Utility-Scale Distribution-Connected PV in Southern California: Modeling and Field Demonstration Results

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Integrating PV in Distribution Grids: Solutions and Technologies
NREL/SCE Hi-Pen PV Integration Project

- Impetus – in 2009 SCE received approval to install 500 MW of distribution-connected PV in their service territory
- Focus – developing new “rules of thumb” for utility planning engineers for interconnecting large (1-5MW) PV systems on medium voltage (MV) distribution circuits and developing methods to reduce the PV impacts on these systems
- Goal – easing the interconnection concerns of utilities faced with utility-scale distribution-connected PV systems, enabling utility engineers to correctly assess a PV systems potential circuit impacts, and demonstrating that there are current methods for mitigating the impacts of high-penetration PV that can be implemented in the near-term for low cost
**NREL/SCE Study Circuits**

- **Fontana Characteristics:**
  - 4.5 MW of PV
  - 2 PV systems
  - 12 kV
  - Commercial circuit

- **Palmdale Characteristics:**
  - 3 MW of PV
  - 2 PV systems
  - 12 kV
  - Rural circuit
  - Extremely lightly loaded

- **Porterville Characteristics:**
  - 5 MW of PV
  - Single PV system
  - 12 kV
  - Rural circuit
  - 40 miles total length

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Developed a PV Impact Methodology Based on Salient Operating Points

- Investigated PV impact mitigation techniques on the study circuit – utilizing advanced PV inverter functionality
- Assumed worst case PV ramping
- Investigated three loading levels
- Tried to minimize voltage variations below “Noticeability”

Comparison of Quasi-Static Time-Series and Transient Simulation Analysis Techniques

IEEE 8500 node test feeder model

- Evaluated quasi-static time-series analysis results at multiple time steps over a 16 minute period
- Analysis run times are on the order of 5 hours for PSCAD and 5 seconds for OpenDSS

Fontana: Data Acquisition Deployment

Auto-Cap 1.8 MVAr

1.5 MW PV
Auto-Cap 1.8 MVAr

3 MW PV
Auto-Cap 1.2 MVAr

Adjacent Feeders

PS
Auto-Cap 1.2 MVAr

Time of Day

Line Current [A]

Auto-Cap 1.8 MVAr

1.5 MW PV

Time of Day

Line Current [A]

1.2 MVAr

12AM 6AM 12PM 6PM 12AM

0 20 40 60 80 100 120 140 160 180 200

$\phi_A$
$\phi_B$
$\phi_C$

12AM 6AM 12PM 6PM 12AM

0 20 40 60 80 100 120 140 160 180 200

$\phi_A$
$\phi_B$
$\phi_C$

12AM 6AM 12PM 6PM 12AM

0 20 40 60 80 100 120 140 160 180 200

$\phi_A$
$\phi_B$
$\phi_C$
Case Study: Porterville, CA Study Circuit

- 5 MW PV fixed-tilt system near the end of the circuit (about 7 miles from the start-of-circuit)
- Circuit is typically lightly loaded (dominated by agricultural pumping load)
- Voltage along the circuit is regulated by switched capacitors
Determining Mitigation Strategy

PV Impact Assessment Method – Expanded to Determine PV Mitigation Strategies

- Applied PV Impact Assessment Method (3 salient loading levels)
- Added PV mitigation measures to model and evaluated the effectiveness and “performance” cost of implementing the mitigation measure
- Tried to minimize voltage variations below “Noticeability”

Field Measurements Show Impact

Validated PV assessment method using PV impacts measured on the study circuit

Voltage near PV system – Mostly Sunny Day

Voltage near PV system – PV Offline

Demonstration of Adv. Functionality Ability

- All 10 PV inverters were adjusted to operate at an inductive power factor of 0.95.
- On the 5th day of the demonstration 2 inverters reverted to unity power factor operation (reasons unclear)

During the demonstration period voltage at the PV system’s interconnection was less variable.

Voltage is about 400 V lower or 0.03 per unit.
Impact of Mitigation – Reactive Current

- During the demonstration period current (magnitude) at the start-of-circuit is higher due to reactive current flows.
- Additional current on the circuit is modest.
- Mitigation technique seems compatible with voltage control scheme.
- Allows aggregation of variable reactive current flows at sub-trans./trans. sys,
Looking forward – What to expect next

This study looked at what distribution-system-level impacts should be expected at even higher rates of PV penetration (up to 300%)

Study findings (generally stated):
• Impact types remain the same – voltage is still dominant impact
• Mitigation becomes more complicated
• 100% loss and return assumptions become increasingly conservative

Developed under the auspices of the NREL/SCE Hi-Pen PV Integration Project Specifically for Distribution Engineers:

• Condensing the experience gained and research results of the entire project into a handbook for use by distribution engineers facing hi-pen integration challenges in their service territories

• Research expanded to include utility practices and operations beyond just SCE’s current practices and operations (i.e. using capacitors as their sole method of voltage regulation)

• Reviewed by practicing distribution engineer experts working on PV interconnection
Thank you for your attention.

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