Utility Tools and Design Modifications to Mitigate the Impact of PV on the Distribution System

Pepco Holdings
Utility Tools and Design Modifications to Mitigate the Impact of PV on the Distribution System

SEPA – Utility/Lab Workshop on PV Technology and Systems
Nov. 8, 2010
Overview

- Service Territory & PV Activity
- PV System Impact on the Grid
- Project Screening, Impact Study & Tools
- Approach to Mitigating Issues
  - Fixed Absorbing PF
  - Dynamic Var Capabilities
- Project Examples
  - 595 kW Roof Top System – MD
  - 1.9 MW Ground Mount System – NJ
  - 20 MW Ground Mount System -- NJ
PHI Regulated Utilities
DER Installation Types and Sizes

● Typical installations on PHI Distribution System (thru mid-June 2010)
  – Solar: 1 kW – 2 MW
  – Wind: 1.8 kW – 7.5 MW
  – Methane: 400 kW – 5.7 MW

● Typical proposed installations on PHI Distribution System (thru mid-June 2010)
  – Solar: 2 kW – 100 MW
  – Wind: 1.8 kW – 3.8 MW
  – Methane: none
Distribution System Impacts

Atlantic City Convention Center PV

- **Power Output (kW) 3-19-09**
  - Total Output (kW) – One Minute Data
  - Irradiance (Scaled)

- **Power Output (kW) 3-20-09**

- **Power Output (kW) 3-21-09**

- **Max Power Dev Minute to Minute 3-21-09**
Distribution System Impacts (cont.)

Feeder -- Sunday Load Profile Before and After 1.7 MW PV Installation

Sunday April 25, 2010 (Before PV)

Sunday May 2, 2010 (Before PV)

Sunday May 23, 2010 (1.7 MW PV; 73 F and cloudy)

Sun. May 30, 2010 (1.7 MW PV; 89 F and sunny)

Industrial Load Startup

Cloud Activity

Typical Load Curve w/o PV

Monday Holiday

No Startup

Clear Day
For a 1MW system, the **curtailment ramp rate** would be between -13.0 kW/sec and -50 kW/sec or 0.78 – 3.0 MW/min

The **ramp up rate** would be between 12.0 kW/sec and 52 kW/sec or 0.72 – 3.1 MW/min
Distribution System Impacts (cont.)

- Why do we need to screen?

  Actual voltage recording at the POI of a 4.8 MW DG installation on a 12kV feeder (happens to be landfill gas but energy source makes no difference)

*refer to slide titled “Possible Distribution System Impacts – ANSI C84.1 voltage regulation requirements”
Flicker or Fluctuation Guidelines

“Flicker Curve”

Typical maximum PV variations per hour (wind with puffy clouds)

0.6%


Relations of Voltage Fluctuations to Frequency of Their Occurrence (Incandescent Lamps)
Summary of Issues

- Power and Voltage Fluctuation
  - Ramp up rate
  - Curtailment or ramp down rate
- Steady State High Voltage
  - Ability to mitigate w/o unwanted interaction or hysteresis
- Power Factor Correction – ability to help the feeder w/o unwanted interaction or operation at PFs that reduce real power output or require new capacitors on the feeder
- Central vs Autonomous Control
- Anti-Islanding -- Potential for high voltage if an upstream device opens
- Feeder and Power Transformer cold load pick up
- Area stability – voltage and frequency
Screening

• Initial screening done by System Planning to determine if detailed study and/or special requirements are needed:
  
  – Connections to Existing Feeders (Limit: 3 MWs for sum of installs 250kW and over)
    
    • Determine if there would be high voltage at low load → Impact Study needed
    
    • Determine if the maximum voltage change at peak load is over 0.7V → Impact Study needed, over 0.5V → Approved w/VAR requirements schedule
    
    • Determine if a power flow reversal will occur → Impact Study needed
    
    • If significant other generation exists at the substation or other anomalies → Impact Study needed
  
  – Connections to Express Circuits
    
    • Impact Study Required for all
      
      – Determine highest voltage at point of interconnection
      
      – Review impact on the Under Load Tap Changer of the substation transformer w/ and without Dynamic Var Compensating Inverter
**Impacts to a Distribution Feeder**

- Impact severity depends on:
  - Electrical characteristics looking back into the ACE electric system from the location of the DG
  - Daily load profiles during various times of the year
  - Maximum output of DG
  - Substation transformer settings
  - Location and settings of regulators, capacitors, and reclosers

Typical ACE Distribution Feeder

- Concentration of homeowner rooftop installations would have same effect

adapted from actual DG customer application
Non-Dynamic Var Control

- Method: Set an absorbing Var schedule, for example:
  - For hours associated with 0-50% output, 0.99 PF
  - For hours associated with 50+-75% output, 0.98 PF
  - For hours associated with 75+-100% output, 0.97 PF
  - (or use the lowest PF for operations at all times)

- Mitigates some of the voltage fluctuation due to power output changes of the PV system by reducing var absorption when power output is reduced.

- $\Delta V = \Delta P/V_0 \times R + \Delta Q/V_0 \times X$
**Dynamic Var Control**

- For larger systems, for example 3 MWs or greater, or where an absorbing PF of greater than 0.95 would be needed at peak.
  - Set what the system will ride thru – voltage, frequency, etc.
  - Controls normally set to control the voltage at POI
  - Requires Droop setting and Time Delay setting to mitigate interference with existing automatic line equipment
  - Would be nice to be able to only mitigate for voltage fluctuations caused by PV power output fluctuations
  - Generally requires an external tripping signal from utility

- Delta V = Delta P/Vo * R + Delta Q/Vo * X  (System Impedance at Point of Interconnection to be supplied for setting inverter).
595 kW PV System
595 kW PV System

- Customer requested approval for 595 kW PV Distributed Generation (2 - 260 kW arrays & 1 – 75 kW array)
- Feeder is 5 miles long – small wire size – X/R ratio at the PV site is 1
- Three sets of voltage regulators to maintain voltage within tolerance
- Voltage regulators operate on 30 second, 45 second, and 60 second delays – mechanical tap adjustments – excessive adjustments will lead to premature failure
- Because of the nature of the circuit PHI had concerns about the effect of cloud shear on the circuit voltage – would the regulators have adequate time to act?
- Substation has twelve feeders – no impact expected on the bus
595 kW PV System

- Initial study: 4 Power Flow cases
- Ran a Peak Load Case and a Light Load Case (with the sun shining) for the circuit with the generation in operation
- Locked Voltage Regulator Taps – removed generation – Ran cases with changes
- Results showed appreciable change in voltage
- Needed further review to approve the whole facility
- PHI performed study with one of the customer’s three units – change in voltage was acceptable
- PHI approved one array (260 kW) for operation
595 kW PV System

- PHI provided system data and customer data to study consultant who constructed circuit model in MATLAB
- Quasi-static Power Flow study was performed across daylight hours for selected days
- To model effect of irradiance changes due to cloud shear the consultant staggered cloud shear across the three solar arrays at the customer
- The consultant modeled the effect of Power Factor Scheduling on the customer PV arrays – results showed that voltage rise could be effectively controlled, minimizing voltage fluctuation and voltage regulator adjustments
595 kW PV System

Output Quasi-static Power Flow Study

Results provided for each phase over the course of the study day

Study performed by Northern Plains Power Technologies (NPPT)
595 kW PV System

Effect of Power Factor Schedule on Voltage at the Customer Bus

- Power factor schedule used in simulation.
- 0 - 50% Output - 0.99 Power Factor
- 50 - 75% Output - 0.98 Power Factor
- >75% Output - 0.97 Power Factor

Study performed by Northern Plains Power Technologies (NPPT)
1.9 MW PV System
1.9 MW PV System – 3 Options to Mitigate Voltage Issues

<table>
<thead>
<tr>
<th>Summary Table</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Maximum Steady State Voltage (V)</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Without Mitigation</td>
</tr>
<tr>
<td>Absorbing Power Factor Solution**</td>
</tr>
<tr>
<td>500KVA/1500kWh Battery Solution</td>
</tr>
<tr>
<td>750KVA/3000kWh Battery Solution</td>
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<tr>
<td>477 AAC Reconduct</td>
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</tbody>
</table>

*All Maximum Steady State Voltages occurred during low load,*

**Absorbing Power Factor of .97 was used for this study**

***The battery storage solution is unlike the other solutions and may have other operating value streams but also may have maintenance and/or replacement costs over the life of the solar system. These have not been investigated and included in this comparison.*
20 MW Solar Project on Express Feeders

20 MW Solar PV Project

69/12 kV Sub

69/12 kV Substation

New Sub 69/12 kV

12 kV Bus

10 MW

New Feeder NJ xxx

Approximately 59,100 ft of PAC Cable

Recloser

ACE Pole

Number to be determined

PV Solar Generator

10 MW

New Feeder 69/12 kV

POI

10 MW

69/12 kV Sub

69/12 kV Substation

New Sub 69/12 kV

12 kV Bus

10 MW

New Feeder NJ xxx

Approximately 66,000 ft of PAC Cable

Recloser

ACE Pole

Number to be determined

PV Solar Generator

10 MW

New Feeder 69/12 kV

POI

10 MW
### 10 MW Solar Injection with and w/o mitigation

<table>
<thead>
<tr>
<th>20 MW PV System</th>
<th>Maximum Steady State Voltage at PV Site (V)</th>
<th>Maximum Voltage Fluctuation at the PV site (V)</th>
<th>Maximum Voltage Fluctuation at the Substation Bus (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Mitigation</td>
<td>134.4</td>
<td>7.0</td>
<td>0.8</td>
</tr>
<tr>
<td>With Mitigation:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-0.98 Absorbing Power Factor</td>
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<tr>
<td>-103V LTC Reference Voltage</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>-Volt. Reg. 3.4 mi. downstream from Substation set to 118V</td>
<td>124.4</td>
<td>6.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Opportunities for Inverter Solutions

- Non-Dynamic Var Control
- Dynamic Var Control
- Autonomous Control with Central System input
- Anti-Islanding Opportunities
- Storage Opportunities
- Capacity Opportunities
- Auxiliary Services Participation
- Active Feeder Control - participation
Questions

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