Evaluating Near-term Protection Solutions for PV Applications

2019 PV Systems Symposium

May 15, 2019

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

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)

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34233.

SETO Protection of High-Pen: Metrics

Metric	Category	Quantity
1	Dependability	Must detect all faults within the protected zone; failures are disqualifying
2	Security	Must not trip for any fault outside the protected zone; failures are disqualifying
3	Selectivity	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.
4	Sensitivity	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.
5	Speed	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.
6	Cost	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.
7	Cost	Expected purchase, design and installation costs for new communications infrastructure, per feeder, to support the new scheme. Significant communication costs are disqualifying here.
8	Cost	Expected training and engineering costs for a new scheme, per utility, consulting or DER organization.
9	Flexibility	The highest DER penetration level, defined as DER Capacity / Peak Load, for which no disqualifying failures occur.
10	Maturity	The technology readiness level (TRL) of commercial products that could be used.
11	Maturity	The number of vendors that currently supply products that could implement the scheme.

SETO Protection of High-Pen: Solutions

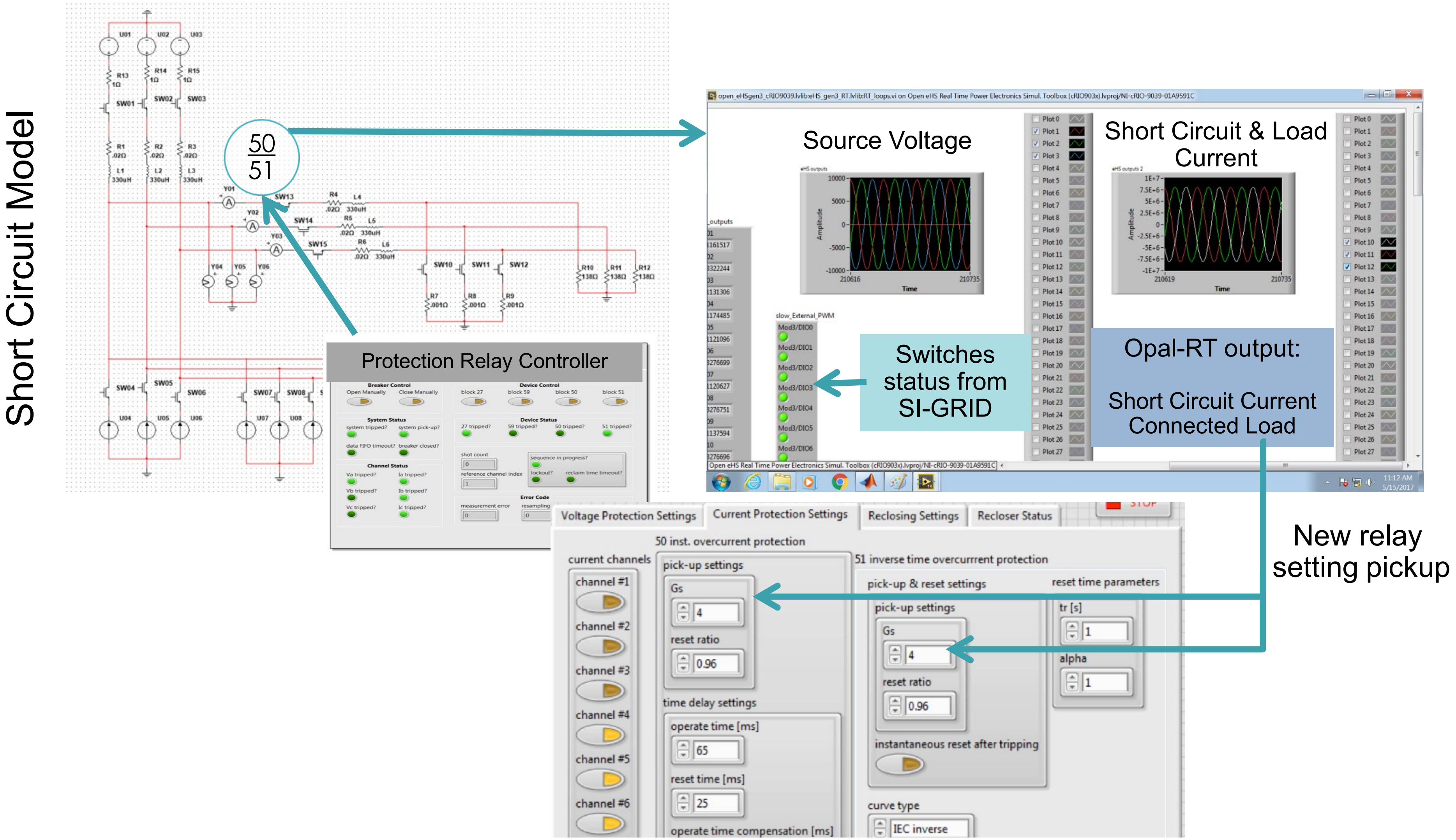
- Traveling Wave* (PNNL)
- Active Power Line Carrier* (PNNL)
- Incremental Distance* (PNNL)
- Focused Directional* (PNNL)
- Machine Learning (PNNL)
- Settingless Relays (GT)
- Model-based Adaptive Relay (ORNL)

*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

50
51

Protection Relay Controller

Source Voltage

Short Circuit & Load Current

Switches status from SI-GRID

Opal-RT output:

Short Circuit Current
Connected Load

New relay setting pickup

50 inst. overcurrent protection

pick-up settings

Gs: 4

reset ratio: 0.96

time delay settings

operate time [ms]: 65

reset time [ms]: 25

operate time compensation [ms]

51 inverse time overcurrrent protection

pick-up & reset settings

pick-up settings

Gs: 4

reset ratio: 0.96

instantaneous reset after tripping

reset time parameters

tr [s]: 1

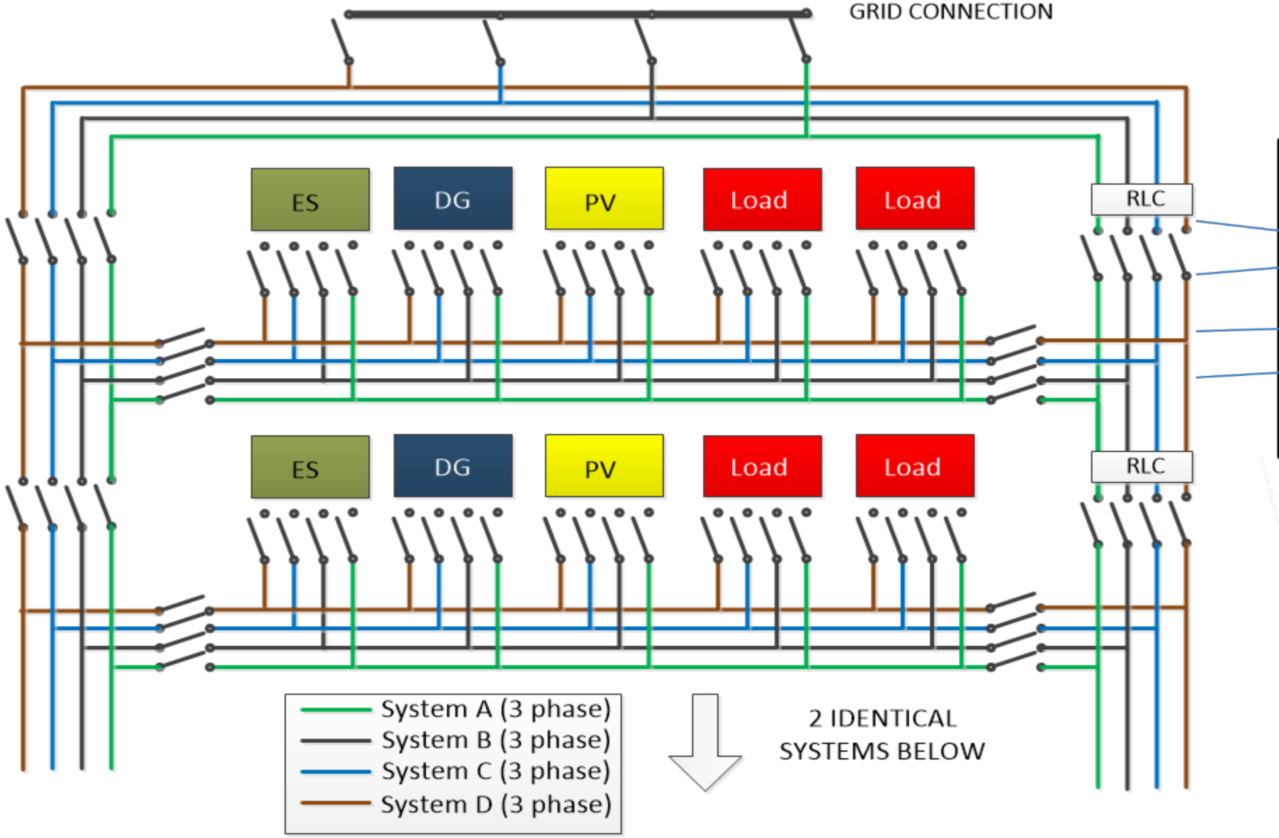
alpha: 1

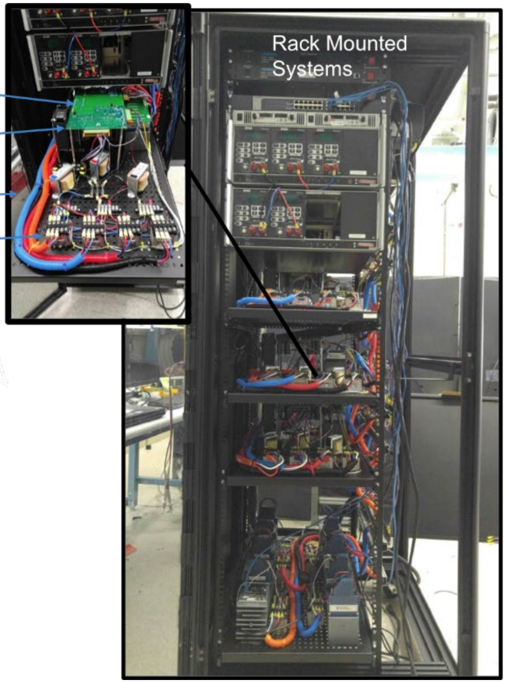
curve type: IEC inverse

SI-GRID Overview

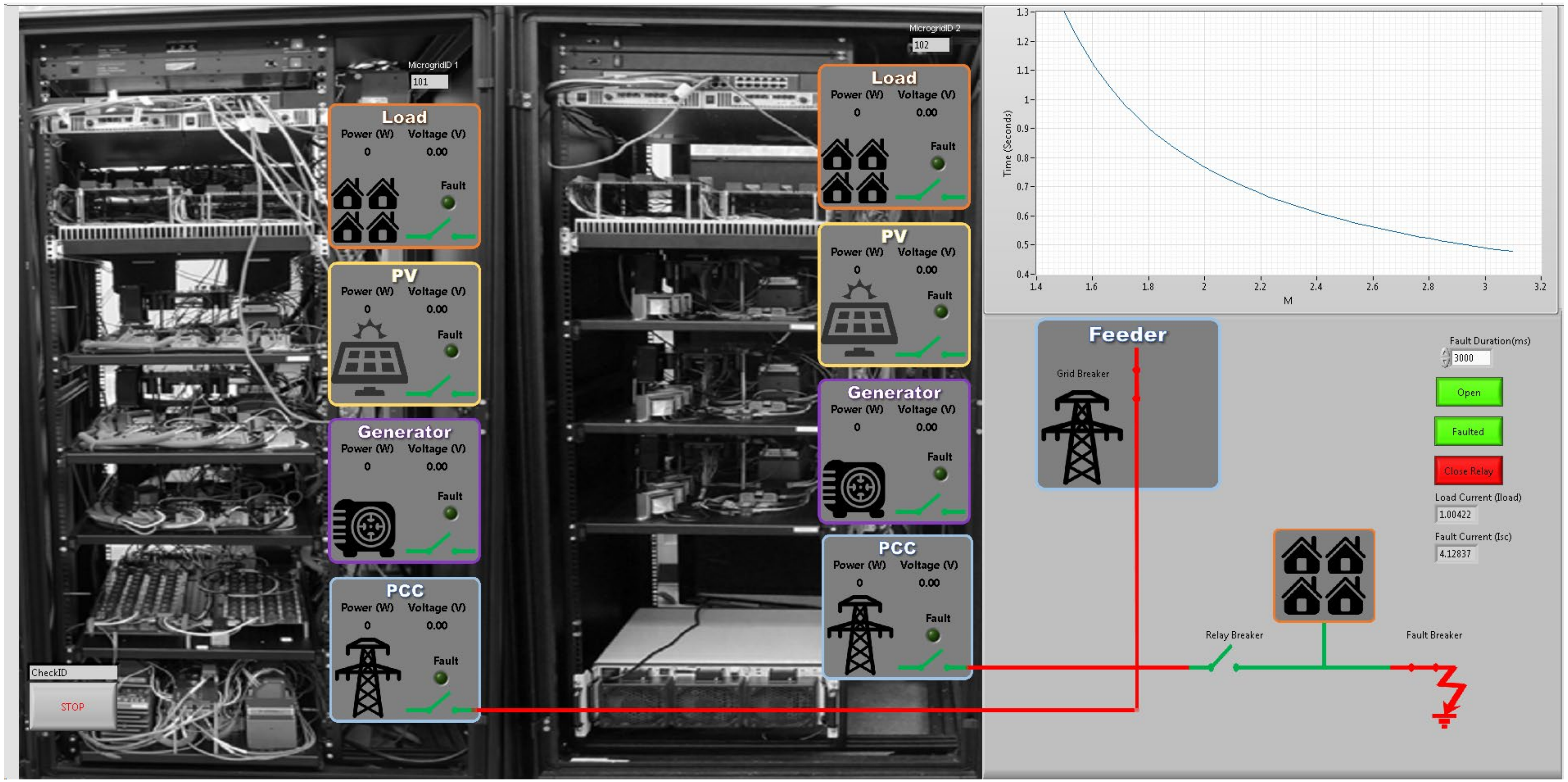
SI-GRID: Software-defined Intelligent Grid Research Integration and Development platform

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 Teting



MicrogridID 1: 101

MicrogridID 2: 102

Load — Power (W): 0 — Voltage (V): 0.00

PV — Power (W): 0 — Voltage (V): 0.00

Generator — Power (W): 0 — Voltage (V): 0.00

PCC — Power (W): 0 — Voltage (V): 0.00

Fault Duration(ms): 3000

Load Current (Iload): 1.00422

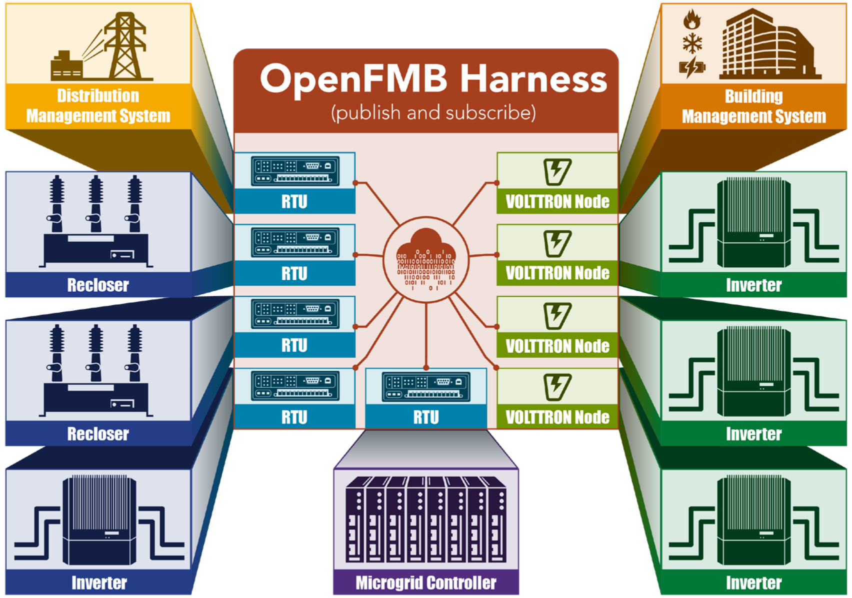
Fault Current (Isc): 4.12837

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?

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