Streamlining Protection Requirements for Generator Interconnections
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DG Protection Issues

With the proliferation of DG: 5k-6k/mo.

- Safety still needs to be the primary protection goal!

- Faulted conditions shall be detected and all generation tripped from the faulted circuit.
DG Protection Issues

- **Equipment Damage**
  - Timely fault clearing minimizes equipment damage.
  - Accomplished by isolating the faulted component as quickly as possible.
DG Protection Issues

• Fault types
  • Phase faults
    • Phase-Phase
      • Slack span, wind, car pole or other force cause the conductors to slap together.
    • Three phase
      • Down pole, storm, car pole, or other conductor failure.
  • Open conductor
    • Failure of conductor, splice or insulator
DG Protection Issues

• Fault types (cont.)
  • Ground faults
    • Phase-ground
      • Tree contact.
      • Conductor down from various means.
  • Combination faults
    • Double –Line ground
      Multiple phase conductors and ground involved.
DG Protection Issues

• Generation Type Characteristics During Faulted Conditions:
  • Synchronous
  • Induction
  • Inverter Based
• Each type has a different fault current response.
DG Protection Issues

• Generation fault current characteristics
• Synchronous Generation
  • Has the rotational inertia of the rotor and excitation of the field.
  • Fault current generally not limited by machine output.
  • Produces phase fault current in 3 stages.
    • $X''$d Subtransient: High level fault current (8-12pu) typically lasts approximately 5-6 cycles
    • $X'$d Transient: Lasts 10-12 cycles
    • $X$s Synchronous: Fault current magnitude can range from 1.0 – 1.2 pu.
DG Protection Issues

Synchronous Generation

Typical Synchronous Generator Current Decrement Plot

\[ i = \{(id'' - id')e^{-(t/Td'')}\} + \{(id' - id)e^{-(t/Td')}\} + id \]
DG Protection Issues

• Generation Characteristics during faulted conditions. (cont.)
  • Induction Machines
    • Are not self excited, do not have sustained high current.
    • Large machines may have initial high current, 6x, but quickly decays to minimal or no short circuit current.
    • Exception:
      • If capacitance or other form of reactive component is electrically close the unit, it will self excite and supply fault current, for a short time until the capacitance decays due to the fault.
DG Protection Issues

• Generation Characteristics during faulted conditions (cont.)
  • Inverter-based Generation
    • PV (photovoltaic)
      • Does not have the rotational inertia of the rotor and excitation of the field.
      • Produces low level fault current typically 1.1-1.3 pu
      • PV generation fault output is limited to available solar energy.
DG Protection Issues

- Generation Characteristics during faulted conditions.
  - Inverter-based Generation
    - Wind
      - Uses induction machines which are generally not self excited.
      - Output is shaped via an inverter, which typically has a “crowbar” feature clamping max fault current to 1.0-1.3 pu
DG Protection Issues

- Protection typically installed on Generator
  - Voltage Restraint Overcurrent (51V)
  - Voltage Control Overcurrent (51C).
  - Distance (step distance) (21).
  - Ground Overvoltage (59N)
DG Protection Issues

• Methods of Fault Detection
  • The protection elements below lend themselves well to synchronous generation:
    • Voltage Restraint Overcurrent (51V) – reduces its pick-up value proportional to measured voltage.
    • Voltage Control Overcurrent (51C). – overcurrent element is enabled at a low voltage threshold.
    • Distance (step distance) (21). Measures impedance of the protected zone, a subsequent fault reduces impedance into the trip zone resulting in a trip.
DG Protection Issues

• Methods of Fault Detection
  • Ground faults
  • Ground faults can be detected by use of grounding banks.
    • The grounding bank is configured to measure broken delta (3Vo) voltage.
DG Protection Issues

- Methods of Fault Detection
  - Ground faults
  - Ground faults can also be detected by use of ground overcurrent relay on Wye/Delta XFMRs
    - The overcurrent relay is wired in the neutral of the Wye/Delta XMFR to measure Neutral Ground Overcurrent (3Io).
DG Protection Issues

- Typical Protection Minimum Pick-up Settings.
  - Phase Overcurrent.
    - 60% of minimum 3 phase fault current (derived from fault study).
    - At least 120% over maximum load.
  - Ground Overcurrent.
    - 50% of minimum ground overcurrent. (derived from fault study).

![Diagram of electrical system with labels: Gen, Igen, Va, Ia, Close-in fault, EOL, Ib, Vb]
DG Protection Issues

- Traditional Methods of Fault Detection
  - They do not work well for phase faults with Inverter-based generation.
    - Due to the low level of fault current.
    - The variable nature of renewable generation.
      - Cannot set the protection low enough without limiting full rated output.
  - Ground fault detection can be implemented with Inverter-based generation. Since the interconnecting XFMR is a Wye/Delta, broken delta voltage or zero sequence current can be monitored.
DG Protection Issues

• Alternative Protection Methods:
  • DTT – System protective element sends trip to generation via communication.
    • Expensive to implement and maintain.
  • Allow load to swamp the generator.
    • 2X load is required to ensure generation is swamped, via UV elements.
    • Higher penetration on distribution feeders is making this difficult to achieve.
    • Undervoltage, or negative sequence elements may be applied but may not operate for a high impedance fault and negative sequence may not operate for a three phase fault plus it’s difficult to coordinate with other ground elements.
  • Use of UL 1741 “Anti-Islanding” certification.
    • Most common method is frequency bumping, however interaction with other generation may desensitize or defeat the scheme.
DG Protection Issues

DTT Schemes
Radial System Configuration

Source
Station A

Trip Generator

DTT

CB A

Distribution Substation
DG Protection Issues

DTT Configuration Types

Loop Substation applicable if generation backfeeds on to the transmission

Distributed connected generation

- Trip Gen if both remote DTT’s are initiated.

Station A and B have multiple sources
DG Protection Issues

DTT can be expensive and time consuming to implement (250k per terminal for lease line) in addition to reoccurring lease line cost.

• Implementing a lease line DTT Reduction Strategy.
  • Approved Use of 900Mhz spread Spectrum Wireless for DTT application.

• Developed DTT exemption process for evaluation of interconnections to remove the need for DTT.
  • Utilizing certified anti-islanding for tripping
  • Based on size of generator in relation to load and other generation on line section.
DG Protection Issues

900 Mhz Spread Spectrum DTT Components

Source Station 1

Transmitter SEL 3031

Protection Trip to Gen

Protection Trip to I/O Device

Receiver SEL 3031

Trip Generator Breaker

SEL 3031
Even with the exemption paper and adoption of the 900Mhz spread spectrum DTT system, a more streamlined protection approach was needed.

The major issue was whether a feeder with mixed certified inverters would interfere with each other resulting in delayed tripping > 2seconds.

Comprehensive testing was needed to evaluate how mixed certified inverters would interact in an unintended island.
  - Providing information to relax certified inverter DTT requirements.
IEEE-1547.1 and UL-1741 specified anti-islanding tests for a single inverter. But there are usually multiple inverters on a feeder and it is not clear how multiple inverters will perform on the island.

Thru the CA CSI-3 funding, GE & PG&E collaborated on a 4 year unintended islanding study to better understand the probability of unintended islands with multiple certified inverters.

Extensive load modelling was done.

Over one thousand tests with different combinations of actual certified inverters and simulated loads, using two GE power amplifiers and RTDS, were conducted.

Webinar with results was conducted last year. Excerpt slides are shown.

http://www.calsolarresearch.ca.gov/
Unintended Islanding Study

Test set-up

Test Facility: One-Line Diagram
Analysis of Test Results

Prepare
- Associate recordings with test conditions
- Calculate RMS values, P, Q, f, ... from voltages and currents

Extract Attributes
- Determine onset and cessation of island
- Compute scalar attributes of tests

Analyze Trends
- Group, pivot, and visualize the data to determine relationships and trends
Unintended Islanding Study

Islanding test results

Measured island durations

UL1741 limit is 2sec
Unintended Islanding Study

Pure motor loads outlast composite loads

Island Duration vs. Penetration

- CMPLDs
- MotorB

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Risk of Islanding - Experimental Evaluation
Unintended Islanding Study

Impact of load power factor on duration - note that PV inverters are set at unity PF

![Graph showing Island Duration vs. Penetration]
Results of the islanding study

• The GE islanding study showed that multiple inverters each certified to IEEE-1547-2003, on the same island, will still trip within 2 seconds.

• It also showed that the probability of multiple inverters, with potentially different anti-islanding schemes, interacting in a consistent way and causing extended run-on time is highly unlikely.

• As a result, PG&E modified the DTT exemption bulletin to enable the quick interconnection of certified inverters less than 1 MW if there are no significant machine based generators on the island.
Additional Islanding considerations

- Grid interactive (current control) mode PV inverters, including smart inverters with ride through, are certified to be non-islanding and use MPPT to produce the maximum as available energy
  - Rely on the grid for voltage and frequency regulation
  - NEM units also rely on the grid for absorbing excess power generated and for back-up power at night and cloudy days
- They are inherently unstable when separated from the grid and lose the regulation signals from the grid.
- In order for an island to be stable, the generated power needs to match the load power, both real and reactive dynamically.
  - Real power imbalance will lead to frequency excursions.
  - Reactive power imbalance will lead to voltage excursions.
DTT Minimization - Revised

**Box A Requirements:**
Direct Transfer Trip (DTT) and ground fault protection are not required.

**Box B Requirements:**
Ground Fault Protection and Reclose Blocking

**Box C Requirements:**
PGE Scada Equiped Recloser

**Box D Requirements:**
Customer side UG Interrupter or CH Recloser to be installed if not present.

**Box E Requirements:**
Redundant sets of PG&E approved, protection relays installed by customer. These specific relay device numbers are 27, 59, 81O, 81U, 51V or 51C.

**Notes:**
1. PG&E, at its discretion may still require DTT on any DG system. (Especially machine based generators that cannot detect phase and ground end of Line faults.)
2. Phase and Ground protection are required to detect End of Line Faults.
3. These exemptions do not apply to certified and non-certified Inverters with Stand-Alone capabilities.
4. Transmission DTT requirements are independent and still apply.
5. For a line section with all certified inverters, reclose blocking will not be required if the first reclose can be delayed to 10 seconds.
6. If an existing uncertified DG already has DTT then this uncertified DG would not count towards the 10% limit for the “other machine or uncertified DG...” screen. Other uncertified DG with previously approved protection may still need to be re-studied on a case by case basis.
Streamlining Protection Requirements

- **Continuing Issues**
  - Use of anti-islanding for fault detection could be adversely affected by the implementation of LVR & LFR which could reduce the ability of anti-islanding schemes to detect loss of the source and trip the unit.
  - Due to the above concerns DTT may still have to be installed. This is costly and can make a project not viable, also adding to the maintenance and operational complexity of the system.
  - Larger units or generation on distribution feeders with high penetration may require DTT from the transmission source.
Streamlining Protection Requirements

Summary

• The current UL 1741 certification has been shown to be effective at ensuing the multiple inverter installations trip within 2 seconds.
• This has allowed for the rethinking of the DTT requirement resulting in significant reductions in the requirement.
• Since there will be instances where DTT may be required there needs to alternative forms of protection.
  • Use of wireless spread spectrum or other wireless communication.
  • Investigate other methods of insuring separation from the grid (ie Power Factor setpoint and feeder capacitor settings to force a mismatch in reactive power on island).
  • Permissive PLC (Power Line Carrier) tripping of the DGs.
Streamlining Protection Requirements

Questions?