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High-Penetration PV Deployment in the Arizona Public Service System, Phase 1 Update

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***Abstract* — In an effort to better understand the impacts of high penetrations of photovoltaic generators on distribution systems, Arizona Public Service and its partners have begun work on a multi-year project to develop the tools and knowledgebase needed to safely and reliably integrate high penetrations of utility- and residential-scale photovoltaics (PV). Building upon the APS Community Power Project – Flagstaff Pilot, this project will analyze the impact of PV on a representative feeder in northeast Flagstaff. To quantify and catalog the effects of the estimated 1.3 MW of PV that will be installed on the feeder (both smaller units at homes as well as large, centrally located systems), high-speed weather and electrical data acquisition systems and digital "smart" meters are being designed and installed to facilitate monitoring and to build and validate comprehensive, high-resolution models of the distribution system. These models will be used to analyze the impacts of the PV on distribution circuit protection systems (including anti-islanding), predict voltage regulation and phase balance issues, and develop volt/var control schemes.**

This paper continues from a paper presented at the 2011 IEEE PVSC conference that introduces the project and describes some of the preliminary consideration, as well as project plans and early results. This paper gives a status update of the project and presents selected results from Phase 2 of the project. It discusses baseline feeder modeling, load allocation, data acquisition, utility-scale PV integration, preliminary model validation, and plans for future phases.

***Index Terms* – photovoltaic power systems, SCADA systems, data acquisition**

I. Introduction

Over the next 15 to 20 years, renewable energy will meet more than 1,600 MWh of the increase in energy consumption that Arizona Public Service (APS) expects. While much of this energy will come from large power plants, distributed energy will also play an important role in the needs of APS customers. Arizona's Renewable Energy Standard (RES) requires that 30% of APS' renewable energy be generated from distributed energy sources, such as PV systems on customer homes and businesses.

The project described here is taking advantage of the APS Community Power Project – Flagstaff Pilot. The Flagstaff pilot is designed to increase the deployment of renewable energy, especially distributed energy from photovoltaic panels (PV) and provides another opportunity for APS customers to "go solar." Community Power project members host solar electric systems on their rooftops and join with their neighbors to form what can be described as an interconnected renewable power plant. As part of the project, APS owns, operates and receives energy from solar panels on eligible customer sites. Participating customers will benefit from worry-free renewable energy for no up-front cost and an attractive long-term community power rate for a portion of their bill, which will remain fixed at a guaranteed level for 20 years. APS anticipates it will install 1.3 MW of PV as part of the Community Power Project along a feeder in northeast Flagstaff, which serves 2,600 residential and business customers.

The pilot is a part of the APS smart grid initiatives for operation and data collection. Flagstaff is at the forefront of APS's smart grid technology initiatives and APS has been installing automated network distribution switches and remote monitoring equipment that should help improve the responsiveness and reliability of the electric distribution system. This improvement includes the installation of more than 35,000 digital "smart" meters at APS customer homes and businesses. Together with the Community Power Project, smart grid technologies will help APS learn how distributed energy impacts its system and results will be evaluated for applications beyond the Community Power Project.

This paper continues from a paper presented at the 2011 PVSC conference [1]. It summarizes results from Phase 1 and presents selected updates and results from Phase 2 of this five-phase project which focuses on the analysis and simulation of this high penetration PV scenario. More detailed information from Phase 1 of the project can be found in the Phase 1 final technical report [2].

II. Model Development

The goal of Phase 1 and Phase 2 of this project is to develop a baseline model suitable for analysis of high-penetration PV scenarios. Reference [1] describes many of the initial considerations for the selection of the modeling software and the capabilities needed in a model to perform meaningful analysis of high-penetration PV scenarios.

To create the model, the Arizona State University (ASU) lead modeling team needed input from a variety of different data sources within the utility to sufficiently describe the physical system. A summary of the data provided by APS follows:

- GIS data (in both personal geodatabase and file geodatabase formats), which give locations and basic information (e.g. equipment type, rating, etc.) for lines and equipment on the feeder
- APS construction standards for line conductors and spacing
- Transformer impedance data
- Load data, including:
  - hourly/sub-hourly load data for a few customers corresponding to different rate plans
  - hourly load data at feeder head
- monthly energy consumption data at the customer level
- System equivalent impedance at the substation
- PV panel and inverter manufacturers
- In-field voltage measurements for model validation

To fully evaluate the impacts of high penetrations of PV generation on the distribution system, a time-series simulation is needed. To accomplish this, a detailed load model must be developed. This load model must accurately represent the behavior of load including load characteristics such as load diversity and variability, behavioral considerations such as work schedules (weekday/weekend), seasonal impacts on load, etc. For this purpose, project partner GE developed a stochastic load model that seeks to recreate the randomness of loads using historical load data.

The load model also represented generation from the various PV locations throughout the circuit. To accomplish this, the team used a process similar to the load allocation methodology described above.

The methodologies used to create and evaluate both the load allocation and solar generation allocation methodologies are described in detail in [2].

Rather than focus on building a single model to use in this project, the team developed algorithms and methodologies to help facilitate modeling efforts on future high penetration PV circuits. In future phases, the deployed data acquisition systems will be used to validate and refine the model development methodologies developed in the early phases of the project. Additionally, both the load and generation allocation techniques will be evaluated and refined.

III. Data Acquisition

The Flagstaff demonstration is designed to answer several core questions related to high-penetration scenarios. The core questions focus on technical impacts, but also include operational or deployment questions that may provide insight into the structure and methodology for future high-penetration PV demonstrations. This data acquisition context is described in detail in [1] and [2]. A summary of the data acquisition for this project is shown in Table 1.

In addition to substation data, which is already being collected by APS, the team identified several solutions to accomplish the data acquisition goals of this project. The following sections describe these solutions.

A. Advanced Metering Infrastructure

AMI is currently deployed to almost the entire Flagstaff region (~36,000 customers). The study leverages this deployment to provide customer load and customer-sited PV generation data. Following are items to note regarding the AMI deployment:

- The configuration requires a second meter to be installed at the customer site to measure PV production.
- The physical installation required the development of a novel dual-meter socket adapter to allow for a utility side interconnection required for the study.
- Utility AMI systems are generally configured to read 1 (demand) meter per site, and significant modification was required to update business processes and software to allow a second meter to be placed at a customer location.

B. Weather Station

A weather station prototype was constructed at the APS STAR facility to prove design principle and provide a training station for field installation. The weather station prototype consists of weather sensors mounted on a 1-inch rigid pipe upright.

The sensors are wired to a Campbell Scientific (CSI) CR1000 data acquisition system. The weather data are sampled and stored at 1-second interval. A GPS receiver is used to accurately set and maintain the system clock. A wireless radio network is used to create an Ethernet network for communication to the CR1000. Data are transferred to the APS network using the DNP3 protocol over TCP/IP.

CSI LI200X pyranometers are used to measure global horizontal and south-latitude tilt irradiance. A CSI HMP50 temperature and relative humidity probe is used to measure site temperature and relative humidity. A CSI CS106 barometer measures atmospheric pressure. A RM Young heated rain bucket is used to measure precipitation, including snowfall. A CSI wind sentry set is used to measure wind speed and direction.

The CR1000 is programmed to sample data every second. The calibration factors (multiplier and offset) of various sensors are programmed into the CR1000. The barometric pressure reading is refreshed every 15 minutes. Both raw data (mV, Hz, counts) and processed data are stored in a table every second. Each second, the CR1000 receives a text string array from the GPS unit. This text array is parsed and time information is used to synchronize the data logger clock with the GPS clock. Time is only synchronized if adequate GPS signal is acquired. Every second, the CR1000 updates a DNP3 slave table, which is read by a real-time automation controller and the data is fed into the APS time series database. Fig 1 shows the weather data system prototype.

After successful design and evaluation of the weather stations at the STAR facility in Phase 1, the weather stations have been successfully deployed along the feeder.

Fig. 1. Weather data acquisition system prototype

C. Customer Premise Data Acquisition

A 4-kW photovoltaic (PV) system was installed on a mock-up roof at the STAR facility. A customer premise data acquisition system was constructed at the STAR facility to prove design principle and provide a training station for field installation.

The customer premise data acquisition prototype, at the basic level consists of an AMI meter that collects 15-min interval data for all PV generation sites. For a select number of installations, a Schweitzer Engineering Laboratories (SEL) SEL-734P advanced metering system will collect additional power quality information every second. A wireless radio network is used to create an Ethernet network for communication to the SEL-734P Data are transferred to the APS network using the DNP3 protocol over TCP/IP. The SEL-734P time is synchronized to the APS network through the DNP3 protocol. The SEL power quality meter was chosen after considering a number of factors, including the ability to interface to utility communications network and infrastructure, ability to capture information at desired speed and resolution, and ability to be integrated into utility processes for deployment and maintenance.

After successful design and evaluation of the customer premise data acquisition systems in Phase 1, the team deployed these systems at select locations. Data from these systems will be used for analysis and model validation in subsequent phases.

D. Feeder data acquisition systems

Electrical parameters relating to the distribution feeder will be collected using six utility-pole-mounted power quality meters manufactured by SEL. The specific meter to be used is an SEL 735 power quality meter. The project team explored multiple options before finalizing the platform. The final design leverages existing knowledge, infrastructure and processes for maintenance that will allow for a more seamless integration into utility operations for the duration of the study.

The core functionality of this set of data collection devices is that the power quality meters are enabled with cross-device triggering, which will allow the project team to measure and record parameters from six separate locations along the feeder simultaneously. The data measurements can be scheduled to be taken automatically at a certain time, or they can be taken based on a user-defined “trigger,” such as a change in irradiance levels or change in electrical parameters at any of the locations. The device will operate in two modes. In “standard” mode, measurements will be taken every second. In “high bandwidth” mode, the measurements will be taken at a very fast rate (thousands of measurements every second) to ensure that as many fluctuations in grid parameters as possible are captured.

After successful design and evaluation of the feeder data acquisition system in Phase 1, all feeder data acquisition systems have been deployed. These systems will be used in subsequent phases for analysis and model validation.

IV. Inverter Deployment

Part of the project involves the deployment of a 500-kWac utility-scale PV system along with a smart inverter capable of advanced grid support features. The smart inverter is designed and supplied by project member GE. The goal of the inverter testing during Phase 1 of the project was to prepare for the deployment of the inverter at the Flagstaff site during Phase 2. To accomplish this, the inverter was first deployed at the APS Solar Test and Research (STAR) test site.

The inverter was unpacked and commissioned at the STAR facility by GE and APS personnel, and communication was established between the GE inverter/SCADA system and the GE Remote Operations Center. To give APS personnel experience with the inverter before energizing the APS grid, a layout including a load-bank and reverse-power-relay was designed to insure that power would not be transferred from the inverter to the APS grid during the initial testing phases. Once this setup was complete and connected to the satisfaction of both APS and GE, reduced-power testing of the inverter began. Due to dc power limitations at STAR, the inverter output power for testing at STAR was limited to approximately 10% of the inverter's rated power.

Testing resulted in data showing inverter operation on both cloudy and sunny days. During Phase 1, inverter's data-logging system has captured a significant amount of data to be used to for analysis in subsequent phases.

In Phase 2, initial testing of the inverter was completed, and the inverter was installed at the deployment site. Energy production and data collection for this site has begun. The inverter has been initially deployed in a UL 1741-compliant mode with several of the advanced grid support features disabled.

VI. Conclusion

This report presents the results from Phase 1 and as well as the first potion of Phase 2 of this 5 phase high penetration PV project. This portion of the project has focused primarily on model development, data acquisition design and deployment, and utility scale inverter deployment. Major accomplishments of the project thus far include:

- Development of a baseline model suitable for analysis of high-penetration PV scenarios
- Design and deployment of data acquisition systems suitable for analysis and model validation
- Initial evaluation and deployment of an advanced utility-scale inverter

Through the rest of this project, these fundamental steps will provide the necessary models and data necessary to understand the impacts of high penetrations of PV on electrical distribution systems.

More information on this and other DOE-funded high-penetration PV project can be found at the SunShot Initiative High Penetration Solar Portal [3].

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[1] D. Narang and J. Hambrick. "High Penetration PV deployment in the Arizona Public Service system.", 37th IEEE PVSC, 2011.

[2] "High Penetration of Photovoltaic Generation Study – Flagstaff Community Power: Final Technical Report: Result of Phase 1.", http://www.osti.gov/servlets/purl/1036532/

[3] "SunShot Initiative High Penetration Solar Portal." http://solarhighpen.energy.gov.

Table 1 Table 1: Data acquisition summary

Measurement Type		Collection Platform	# Field Locations	Data Interval	Data Availability	Data Points Collected (sample)	Analysis Supported
Environmental Parameters		CSI Data Loggers	7	1 sec	"Real-time"	Solar irradiance, temperature, wind	Steady-State Model Validation, PV O&M, Grid Operations, Cost-Benefit
Customer Load		Elster REX2 AMI Meters	~ 3,000	60 min	Day-behind	kWh	Steady-State Model Validation, Cost-Benefit
PV Inverter Generation	Data Stream 1	Elster REX2 AMI Meters	127	15 min	Day-behind	kWh	Steady-State Model Validation, PV O&M, Cost-Benefit
	Data Stream 2	SEL 734P Power Quality Meters	18	1 sec	"Real-time"	kWh, V, I, kVAr, harmonics, other PQ	Steady-State Model Validation, Grid Operations
Feeder Device Electrical Parameters		Feeder Reclosers	2	10 sec	"Real-time"	I	Steady-State Model Validation, Grid Operations
Feeder Head (Substation) Electrical Parameters		Substation Relay	1	10 sec	"Real-time"	kW, V, I, kVAr	Steady-State Model Validation, Grid Operations
Feeder Point Electrical Parameters	Data Stream 1	SEL 735 Power Quality Meters	6	1 sec	"Real-time"	kWh, V, I, kVAr, harmonics, other power quality	Steady-State Model Validation, Cost-Benefit, Grid Operations
	Data Stream 2	SEL 735 Power Quality Meters	6	8 kHz	Day-behind	kWh, V, I, kVAr, harmonics, other power quality	Dynamic Model Validation