Evaluating Near-term Protection Solutions for PV Applications

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Joshua Hambrick, PhD
Oak Ridge National Laboratory
Future State of Protective Relaying

• ORNL along with PNNL and Los Alamos developed an overview of near-, mid- and long-term issues facing protective relaying

• Peer review of white paper in 2018
  – ~60 attendees including 8 different utilities, NERC and EPRI

• Develop a roadmap for DOE protective relaying

• Inverter implications on protection a primary near-term concern for both transmission and distribution utilities.
  – Implications of 1547 revision a primary concern for distribution utilities
IEEE 1547 Revision

- IEEE 1547 was originally published in 2003, amended in 2014 and revised in 2018.

- IEEE 1547.1 under revision now (about to go to ballot), feeds into UL 1741.

- In 2003, rotating machines were primary DER. 2018 has a much greater focus on inverter-based DER.
  - 2003: When in doubt, get offline
  - 2018: Grid support required

- Notable changes:
  - Elimination of minimum size
  - Voltage & frequency ride-through requirements
  - Basic VV control required, advanced controls permitted
  - Communication capability required for all DER
1547 Revision – Protection Implications

• Ride through impact on anti-islanding / reclosing schemes

• Modeling / sim still a challenge

• Added complexity
  – 2003: 15 pages (including Annex)
  – 2018: 136 pages (including Annexes)

• As protection engineers know, configurability is opportunity for misconfiguration

• Ride-through requirements are important for system stability; however, distribution utilities must prioritize safety of public, utility personnel, and equipment.

• Need: Immediate protection solutions in many markets
SETO Protection of High-Pen: Overview

• Solve IEEE 1547-2018 protection in the near term (without DTT)
• Try relays tested on transmission, or new combinations of existing relay functions.
• Techno-economic analysis of two new protection schemes for host utility review. Summer 2019.
• Final metrics on two utility feeders. End of 2019.
• Team: PNNL (lead), ORNL, GA Tech, Chattanooga EPB, Dominion Energy Virginia, Duke Energy (observing)

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## SETO Protection of High-Pen: Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Category</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dependability</td>
<td>Must detect all faults within the protected zone; failures are disqualifying</td>
</tr>
<tr>
<td>2</td>
<td>Security</td>
<td>Must not trip for any fault outside the protected zone; failures are disqualifying</td>
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<tr>
<td>3</td>
<td>Selectivity</td>
<td>Must trip the minimum number of devices to isolate the fault, after any reclosing activity has completed. Primary protection must trip before backup protection. Failures are disqualifying.</td>
</tr>
<tr>
<td>4</td>
<td>Sensitivity</td>
<td>Maximum ground fault resistance before the scheme fails to operate for a ground fault. This can be presented in the form of a graph, resistance vs. fault location.</td>
</tr>
<tr>
<td>5</td>
<td>Speed</td>
<td>Time between fault inception and a relay command to trip. This can be presented in the form of a graph, time vs. fault location for different types of fault.</td>
</tr>
<tr>
<td>6</td>
<td>Cost</td>
<td>Expected purchase, design and installation costs for all relays and sensors, per feeder, including both utility-owned and DG relays for a high-penetration case.</td>
</tr>
<tr>
<td>7</td>
<td>Cost</td>
<td>Expected purchase, design and installation costs for new communications infrastructure, per feeder, to support the new scheme. Significant communication costs are disqualifying here.</td>
</tr>
<tr>
<td>8</td>
<td>Cost</td>
<td>Expected training and engineering costs for a new scheme, per utility, consulting or DER organization.</td>
</tr>
<tr>
<td>9</td>
<td>Flexibility</td>
<td>The highest DER penetration level, defined as DER Capacity / Peak Load, for which no disqualifying failures occur.</td>
</tr>
<tr>
<td>10</td>
<td>Maturity</td>
<td>The technology readiness level (TRL) of commercial products that could be used.</td>
</tr>
<tr>
<td>11</td>
<td>Maturity</td>
<td>The number of vendors that currently supply products that could implement the scheme.</td>
</tr>
</tbody>
</table>
SETO Protection of High-Pen: Solutions

- Traveling Wave* (PNNL)
- Active Power Line Carrier* (PNNL)
- Incremental Distance* (PNNL)
- Focused Directional* (PNNL)
- Machine Learning (PNNL)
- Settingless Relays (GT)
- Model-based Adaptive Relay (ORNL)

*COTS relay evaluation
Model-based Adaptive Relay

- Real-time simulator embedded in relay (NI cRIO hardware)
  - OPAL-RT + in-house solver
- Use real-time model to calculate protection settings as system changes
- Input: Utility protection philosophy, system model
- Output: Relay settings (pick up, time dial, etc.)
- In this project:
  - Update model to include solar input
  - Interface with COTS relay (currently interfaces to open source recloser)
Model-based Adaptive Relay

Short Circuit Model

Opal-RT output:
- Source Voltage
- Short Circuit & Load Current
- Switches status from SI-GRID

New relay setting pickup

Short Circuit & Load

Model-based Adaptive Relay

Opal-RT output:
- Source Voltage
- Short Circuit & Load Current
- Switches status from SI-GRID

New relay setting pickup

50 51
SI-GRID Overview

SI-GRID: Software-defined Intelligent Grid Research Integration and Development platform

SI-Grid power system emulator is a mix of analog, discrete, electronic, and digital components. Including: low voltage power grid, operational controllers, communications, and protection.
SI-GRID Adaptive Relay Testing
Resilient Distribution System – Distributed FLISR

• GMLC project to investigate distributed communication & control
  – OE, OC-Cyber, EERE-BTO, EERE-SETO

• (OE, SETO, BTO, Cyber)

• Distributed vs centralized fault location, isolation and service restoration (FLISR)

• Team: PNNL (lead), ORNL, NREL, UNCC, UTK, Duke Energy
Open Field Message Bus (OpenFMB)

- Industry effort lead by Duke Energy
- Pub / Sub communication for deployed
- Compatible with CIM, 61850
- Field demonstration on feeder with solar, storage
- Reclosers will use OpenFMB to switch between settings group
Summary

- Inverter-based DER presents many challenges to system protection…but many solutions exist
- Advancements in communication/control are expanding protection capabilities
- Testbeds and testing capabilities for protection are expanding
- Many projects underway, and many more in near future
Questions?

Joshua Hambrick, PhD
R&D Staff
Oak Ridge National Laboratory
hambruckjc@ornl.gov