Distribution Operations with High-penetration of Beyond the Meter Intermittent Renewables

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SCE provides power to:
- Nearly 14 million people
- 180 cities in 50,000 sq mi
- 11 counties in central, coastal and southern California
- Commercial industrial and nonprofit customers, including:
  - 5,000 large businesses
  - 280,000 small businesses

To deliver that power, it takes:
- 16 utility interconnections
- 4,990 transmission and distribution circuits
- 425 transmission and distribution crews
- More than a century of experience
Background

• Significant amounts of generation are being proposed for interconnection to SCE’s distribution systems.

• High influx of proposed generation has resulted from state sponsored programs such as:
  – Solar Photovoltaic Program (SPVP) – 500 MW of PV generation mostly installed on roofs of large warehouse buildings
  – Feed-in programs such as the California Renewable Energy Small Tariff (CREST)
  – Net Metering Program – Primary residential and commercial
  – Others

• Distribution systems where not originally designed for generation.

• System operations, planning, and standards need updates to account for distributed generation being connected to distribution feeders.

• New technology operating characteristics are just now being understood.
Identified Grid Integration Issues

• Protection
• Field Engineering
• Operations
Protection Issues

- **Overall circuit protection coordination**: Problems arise on project by project basis. Integrate more sophisticated protection schemes as needed. Problems occur on long, weak distribution circuits.

- **Directional over-current relay capabilities for reverse current flow**

- **Coordination with inverter protection to avoid breaker reclosing into hot line**

- **Fault current effects on breaker ratings**

- **Ground fault detection at the inverters**

- **No known issues with subtransmission and transmission protection**

- **No major issues**

- **More analysis needed**

- **Steps need to be taken**
Example Protection System
Distribution Upgrade

Substation
Low MT settings

Long Circuit
Small wire - high impedance

Weak electrical system
3Φ Short Circuit

- Inverter #2 (top figure)
  - $I_{SC} = 163\%$ of full load for 1st cycle
  - $I_{SC}$-Average = 110%
  - Typical rotating generator fault current is 600-800% of full load

- Inverter #3 (bottom figure)
  - $I_{SC} = 120\%$ of full load for 1st cycle
  - $I_{SC}$-Average comparable to steady state

- Trips off in less then 10 cycles
Field Engineering Issues

- **Voltage regulation***
  - Steady-state voltage regulation issues
  - Inverter system can help if properly designed/operated

- Remote switching capability

- Inverter monitoring

- Lack of standard communications protocol

- Harmonic issues on distribution circuits

- No major issues
- More analysis needed
- Steps need to be taken
Voltage Regulation – Peak Case

(High load with and without high PV generation)

- PV helps maintain voltage at acceptable levels by lowering the voltage drop (top figure)
- PV disconnection reveals low voltage conditions (bottom figure)
  - Some circuits are OK
- Caps will help maintain the voltage at acceptable levels when no PV is present
Transient Voltage Regulation During Cloudy Days

- Voltage regulation utilizing switched capacitors or voltage regulators is designed for slow (minutes) changes.
- On a specific circuit, variations in solar output can exceed the capability of existing voltage regulation.
- Use of inverter volt/var control could help this situation as long as it does not "fight" existing measures.
Operations Issues

- Switching impacts resulting from large levels of DER
- Transient over-voltage when islanded with little load
- Fault ride-through and system level impacts
- Distribution System Operations
- Training

- No major issues
- More analysis needed
- Steps need to be taken
Transient Over-voltage (TOV)

- Caused when an inverter is disconnected from its load while in operation with little or no load remaining
- Voltages up to 250% of normal are experienced for a few cycles
- Can affect the inverter and connected metering
- Can affect a circuit or circuit section if there is a large amount of inverter-based generation with little load
- Can affect the ability of a disconnect switch to separate an operating inverter from the grid
Inverter TOV Before & After

- Inverter behavior can be improved with firmware updates
- Faster response can be obtained by sensing instantaneous voltage instead of rms for tripping the inverter
- Lab test have verified improvement (see Before and After graphs to the right)
Inverter Advanced Features
Inverter Advanced Feature Tests

• Output Ramp Rate Limitation
• Voltage and Frequency Ride Through
• Over-frequency Power Limitation
• Volt/var Control
  – Power Factor Control
  – Over-voltage Behavior
  – Under-voltage Behavior
• Auxiliary Power Output (on loss of grid)
Ride Through (voltage and frequency transients)

• Needed in high penetration scenarios to avoid loss of distributed generation

• Requirements based on NERC Standard PRC-24?
  – “Ensure that generators remain connected to the Bulk Electric System during voltage and frequency excursions within the defined criteria of this standard in coordination with other system protection schemes to support transmission system transient stability.”

• IEEE 1457/ CA Rule 21 are looking at setting ride-through times for over/under voltage and frequency operation

• Potential conflict with anti-islanding algorithm – although nothing seen in tests to date
Under-voltage Ride-through

- Inverter continues to produce power for period of time as long as voltage is above threshold (40% in this case)
- This prevents loss of generation during under-voltage events when support is needed

Power Limited to Watt Rating

Power Output Limited by Current
Over-frequency Power Limitation

- Power output in reduced as frequency rises above threshold (60.2 Hz in this case) and resets when back to threshold
- Reduces generation to help over-generation cases
Volt/var Control – Over-voltage

- As inverter voltage rises, reactive power is withdrawn from grid to help reduce voltages.
- Three cases: no support, 1% ramp rate, and 3% ramp rate (relationship between real and reactive power).

Absorbed vars Limit Over-Voltage
Summary Thoughts for DG Integration
Typical Distribution Upgrades

• Areas with low penetration
  – Switching devices
  – Line extensions

• Areas average penetration
  – Cable/Conductor upgrades
  – Protection devices
  – Voltage regulating devices

• Areas with high penetration
  – New distribution circuits

• Areas with very high penetration
  – Substation transformer upgrades

• Areas with extreme penetration
  – Sub transmission/transmission upgrades
Need to Improve Inverter Standards

- **IEEE 1547**
  - Developed with low penetration in mind
  - Does not allow:
    - Volt/var control
    - Low-voltage ride-through
    - Staggered/ramp-up restart
  - Does not address:
    - Transient overvoltages
    - Higher order harmonics
  - Standard amendment in progress to address volt/var and ride-through
  - Full standard is also under revision, but will take time

- Will need to modify UL 1741 and Calif. Rule 21 also
Contemplated Inverter Characteristics

- Ability to help regulate voltage and var flow
- Fast overvoltage protection when islanded (TOV)
- Limited fault current contribution
- Ability to communicate in a standard manner for monitoring and control
- Potential for fault ride-through (voltage and frequency)
- Low harmonic distortion of output current including higher frequency PWM components
- Ability to curtail power level remotely
- Staggered/ ramp-up restart
- Damp voltage and frequency oscillations
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