DER’s Impact on Bulk System Reliability

Barry Mather Ph.D.

Inverter Response to Abnormal Conditions/Faults

Background/Motivation

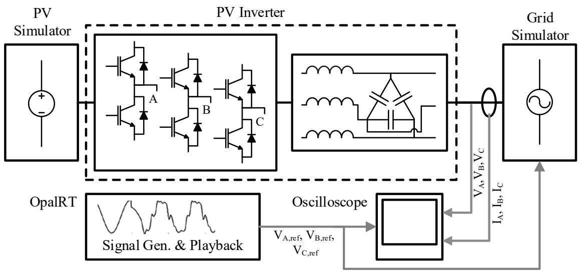
Findings: mis-measurement of system frequency and momentary cessation on low voltage, inconsistency in requirement interpretation

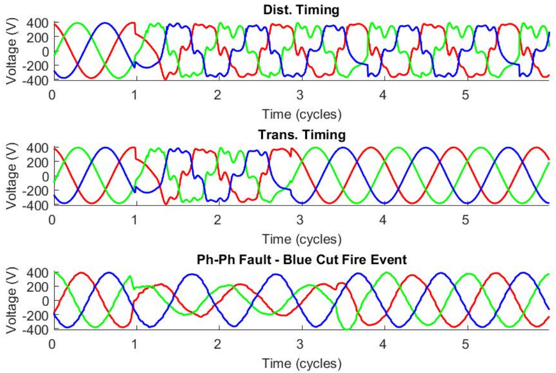
Findings: no erroneous frequency measurements, continued use of momentary cessation, interpretation of voltage trip requirements, PLL operation…

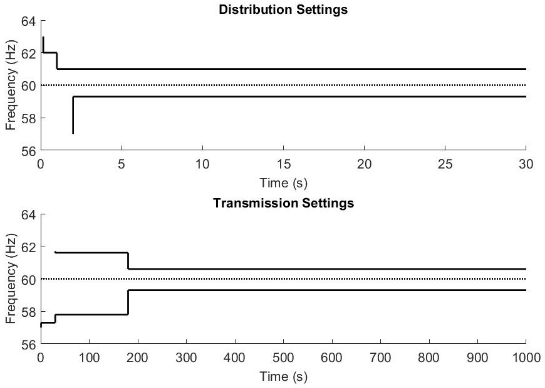
Findings: continued use of momentary cessation, DER generation loss during fault…

System Setup – Event Playback

- Three different "faults" or "grid disturbances" were tested
- Two PV inverter VRT capabilities evaluated



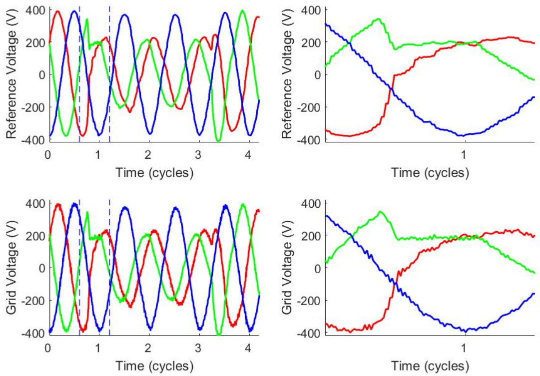




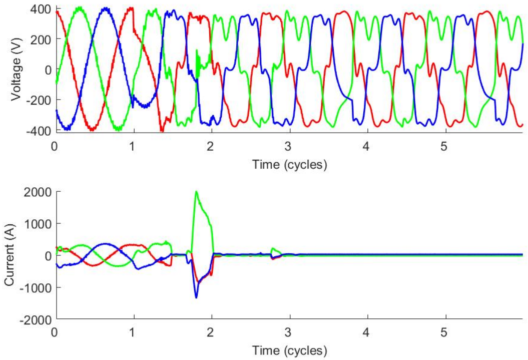
See: B. Mather, O. Aworo, R. Bravo, D. Piper, "Laboratory Testing of a Utility-Scale PV Inverter's Operational Response to Grid Disturbances," in proc. IEEE Power and Energy Soc. Gener. Meet., Portland, OR, Aug. 2018.

Example Results from Lab Evaluation

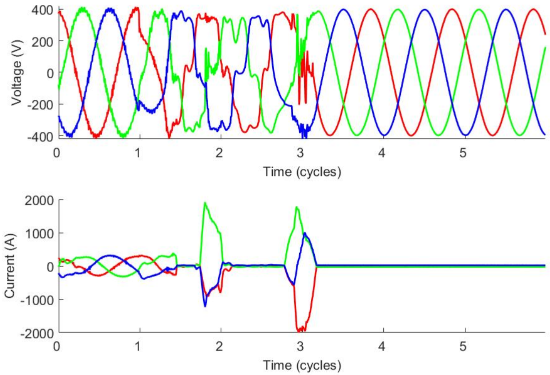
Disturbance signal play back



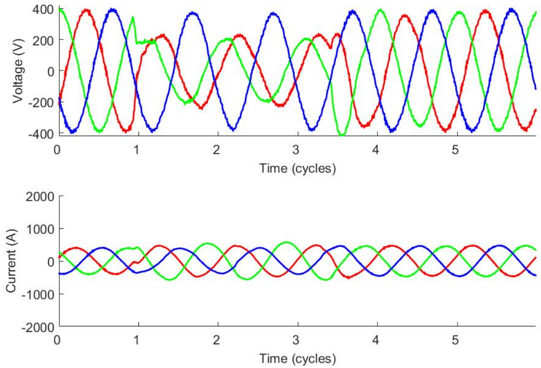
"Distribution" FRT Settings



"Transmission" FRT Settings

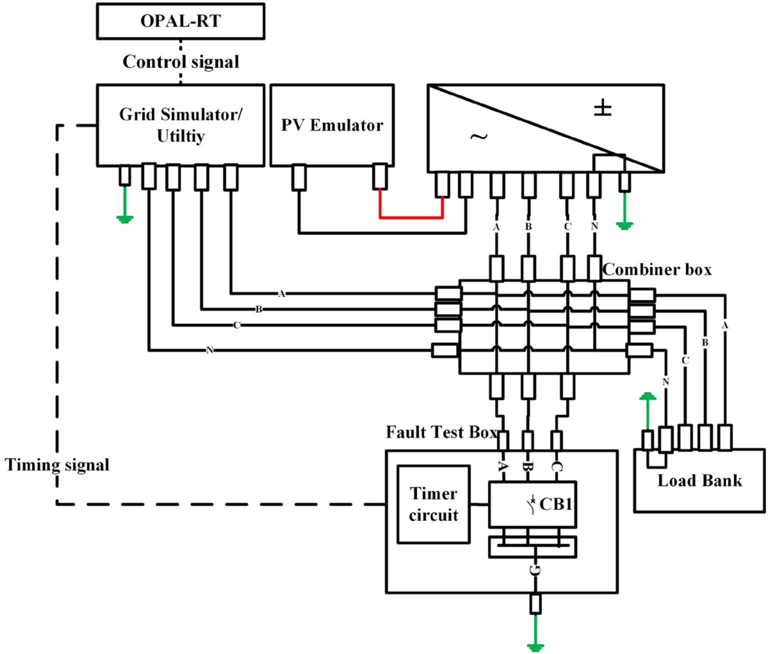


Blue Cut Fire Event Results (note phase)



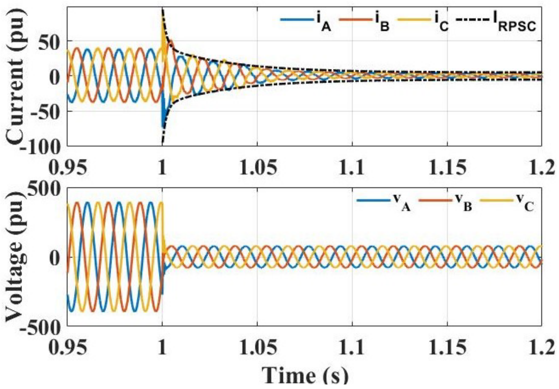
Short-Circuit Response Modeling

- Model development and validation based on lab evaluation
- Response is dictated by complex control & programming, not slower order physical constraints

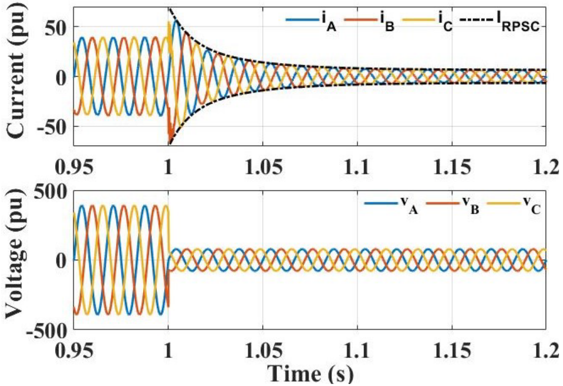


Fault Response Reduced-Order Parameterized Short-Circuit Modeling

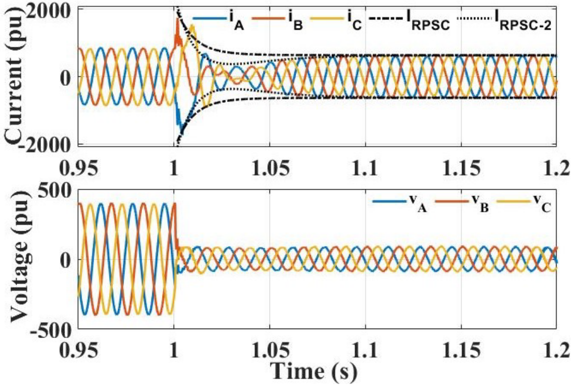
20 kW class inverter - experimental



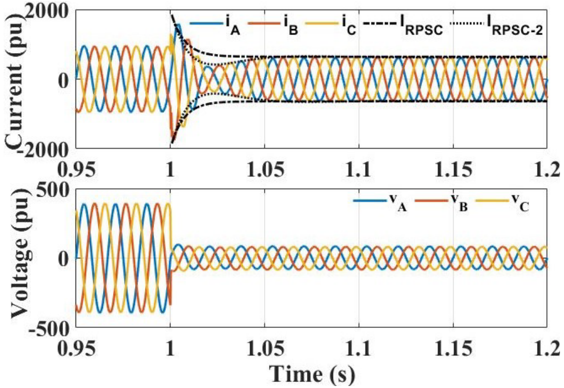
20 kW class inverter - simulated



500 kW class inverter - experimental



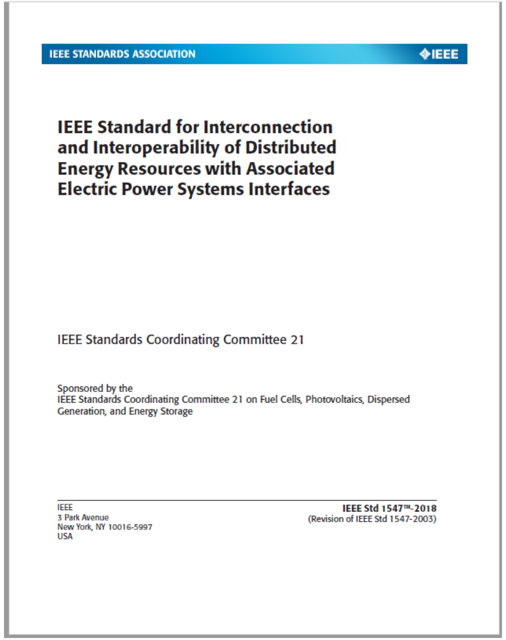
500 kW class inverter - simulated



See: R. Mahmud, D. Narang, A. Hoke, "Reduced-Order Parameterized Short-Circuit Current Model of Inverter-Interfaced Distributed Generators," accepted IEEE Trans. Power Delivery.

Translating DER Response to Bulk System Impact

IEEE 1547-2018 Bulk System Support Modeling



IEEE STANDARDS ASSOCIATION

IEEE

IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

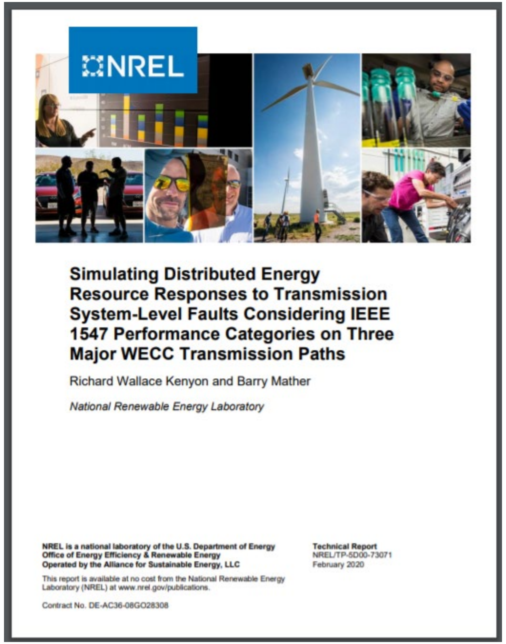
IEEE Standards Coordinating Committee 21

Sponsored by the
IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1547™-2018
(Revision of IEEE Std 1547-2003)

With the many settings and performance categories defined within IEEE 1547-2018, how do we figure out the appropriate settings? Should these be regional? Based on DER policy or technical requirements?



Simulating Distributed Energy Resource Responses to Transmission System-Level Faults Considering IEEE 1547 Performance Categories on Three Major WECC Transmission Paths

Richard Wallace Kenyon and Barry Mather

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-73071
February 2020

https://www.nrel.gov/docs/fy20osti/73071.pdf

Study Impetus

There is 10GW+ of DER in WECC
More is coming, much more

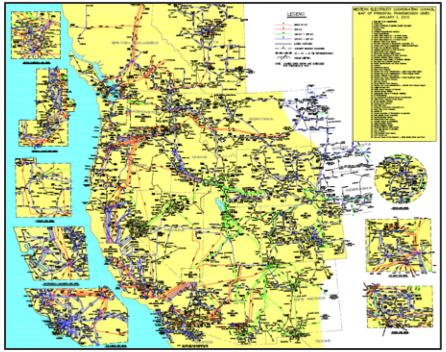
How do we figure out where and when various IEEE 1547-2018 performance categories should be used/implemented

Focus is on low voltage ride-through (*seems the area of most difficult compromise*)

Ride-through: indicates if, and for how long, the DER maintains its pre-disturbance power supply through a disturbance (frequency/voltage deviations). Not necessarilly indicative of any grid-support functionality.
distributed generation (DG): a subset of DERs, assumed to be Solar PV (I.e. DPV) for this study.

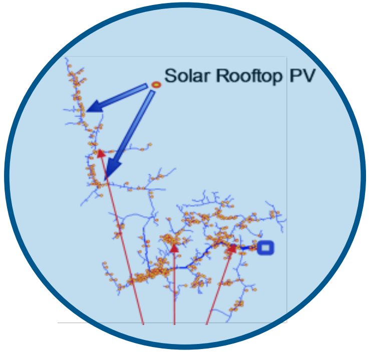
Two Types of Simulators; One Power System

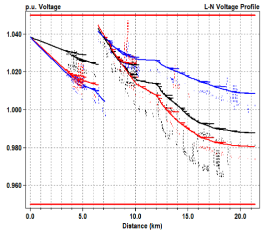
Transmission Simulations:



- Positive sequence/balanced
    - Reduces three phases to one
- Bundled Load/DERs
    - *Obscured individual operation*
- Reduces complexity/enables large system simulations

Distribution Simulations:

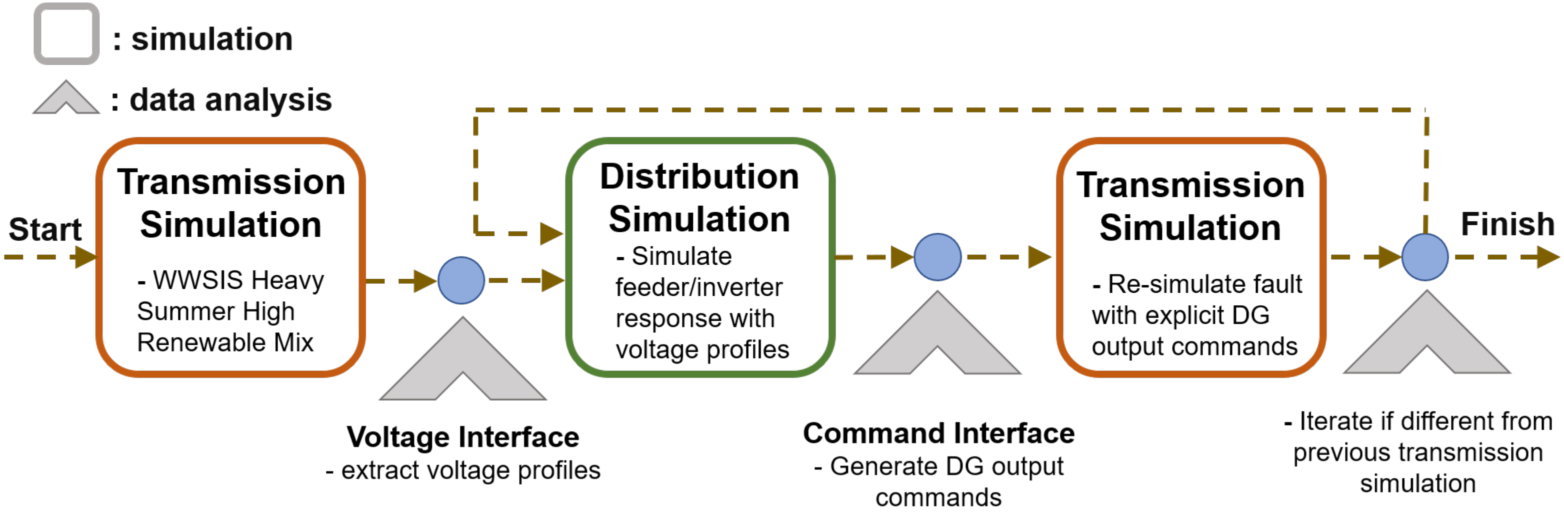




- Three phases/unbalanced
- Models radial networks
    - Feeder head to secondaries
- Individual inverter operation
    - *Can apply IEEE 1547 compliant ride through to individual devices*
- Single/few feeder simulations

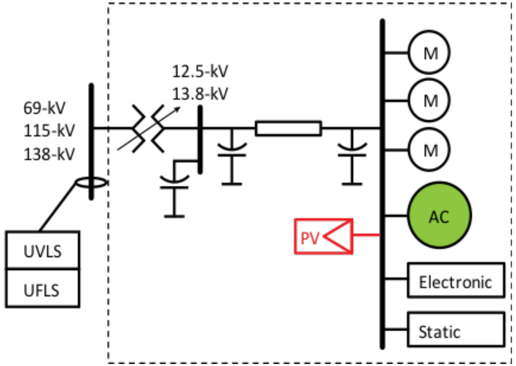
How do we incorporate the response of DERs, as determined in distribution simulations, in transmission simulations?

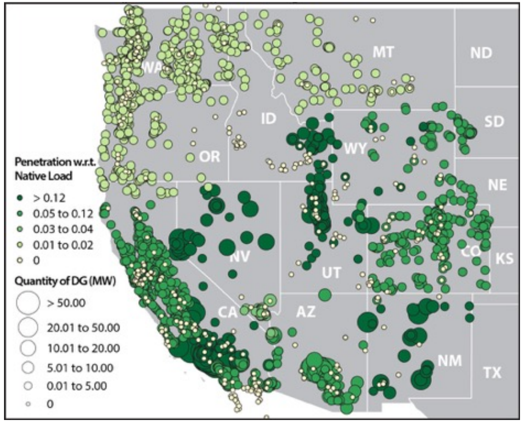
Simulation Pathway



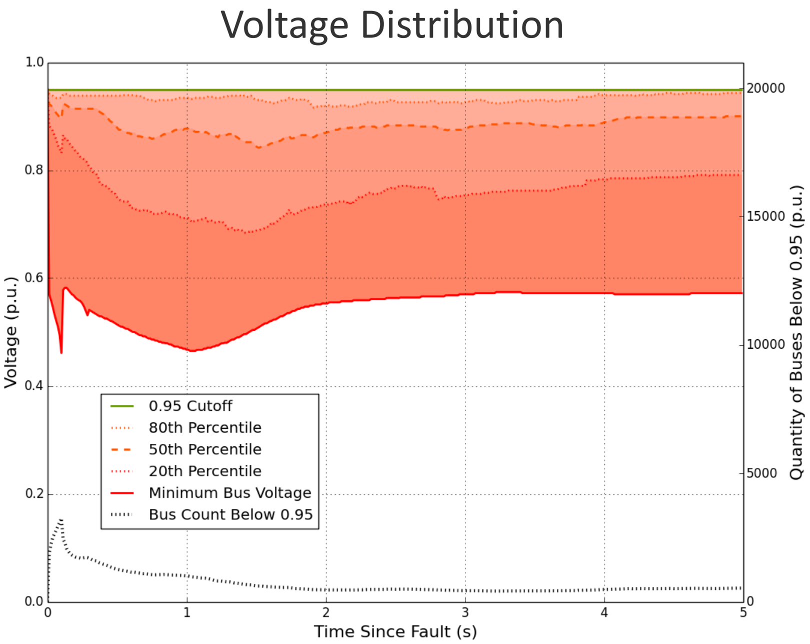
Simulations of the Western Interconnection (WI)

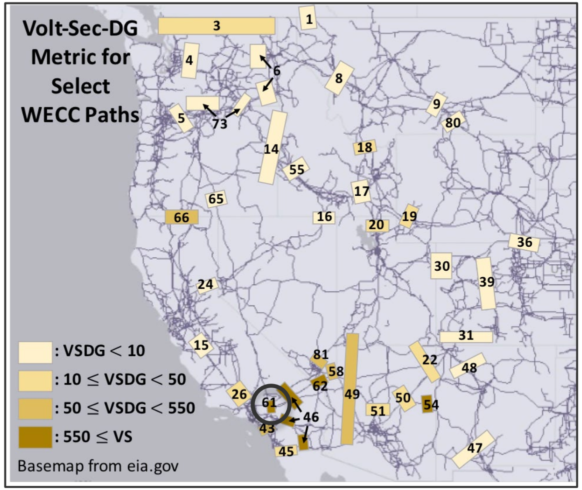
- GE Positive Sequence Load Flow
- Heavy Summer 2023 planning case with high levels of utility scale (~17%), and distributed (~5%), renewable sources
- Composite load model with generation is used
- Three phase fault scenario on all WI Paths to identify the most severe reactions
  - Fault cleared after six cycles; 0.1 s
  - Severity with respect to DG assessed with the introduced Volt-Sec, Volt-Sec-DG metric

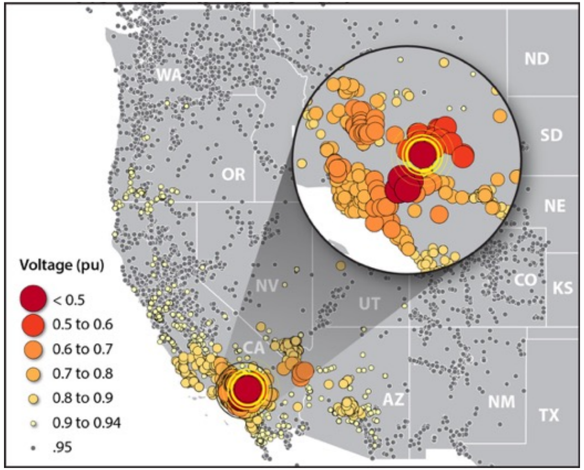




Path 61 Lugo 500 kV

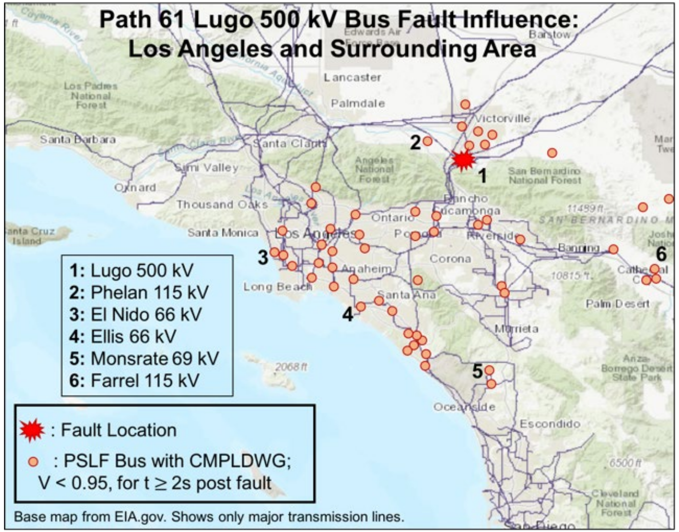


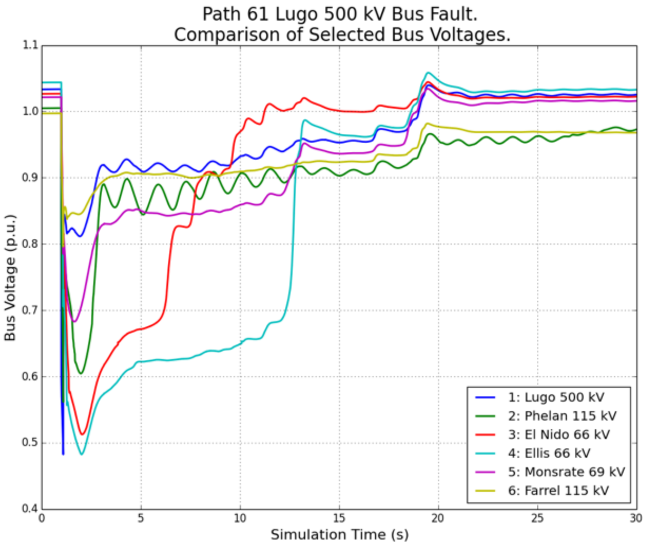




- All buses across the system; any transmission voltage level
- Fault Induced Delayed Voltage Recovery (FIDVR)

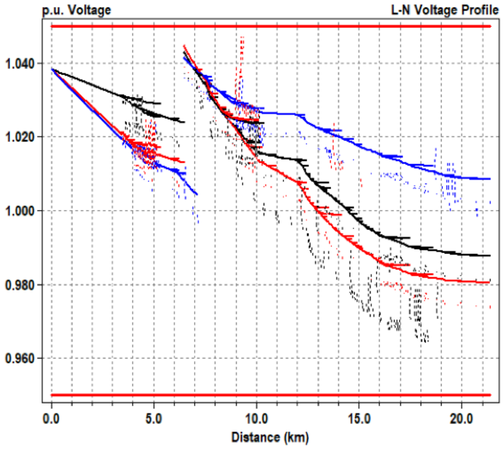
Path 61 Lugo 500 kV: Extracted Information



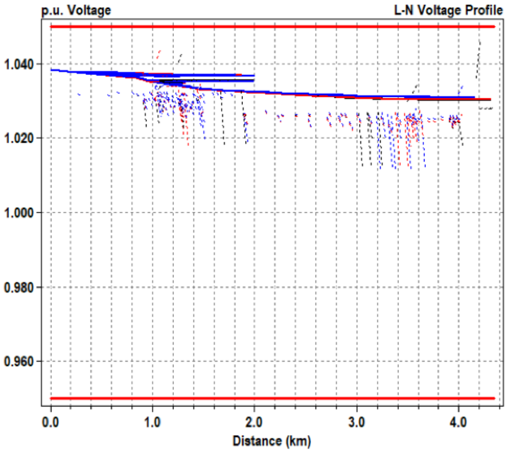


- 123 composite load models with voltage deviations triggering IEEE 1547 action
- Accounts for approximately 4 GW of DG across this system
- Majority of influence is in Southern California

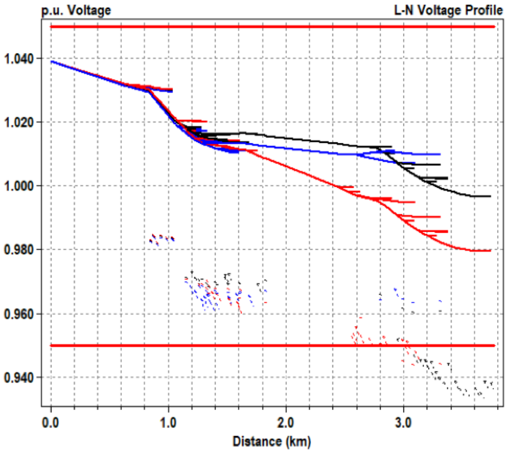
Open Distribution System Simulations



Commercial/residential: 12 kV



Industrial: 16 kV



Residential: 4 kV

- 123 ‘feeder head’ voltage profiles for distribution systems
- 50 inverters (DG units) compliant to selected IEEE 1547 ride-through criteria on each feeder; located on secondaries.
- Proportional representation of residential/commercial/industrial feeders based on impacted region.

IEEE 1547 Ride Through Implementation

Voltage	IEEE 1547: 2003 Pessimistic	IEEE 1547: 2018 Category I	IEEE 1547: 2018 Category II	IEEE 1547: 2018 Category III
$V < 0.3$	Immediate trip	Immediate trip	Immediate trip	Momentary cessation; trip after 1.0 s
$0.3 \leq V < 0.5$			Momentary cessation; trip after 0.32 s	
$0.5 \leq V < 0.65$		Momentary cessation; trip after [illegible]		Continuous operation; trip [illegible]0.0 s
0.65 ≤ [illegible]			[illegible]	
$0.7 \leq V < 0.88$		Trip after 0.7 s + (4 s/p.u.) × (V – 0.7 p.u.)	[illegible]rip after 3 s + (8.7 s/p.u.) × (V – 0.65 p.u.)	Continuous operation; trip after 20.0 s
$0.88 < V$	Continuous operation	Continuous operation	Continuous operation	Continuous operation

- All ride-through control based on pessimistic interpretation of standard—i.e., if current injection is not explicitly required, then current injection is assumed to be zero

In general, greater ride through participation at lower voltages, for longer periods of time.

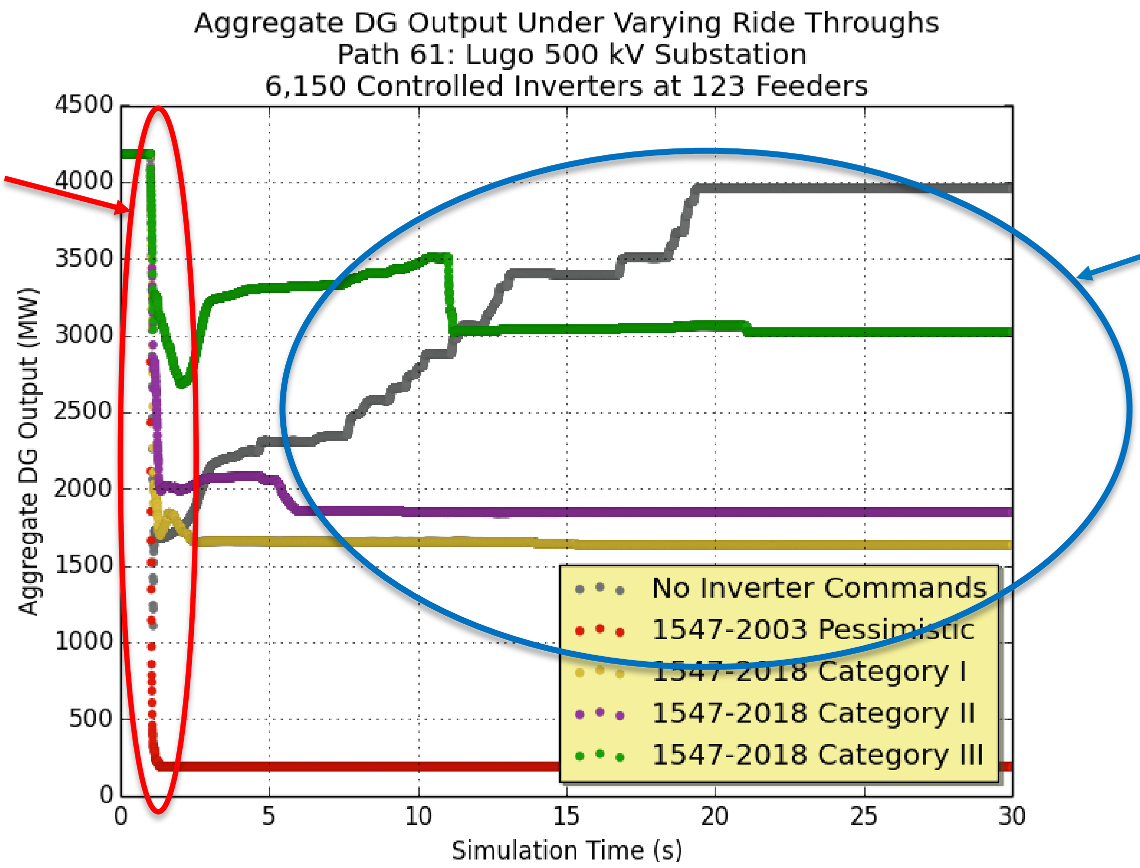
Overall Distributed Generation Loss

- Results of these distribution simulations scaled to match the DG levels in the transmission system
- Four simulations of each unique voltage profile dependent on type of ride-through criteria implemented

	IEEE 1547 2003 Pessimistic	IEEE 1547 2018 Category I	IEEE 1547 2018 Category II	IEEE 1547 2018 Category III
Lost Distributed Generation	4,000 MW	2,550 MW	2,340 MW	1,500 MW

Aggregate Results

These responses are still based on aggregate dynamic models but the "during fault" response is critical to determining overall bulk system impact



These responses appear to reflect longer time-scale agg. DER response

Q&A

Breakout Session Guide

Try and address the 3 following questions:

- **From a high-level industry perspective, what are the most critical research challenges regarding the use of higher levels of power electronics in our electrical grids?**
- **What functionality/capability of the PEGI Platform is most critical for your research needs (i.e. what would be most useful to you)?**
- **What questions have we not asked that we should be (i.e. what are we missing)?**

We want to hear from you!

Workshop Feedback, Comments, Further Discussion – barry.mather@nrel.gov

NREL/PR-5D00-78606