demand