HIGH PENETRATION OF PHOTOVOLTAIC GENERATION STUDY – FLAGSTAFF COMMUNITY POWER
DE-EE0004679
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Project Sponsors and Partners

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Arizona Public Service Company
Arizona State University
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National Renewable Energy Laboratory
ViaSol Energy Solutions
Arizona Corporation Commission
Flagstaff Customers
PV deployment partners/installers
Presentation Overview

- Overall Project Context
- Project Focus
- Results to Date
  > Deployment
  > Modeling
  > Smart Inverter
  > Visualization Tools
- Next Steps
## Overall Project Context
### APS Renewable Generation Portfolio

### Portfolio by Acquisition (as of 2/14/13)

<table>
<thead>
<tr>
<th>Purchase Power Agreements</th>
<th>Online</th>
<th>In Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>APS owned and operated</td>
<td>349 MW</td>
<td>280 MW</td>
</tr>
<tr>
<td>Customer owned and operated</td>
<td>81 MW</td>
<td>49 MW</td>
</tr>
<tr>
<td></td>
<td>237 MW</td>
<td>94 MW</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>667 MW</strong></td>
<td><strong>423 MW</strong></td>
</tr>
</tbody>
</table>

### Variable Generation

- **Wind**: (290MW)
- **Solar CSP**: (280 MW)
- **Solar PV**: (69kV, 19MW)
- **Distributed**: (≤ 21kV, 350MW)
Project Focus

Primary Objective:
Determine how high penetration of PV affects a working utility distribution feeder and study challenges of grid integration

Study Focus Areas:
- Data Acquisition Platform
- Feeder Models
- Grid Support Measures (complementary to PV)
PV Deployment

Residential PV
~ 130 installs / 442 kW

Commercial PV
Cromer Elementary School (400 kW)

Greenfield PV (DPRES)
(500 kW)

APS Study Feeder
Flagstaff, AZ
## Data Acquisition Deployment

### High Penetration Solar Deployment Study – Data Acquisition Summary

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Device/Sensor</th>
<th>Data Collection Location</th>
<th>Time Interval</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Load</td>
<td>Elster AMI meter</td>
<td>All customers on feeder</td>
<td>60m, 15m</td>
<td>2950</td>
</tr>
<tr>
<td>PV Generation</td>
<td>Elster AMI meter</td>
<td>APS FCPP/Solar Host Sites</td>
<td>15m</td>
<td>125</td>
</tr>
<tr>
<td>PV Generation / Power Quality</td>
<td>SEL-734p Power Quality Meter</td>
<td>APS FCPP/Solar Host Sites and 500kW solar site</td>
<td>1s</td>
<td>13</td>
</tr>
<tr>
<td>Environmental Parameters</td>
<td>Campbell Scientific CR1000</td>
<td>7 sites in Flagstaff</td>
<td>1s</td>
<td>7</td>
</tr>
<tr>
<td>Feeder Load / Power Quality</td>
<td>SEL-351 Relay</td>
<td>Feeder's originating substation</td>
<td>10s</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>SEL-735 Power Quality Meter</td>
<td>6 sites along feeder</td>
<td>1s</td>
<td>6</td>
</tr>
</tbody>
</table>
High Penetration Study Modeling – Phase 2

NEW GIS Extract

(Extended) CYMDIST Model

Including Secondaries

New OpenDSS Model

High Penetration
Quantifying $dV(\text{Peak}_{PV})$

- The greatest voltage change does not coincide with the largest PV site!
- Do not overlook the impact of distributed PV!
- Watch out if placing large PV sites in areas of high susceptibility!
Voltage Profile at Highest Penetration

May 4, 2012 at 1pm

Total Loads: 2937 kW
Total amount of PV: 1299 kW
Penetration: 30.66 %
KW Profile at Highest Penetration

KW Profile under 2989th hour
With PVs

KW Profile under 2989th hour
Without PVs

Cromer
Doney Park

May 4, 2012 at 1pm
KVAR Profile at Highest Penetration

May 4, 2012 at 1pm
Steady State Model Validation

- Compare power flow results from simulation tools (CYMDIST vs. OpenDSS)
- Compare simulations vs. field measurements
- Quantify error contribution from:
  - Feeder head voltage drift correction
  - Non-metered loads correction
  - Non-metered PV generation correction
  - Indeterminate phase allocation of distribution transformers
  - Phasing inconsistent/swapped between measured and modeled
  - “Zone” approach to reactive power allocation
  - Fine-tune data retrieval method from PI historian
  - Discrepancy in location of modeled vs. actual DAS locations
Steady State Model Validation (Voltage at DAS 5)

Phase A Voltage (kV)

- Va_measured
- Va_simulated

Pct Error

0.0% 0.6% 1.2% 1.8%

00:00 06:00 12:00 18:00 00:00
Steady State Model Validation - Active Power

One-minute-interval simulated (top) and measured (bottom) DAS02 kW profiles in Sept 26th
One-minute-interval simulated (top) and measured (bottom) DAS05 kVAR profiles in Sept 26th
SMART INVERTER

GE BRILLIANCE™ INVERTER/SUNIQ™
DPRES Installation One-Line

One – line diagram of equivalent circuit showing major grid devices
## Grid Support Demonstration – Data Collected

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Active Power Mode</th>
<th>Power Factor Control Mode</th>
<th>Reactive Power Control Mode</th>
<th>Voltage Control Mode</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Load</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Low Load</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum PV Penetration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunny Day</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fault (if possible)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cap Bank On</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cap Bank Off</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Recloser Operation (if possible)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Day, Slow Clouds</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable day, Fast Clouds</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>Nighttime</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Grid Support – reactive power & voltage control

Line voltage, active power and reactive power at the point of interconnection
December 3-9, 2012

Reactive Power Mode

Voltage Control Mode

Line voltage, active power and reactive power at the point of interconnection
December 3-9, 2012
Grid Support – general observations

2012/12/2 - 2012/12/8

Reactive power mode

Voltage mode

lost the data feed at sub
VISUALIZATION PLATFORM
Visualization Platform

AMI Meters → AMI Data Collector → Meter Data → Cust. Info


Public internet → High Penetration
Visualization Platform

APS Display for Visualization of Real-Time* PV Production & Effects on Feeder

APS Display for Visualization of Real-Time* Irradiance

*Real time production has 90s delay
Integration of Google Earth Platform
Next Steps

- Improve and Validate Feeder Model
- Enable & Test “Improved” GE Voltage Control Mode
- Enable & Test APS Control of GE Inverter Advanced Functions
Dave Narang  
(602) 250-4306 | David.Narang@aps.com

APS High PV Penetration:  

Community Power Project – Flagstaff  

U.S. Department of Energy Solar High Penetration Portal  
https://solarhighpen.energy.gov/

Office of Scientific & Technical Information  
http://www.osti.gov/bridge/product.biblio.jsp?query_id=0&page=0&osti_id=1025589&Row=1&formname=basicsearch.jsp

Q & A AND DISCUSSION