CSI3 RD&D3: Screening Distribution Feeders: Alternatives to the 15% Rule

Task 6 Update: PV Hosting Capacity Analysis of PG&E Feeders

10/07/2014
Overview

• Background
  – More PV interconnected at distribution level than any other DG
    • Small rooftop PV
    • Large, MW-class systems
  – Increased pressures for utilities to
    • accommodate higher levels of PV
    • expedite interconnection process

• Project Objective: Develop new methods to quickly and accurately determine the capacity of individual feeders for PV generation
  – Consider size/location of PV and specific feeder characteristics
  – Evaluate impact on voltage (overvoltage, voltage fluctuations), regulation equipment, protection, thermal loading/reverse power
Why Consider Alternatives to Existing Screening?

- Feeder’s ability for hosting PV w/o adverse impact on performance depends upon many feeder-specific factors.
- 15% “rule-of-thumb” is not very accurate in determining whether an issue may arise.
- Simple characteristics used to classify/screen feeders (i.e. peak load level) may not be sufficient.
- Example illustrates different hosting capacity for “similar” circuits.

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Sample feeders from DOE-funded VT/EPRI Hi-Pen Project

<table>
<thead>
<tr>
<th>Feeder Characteristics</th>
<th>Feeder A</th>
<th>Feeder B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (kV)</td>
<td>13.2</td>
<td>12.47</td>
</tr>
<tr>
<td>Peak Load</td>
<td>5 MW</td>
<td>6 MW</td>
</tr>
<tr>
<td>Minimum Load</td>
<td>0.8 MW</td>
<td>0.7 MW</td>
</tr>
<tr>
<td>Minimum Daytime Load</td>
<td>1.1 MW</td>
<td>0.7 MW</td>
</tr>
<tr>
<td>Existing PV (MW)</td>
<td>1.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Feeder Regulation</td>
<td>Only @ Substation</td>
<td>Yes, highly regulated</td>
</tr>
<tr>
<td>Total Circuit Miles</td>
<td>28</td>
<td>58</td>
</tr>
<tr>
<td>Feeder “Footprint”</td>
<td>7 mi²</td>
<td>35 mi²</td>
</tr>
<tr>
<td>Minimum Hosting Capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Due to Voltage Impacts</td>
<td>&gt;3500 kW</td>
<td>250 kW</td>
</tr>
</tbody>
</table>

70% of Peak Load

4% of Peak Load
Approach

- Document current practices
- Determine the range of feeders in CA
- Collect high-res PV data for model development & screening validation
- High-pen PV analysis
- Develop screening methods
- Validate screening methods

Hosting Capacity Methodology Status Update Provided in this presentation
Leveraging Work Throughout Industry

From Research to Application

2010
Development of “Hosting Capacity” Method for Hi-Pen PV Analysis
EPRI Project

2011
Hosting Capacity Analysis
>20 feeders throughout US
EPRI Project

2012

2013
Development of Alternate Screening Methods using Hosting Capacity Analysis
15 feeders
CPUC/EPRI/DOE Project
Agenda

- CPUC CSI3 Project Update
- Distributed PV Study Overview
- Study Feeders
- Results
- Simplified screening
# Project Status

<table>
<thead>
<tr>
<th>Feeder data collection</th>
<th>PG&amp;E</th>
<th>SDG&amp;E</th>
<th>SCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clustering analysis to identify general differences **</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Select one feeder from each cluster to represent span a range of feeder characteristics</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feeder analysis</th>
<th>PG&amp;E</th>
<th>SDG&amp;E</th>
<th>SCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model feeders in OpenDSS</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Run detailed PV hosting capacity analysis</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Aggregate results</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

Develop Improved PV Screen

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** Clustering Method and Representative Feeder Selection for the California Solar Initiative, Authors: Robert J. Broderick, Joseph R. Williams, Karina Munoz-Ramos (SAND2014-1443, 1.41MB)
Detailed Feeder Study Overview

Methodology Utilized in Industry-Wide Distributed PV (DPV) Study
DPV Feeder Analysis: Hosting Capacity
What are we trying to achieve?

• Better understanding of when, where, and why problems might occur on my feeder
• What are the limiting factors
• Why can one feeder accommodate more than another
• What makes one feeder more problematic than another
• ...

What is Hosting Capacity?
Amount of PV that can be accommodated on a given feeder without impacting reliability or power quality
Overall Approach

- Detailed feeder model in OpenDSS
- Add PV at customer level
- Evaluate 1000’s of possible solar PV deployments
- Considering different load levels
- Considering small rooftop and large MW-class PV

**Feeder Model in OpenDSS**

- Analyze Feeder Impacts
  - Voltage Protection
  - Power Quality
  - Thermal

**Feeder Hosting Capacity**

Evaluation Criteria

- **Voltage**
  - Overvoltage
  - Voltage deviations
  - Unbalance

- **Protection**
  - Increased fault current contribution
  - Sympathetic tripping
  - Reduction of reach
  - Unintentional islanding
  - Fuse saving

- **Power Quality**
  - Total harmonic distortion
  - Individual harmonics

- **Loading**
  - Thermal overloads
# Feeder Impact

## Hosting Capacity Response Thresholds

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
<th>Basis</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Voltage</strong></td>
<td>Overvoltage</td>
<td>Feeder voltage</td>
<td>≥ 1.05 Vpu</td>
</tr>
<tr>
<td></td>
<td>Voltage Deviation</td>
<td>Deviation in voltage from no PV to full PV</td>
<td>≥ 3% at primary</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥ 5% at secondary</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥ 1/2 band at regulators</td>
</tr>
<tr>
<td></td>
<td>Unbalance</td>
<td>Phase voltage deviation from average</td>
<td>≥ 3% of phase voltage</td>
</tr>
<tr>
<td><strong>Loading</strong></td>
<td>Thermal</td>
<td>Element loading</td>
<td>≥ 100% normal rating</td>
</tr>
<tr>
<td><strong>Protection</strong></td>
<td>Element Fault Current</td>
<td>Deviation in fault current at each sectionalizing device</td>
<td>≥ 10% increase</td>
</tr>
<tr>
<td></td>
<td>Sympathetic Breaker Tripping</td>
<td>Breaker zero sequence current due to an upstream fault</td>
<td>≥ 150A</td>
</tr>
<tr>
<td></td>
<td>Breaker Reduction of Reach</td>
<td>Deviation in breaker fault current for feeder faults</td>
<td>≥ 10% decrease</td>
</tr>
<tr>
<td></td>
<td>Breaker/Fuse Coordination</td>
<td>Fault current increase at fuse relative to change in breaker fault current</td>
<td>≥ 100A increase</td>
</tr>
<tr>
<td><strong>Harmonics</strong></td>
<td>Individual Harmonics</td>
<td>Harmonic magnitude</td>
<td>≥ 3%</td>
</tr>
<tr>
<td></td>
<td>THDv</td>
<td>Total harmonic voltage distortion</td>
<td>≥ 5%</td>
</tr>
</tbody>
</table>
Stochastic PV Deployment

Baseline – No PV
PV Penetration 1
PV Penetration 2
PV Penetration 3
Beyond…

Process is repeated 100s of times to capture many possible scenarios

Increase Penetration Levels Until Violations Occur

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Feeder Response

- Feeder-wide impact analyzed for each potential PV deployment
- Range in hosting capacity reported for each issue

Minimum Hosting Capacity

Maximum Hosting Capacity

Increasing penetration (MW)

Increasing penetration (MW)

Minimum Hosting Capacity

Maximum Hosting Capacity

Worst-Case Result for Each Unique PV Deployment

A – All penetrations in this region are acceptable, regardless of location

B – Some penetrations in this region are acceptable, site specific

C – No penetrations in this region are acceptable, regardless of location

Threshold of violation

Details on analysis method:
Voltage and Protection

Small Scale PV
Small, single and three-phase rooftop located at customer loads

Large Scale PV
Large, stand-alone three-phase systems located on any three-phase point

171,000 Simulations per Feeder
Study Feeders
Peak Load Voltage Profiles
Small Scale PV
Feeder 2885 Trends

- Trends evident with increased PV penetration
- Not all issues have adverse impacts
Feeder 2885 PV Hosting Capacities

Yellow region identifies PV locational impact to feeder hosting capacity is greater for voltage issues.

Protection
- Overall
- OpenPhaseV
- FFault
- FuseSave
- MaxV
- RedReach
- SymTrp

Voltage
- SecondaryOV
- SecondaryVdev
- PrimaryImb
- PrimaryRegVdev
- PrimaryVdev
- PrimaryOV

LDC and 1.5V band
Feeder 2885 PV Locational Impact

Voltage Magnitude

Voltage Deviation

- PV location approximated by “Weighted Average Resistance”
- Trends evident with PV location
Issue Specific Results

- Significant difference in hosting capacity based on feeder cluster

First Issue
Overall Small Scale PV Results

- Maximum small scale PV penetration dependent total feeder load
- Higher analyzed penetrations would show similar adverse issues
Large Scale PV
Issue Specific Results

Ungrounded PV Protection

Feeder 888
- Grounded PV Protection
- Voltage
- Can go to higher penetrations
- Can be in more non-optimal locations
- Los Gatos and Newark now show potential issues

Feeder 1354
- Grounded PV Protection

Feeder 2885
- Grounded PV Protection
- Voltage

Feeder 281
- Grounded PV Protection

Feeder 2093
- Grounded PV Protection

First Issue
Characteristics Correlated to Minimum Hosting Capacity for Primary Overvoltage

Greater dependency on
- Voltage
- Resistance to PV

Percent of load screens over/under estimate hosting capacity

- 2093
- 281
- 2885
- 1354
- 888
How does Primary Voltage Deviation Hosting Capacity Relate to PV Characteristic Location

Hosting Capacity exponentially increases with decreased resistance.
Where are the Feeder Violations with Respect to the PV Characteristic Location

Violation electrically closer in than PV

Violation electrically close to PV

Violation electrically further out than PV

Skewed due to PV/fault locations
Loading does not Dictate Hosting Capacity but does have an Influence

Hosting Capacity typically decreases with load

Hosting Capacity typically increases with load, but with LDC the inverse is true
Harmonics with High Penetration PV

Impact of PV is examined as a change from base case without PV. Causes of high harmonic increases:

+ Low load
+ More capacitors
Overall Large Scale PV Results

- Maximum large scale PV penetration dependent on kV class
- Higher analyzed penetrations would show similar adverse issues

Feeder 2093
Feeder 281
Feeder 2885
Feeder 1354
Feeder 888

Primarily influenced by protection issues (high ground fault contribution)
Primarily voltage-based issues
Small-Scale Issue Specific Results

PG&E

Feeder 888
13-Overall
12-OpenPhaseV
11-Fault
10-FuseSave
9-MaxV
8-RedReach
7-SymTrp
6-SecondaryOV
5-SecondaryVdev
4-Primaryimb
3-PrimaryRegVdev
2-PrimaryVdev
1-PrimaryOV

Feeder 1354

Feeder 2885

Feeder 281

Feeder 2093

SDG&E

Feeder Issue

Feeder Issue

Feeder Issue

Feeder Issue

Feeder Issue

Feeder Issue

Feeder Issue

Feeder Issue

Feeder Issue

Host Cap (MW)
Large-Scale Issue Specific Results

PG&E

Feeder 888

SDG&E

Feeder 1354

Feeder 2885

Feeder 281

Feeder 2093