DER Testing and Verification - Overview of IEEE P1547.1

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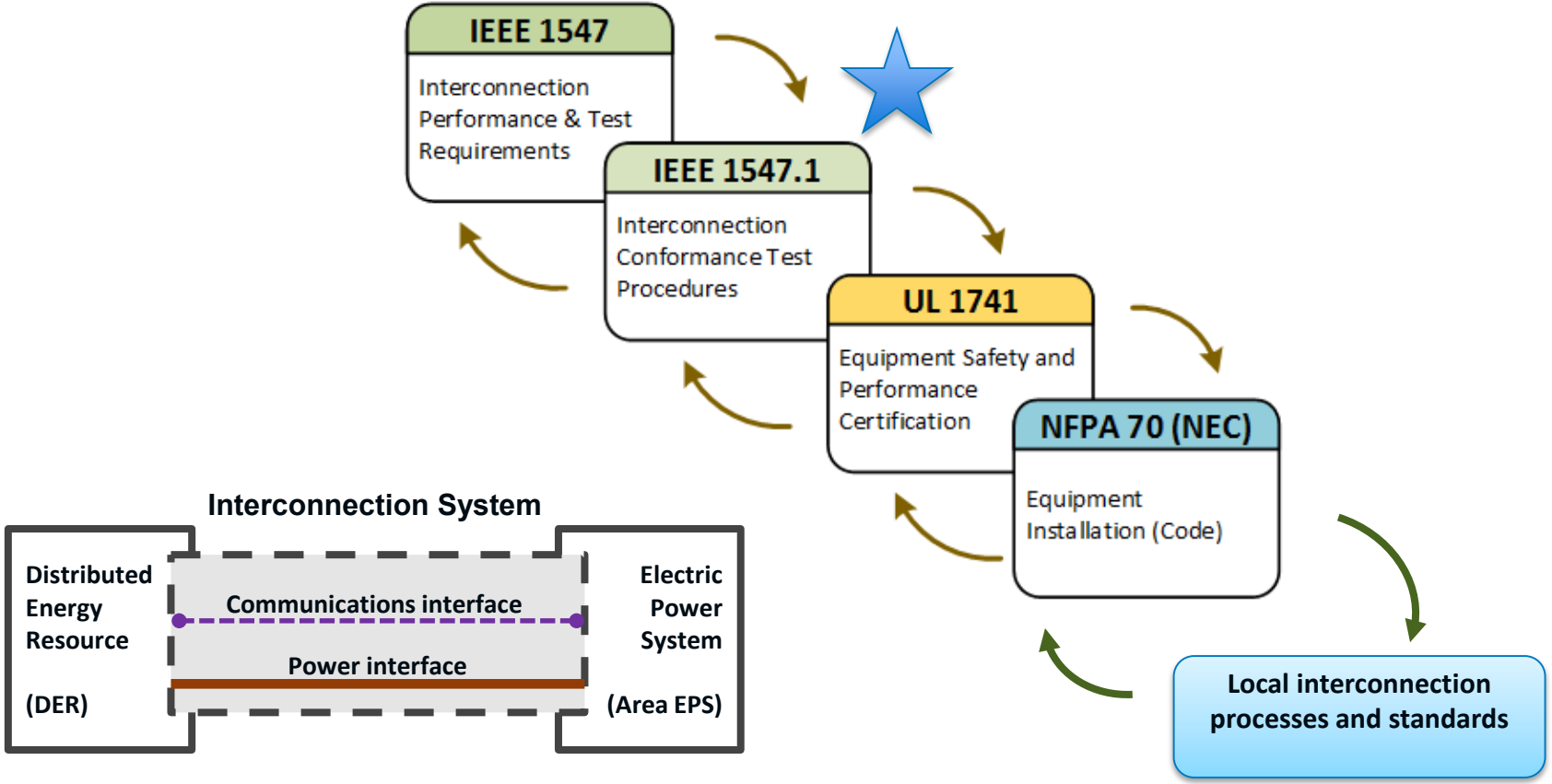
Presentation at PJM Technical Workshop on DER Integration

July 30, 2019

Disclaimer

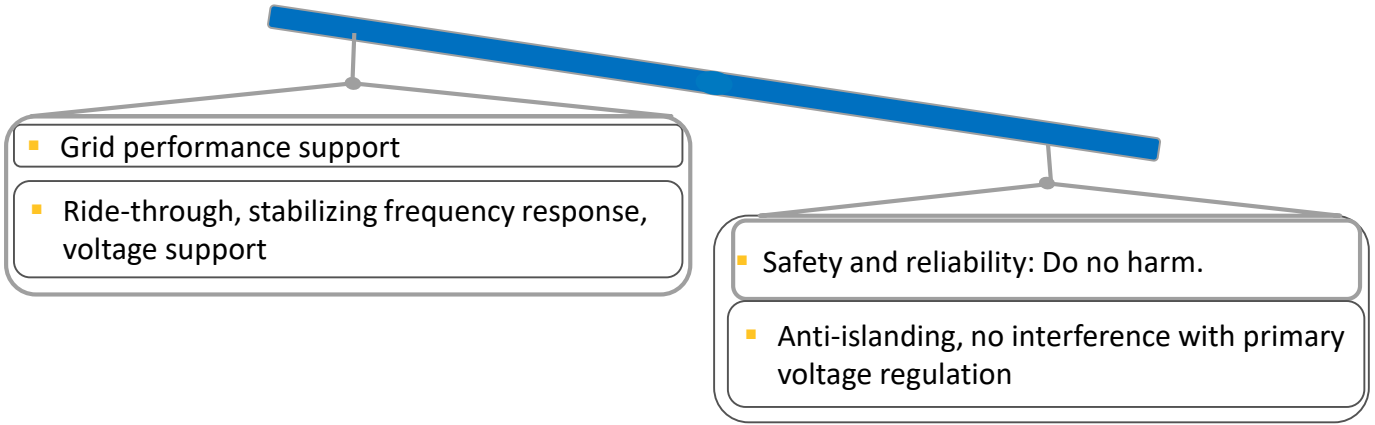
This presentation and discussion here on IEEE 1547 and P1547.1 are individual's views and are not the formal explanation or position of the IEEE.

Intent and Use of 1547.1 and Related Standards



Solving Grid Planning and Operation Challenges

Increasing DER penetration was a major driver for revising IEEE 1547.



1547 Content Growth

	1st Edition		2nd Edition
1547 technical content:	13 pages	→	127 pages
1547.1 technical content:	54 pages	→	256 pages

New/significantly modified 1547-2018 content in red:

4. General interconnection technical specifications and requirements
- 4.2 Reference points of applicability
- 4.3 Applicable voltages
- 4.4 Measurement accuracy
- 4.5 Cease to energize performance requirement
- 4.6 Control capability requirements
- 4.7 Prioritization of DER responses
- 4.8 Isolation device
- 4.9 Inadvertent energization of the Area EPS
- 4.10 Enter service
- 4.11 Interconnect integrity
- 4.12 Integration with Area EPS grounding
- 4.13 Exemptions for Emergency Systems and Standby DER

5. Reactive power capability and voltage/power control requirements
- 5.2 Reactive power capability of the DER
- 5.3 Voltage and reactive power control
- 5.4 Voltage and active power control

6. Response to Area EPS abnormal conditions
- 6.2 Area EPS faults and open phase conditions
- 6.3 Area EPS reclosing coordination
- 6.4 Voltage
- 6.5 Frequency
- 6.6 Return to service after trip

7. Power quality
- 7.1 Limitation of dc injection
- 7.2 Limitation of voltage fluctuations induced by the DER
- 7.3 Limitation of current distortion
- 7.4 Limitation of overvoltage contribution

8. Islanding
- 8.1 Unintentional islanding
- 8.2 Intentional islanding

9. DER on distribution secondary grid/area/street (grid) networks and spot networks
- 9.1 Network protectors and automatic transfer scheme requirements
- 9.1 Distribution secondary grid networks
- 9.2 Distribution secondary spot networks

10. Interoperability, information exchange, information models, and protocols
- 10.1 Interoperability requirements
- 10.2 Monitoring, control, and information exchange requirements
- 10.3 Nameplate information
- 10.4 Configuration information
- 10.5 Monitoring information
- 10.6 Management information
- 10.7 Communication protocol requirements
- 10.8 Communication performance requirements
- 10.9 Cyber security requirements

11. Test and verification requirements
- 11.2 Definition of test and verification methods
- 11.3 Full and partial conformance testing and verification
- 11.4 Fault current characterization

Motivation for IEEE P1547.1

- In some locations, the power system **depends on DERs** for proper operation during normal and abnormal conditions
  - True for both **distribution systems** and **bulk power systems**
  - Number of DER-dependent locations is expected to **continue to grow**

- Major paradigm shift in 1547 from "just get out of the way" to "**stay connected (within limits) and support voltage and frequency**"

- Some power systems failed to recognize this in time, sometimes at great cost. North America has a chance to get it right the first time!

- Now that the grid depends on DERs to perform a certain way, **DER performance must be validated through testing** to ensure the power system continues to be safe and reliable
  - **IEEE 1547.1 contains the test and evaluation procedures to ensure DERs comply with 1547-2018 requirements**

IEEE P1547.1 Full Revision

- Title: ***Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces***

- Scope: Specify the **type, production, commissioning and periodic tests, and evaluations** that shall be performed **to confirm** that the interconnection and interoperation functions of equipment and systems interconnecting **distributed energy resources** with the electric power system **conform to IEEE Standard 1547**

- Like 1547, **applies to all DERs** (not just PV, and not just inverter-based)

- 1547-2018 cannot be fully applied until after revised P1547.1 is published! (Partial application is possible using UL 1741 Supplement A)

- Core of 1547.1 is type testing (lab tests)
  - 1547-2018 contains many new requirements that are not fully verified through lab testing
  - DER evaluations and commissioning tests become more important

P1547.1: Types of Verification Methods

- **Type test** – Test of one or more devices made to a certain design to demonstrate that the design meets certain specifications
- **Production test** – A test conducted on every unit of equipment prior to shipment
- **Design evaluation** – A "paper study" evaluating a proposed DER installation
- **Installation evaluation** – An inspection of the field-installed DER to verify correct installation
- **Commissioning test** – A test conducted in the field when the equipment is installed to verify correct operation
- **Periodic test** – A field test conducted periodically or as needed after the DER is installed and operating

Majority of 1547.1 content

Significant new material

Type Tests (Clause 5)

- These are the tests we typically think of as being run by a NRTL as part of UL 1741 testing
- Some tests from IEEE 1547.1/1547.1a (2005/2015) are largely valid
  - e.g. temp. stability, synchronization, interconnection integrity etc.
- Some tests can be adapted/revised from UL 1741 SA
  - e.g. ride-through, voltage and frequency regulation, islanding detection etc.
- Some tests have been added
  - e. g. temporary overvoltage, transient overvoltage, interoperability, fault current characterization, “watt-var” control, phase jump ride-through, ROCOF ride through, etc.
- Current UL 1741 SA takes 6-8 weeks if fully automated. Will take longer when P1547.1 is incorporated.

Testing of Communications (Clause 6)

- 1547-2018 requires all DERs to be *capable* of communications using at least one of three communications methods:

Table 41—List of eligible protocols

Protocol	Transport	Physical layer
IEEE Std 2030.5 (SEP2)	TCP/IP	Ethernet
IEEE Std 1815 (DNP3)	TCP/IP	Ethernet
SunSpec Modbus	TCP/IP	Ethernet
	N/A	RS-485

- P1547.1 WG reached consensus that **at least a subset of category of type tests shall be run using at least one of the three protocols**
  - I.e. communications tests must be linked to power tests!
  - Can run all tests using protocol, if desired (automate?)
  - Full certification of each protocol is outside the scope of P1547.1
- Hopefully this will result in progress towards communications interoperability!
- No cybersecurity testing included in 1547.1. (Important, but out of scope – see UL 2900-2-4)

Production Tests (Clause 7)

- Production tests verify the operability of **every unit** of DER equipment manufactured for customer use. These tests assume that the equipment has passed the type tests and may be conducted as a factory test or performed as part of a commissioning test

- Historically very limited, and will continue to be limited:

  Response to abnormal voltage

  Response to abnormal frequency

DER Evaluations and Commissioning Tests (Clause 8)

- **DER design evaluation** (desk study) is an evaluation during the interconnection review process to verify that the composite of the individual partially-compliant DERs forming a system as designed meets the interconnection and interoperability requirements of 1547-2018
- **DER installation evaluation** is an evaluation performed in the field to confirm that the DER was installed in a manner compliant with 1547-2018 requirements
- **Commissioning tests** are tests and verifications on one device or a combination of devices forming a system to confirm that the system as designed, delivered and installed meets the interconnection and interoperability requirements of 1547-2018

Due to wide variations in DERs, distribution feeders, and utility practices, P1547.1 content on these installation-specific procedures is **less prescriptive and less detailed than type-test content**.

Periodic Tests (Clause 9)

- **DER design evaluation** (desk study) is an evaluation during the interconnection review process to verify that the composite of individual partially-compliant units forming a DER meets the interconnection and interoperability requirements of 1547-2018
- **Commissioning tests** are tests and verifications on one device or a combination of devices forming a system to confirm that the system as designed, delivered and installed meets the interconnection and interoperability requirements of 1547-2018
- **DER installation evaluation** is an evaluation performed in the field to confirm that the DER was installed in a manner compliant with 1547-2018 requirements

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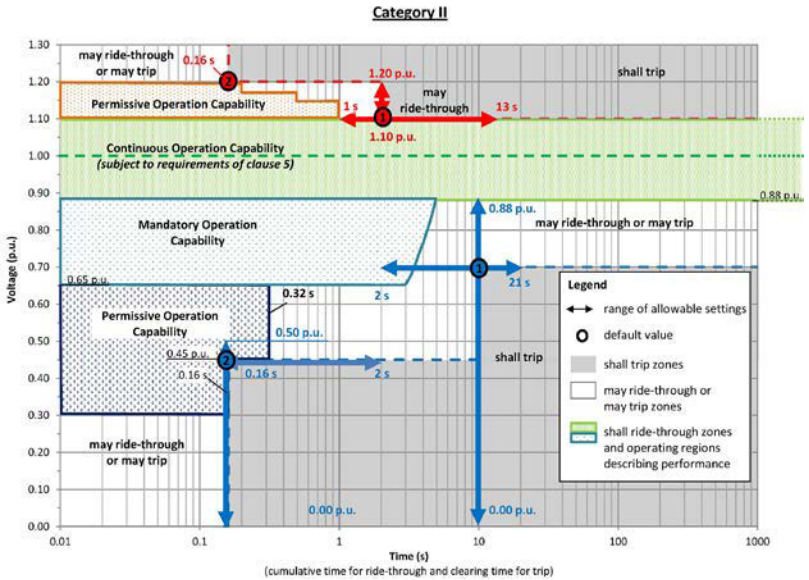
1547/P1547.1 Topics of Potential Special Interest to PJM and its Stakeholders

- **Response to voltage and frequency disturbances (ride-through and trip)**
- **Frequency-power droop**
- **Unintentional islanding**
- **Limitation of active active power**
- **Prioritization of DER responses**
- **Temporary overvoltage contribution (GFOV)**
- **Communications interoperability**
- **Commissioning tests and evaluations**

Topics of Potential Interest: Ride-through

Voltage and frequency event ride-through and trip

- Three “abnormal operating performance” categories: I, II, III.
  - Cat III has widest ride-through
  - Cat I intended to allow DERs with limited RT capability if desirable for other reasons (eg landfill gas, back generation)
- Ride-through is considered an inherent DER capability (not adjustable). Trip settings are adjustable (within limits)
- **Momentary cessation** permitted for Cat I, II; required for Cat III below 0.50 pu voltage
- Other conditions requiring ride-through: **voltage phase jump, ROCOF, phase imbalance**
- Effects of ride-through (etc) on **anti-islanding** are **required to be tested**
- DER design evaluation shall consider:
  - Out-of-phase reclosure
  - Protection coordination



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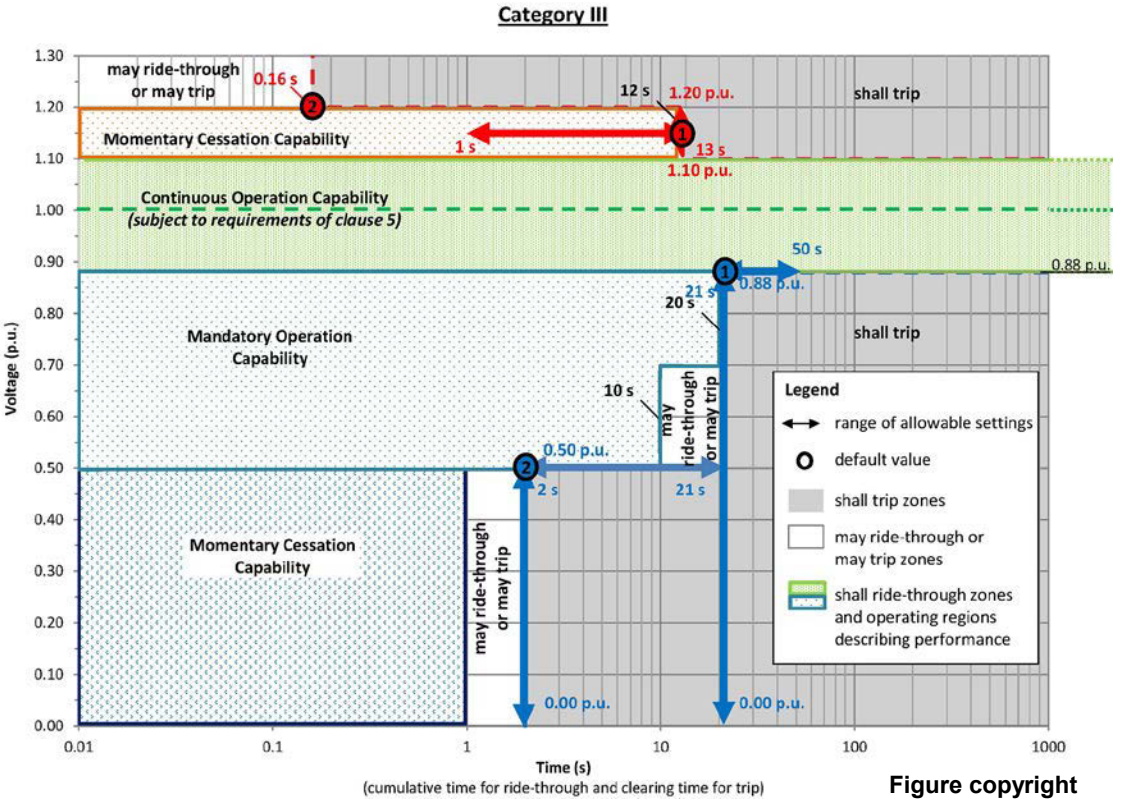
Topics of Potential Interest: Ride-through

Ride through – *new terminology*

- **Cease to energize** – stop exporting current (but not necessarily trip)
- **Mandatory operation** – DER must continue to export current
- **Permissive operation** – DER may continue to export current or may enter momentary cessation (but shall not trip)
- **Momentary cessation** – Temporarily stop current export but maintain synchronism and return to 80% of pre-disturbance current within 0.4 s of voltage recovery



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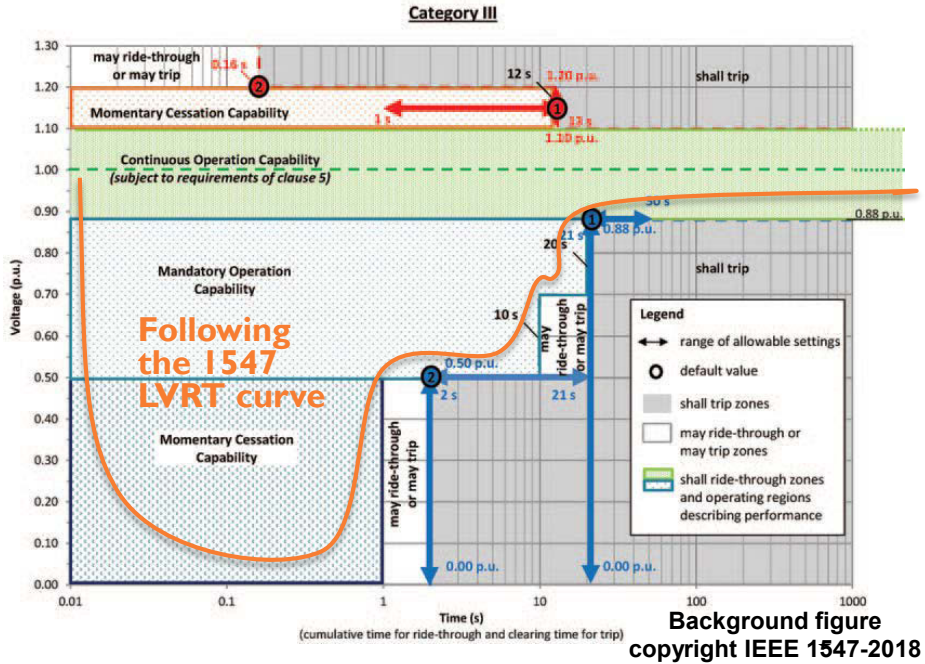
All of these behaviors can constitute ride-through!

Topics of Potential Interest: Ride-through

Should low-voltage ride through test “follow the curve” (more rigorous) or test each voltage region independently (easier test to run)?

Compromise: a rigorous test that is still achievable for multi-MW DERs without needing a multi-MW programmable AC supply



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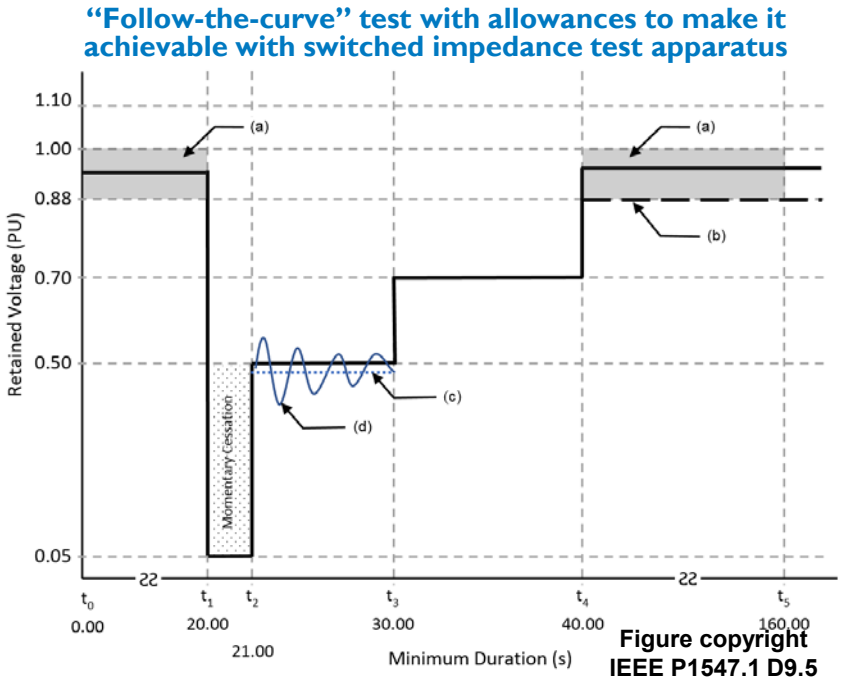

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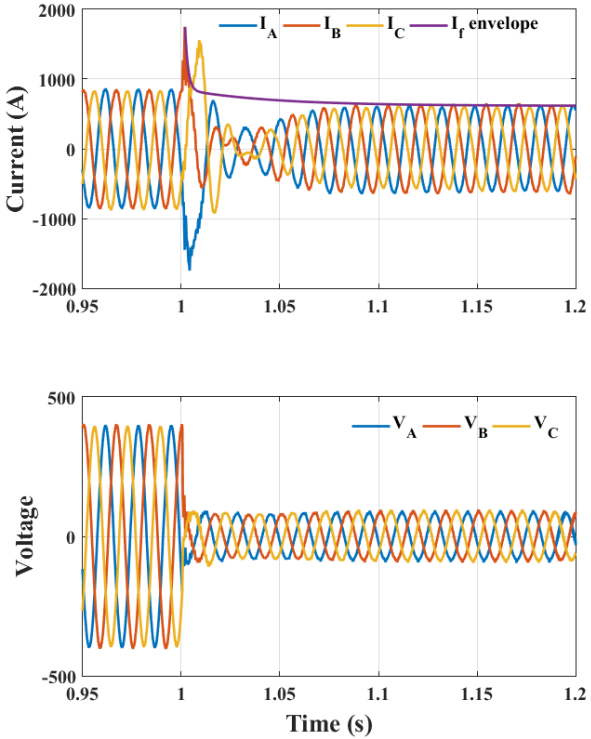
Topics of Potential Interest: Fault current contribution

- New type test characterizes DER response to certain fault types
- **Test waveform data required** to be made available
- Intent is to use data in **protection studies** (but can protection software properly model inverters?)

Three phase voltage dip to 0.20 pu (500 kVA inverter)



Single line to ground fault (20 kVA inverter)

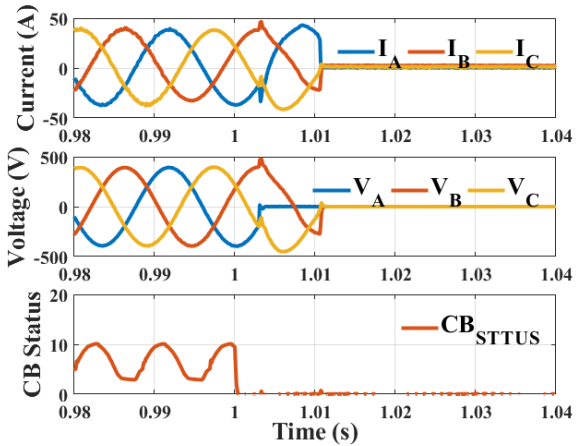
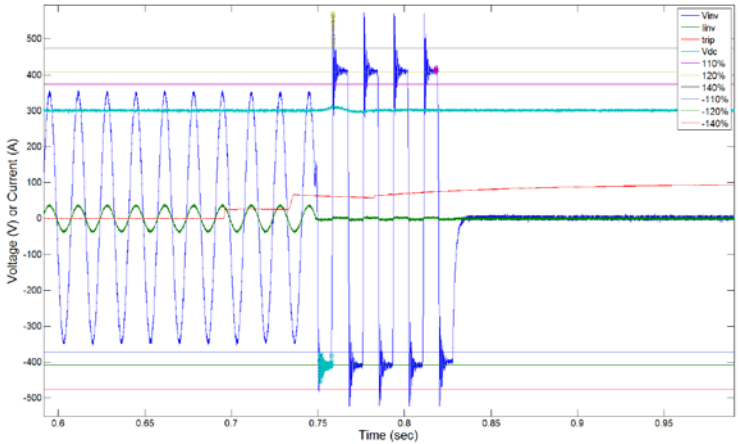


Figure credits: NREL

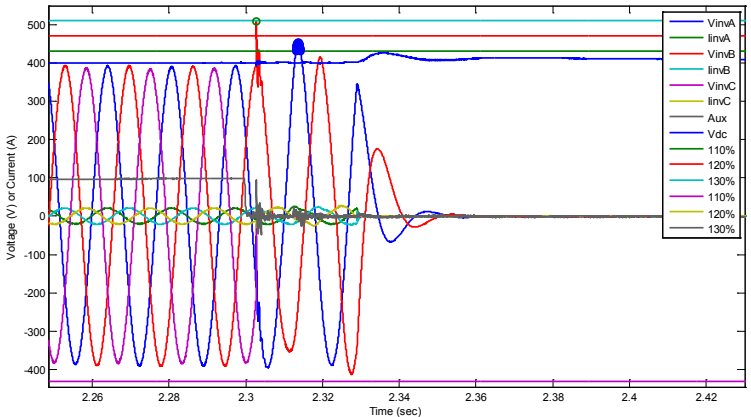
Topics of Potential Interest: Transient & Temporary OV

- New type test verifies DER response to **load rejection** events complies with 1547 requirement not to contribute to transient overvoltage
  - Test designed by FIGII and validated at NREL, in use for a couple of years in Hawaii (HECO)
  - See NREL/TP-5D00-63510
- Optional type test characterizes DER's contribution to **ground fault overvoltage** (aka temporary overvoltage)
  - Refs: IEEE C62.92.6, NREL test report TP-5D00–64173, TPWRD paper

Sample TrOV test



Sample GFOV test



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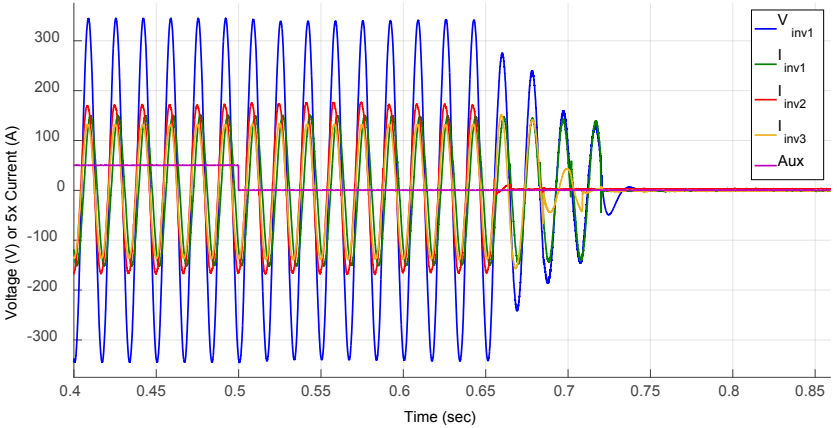
Topics of Potential Interest: Unintentional Islanding

- With rollout of ride-through and other smart inverter functions, possible conflicts with inverter anti-islanding controls became a concern
- NREL, HECO, and SolarCity tested the effects of ride-through, volt-var, and frequency-watt on three inverters' anti-islanding performance
- Tests included cases with multiple inverters connected at multiple neighboring locations on the same feeder

Outcomes

- No islands were found to extend beyond 0.7 seconds
- Volt-var and frequency-watt control had no statistically significant impact on island duration
- Ride-through tended to extend island duration by ~75 ms
- Not examined: Recloser time settings should be coordinated to minimize the chance of out-of-phase reclosure

Example multi-inverter island test waveforms



https://www.nrel.gov/docs/fy16osti/66732.pdf

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Topics of Potential Interest: Frequency-watt droop

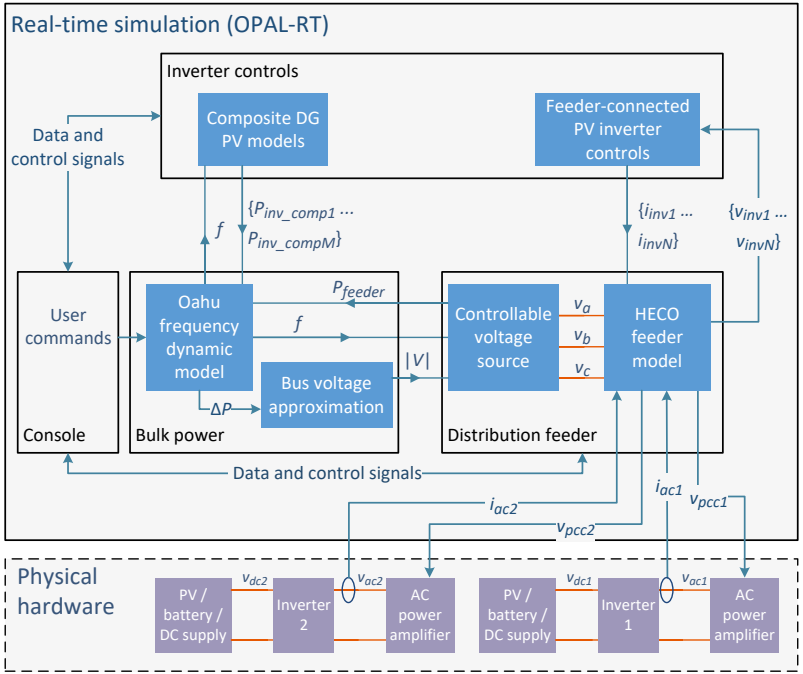
- As PV displaces conventional generation, system frequency stability is degraded
- DERs can help mitigate this by providing rapid frequency response (e.g. frequency-watt droop)

DOE GMLC project (HECO-NREL-SNL) examined ability of real hardware inverters to provide fast droop response

Approaches:

- Inverter hardware response characterization
- PSS/E simulations
- Small-signal stability analysis
- Inverter controls development
- PHIL tests (at NREL ESIF)

PHIL Test Setup Including Real-time Model of Oahu Power System



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Topics of Potential Interest: Frequency-watt droop

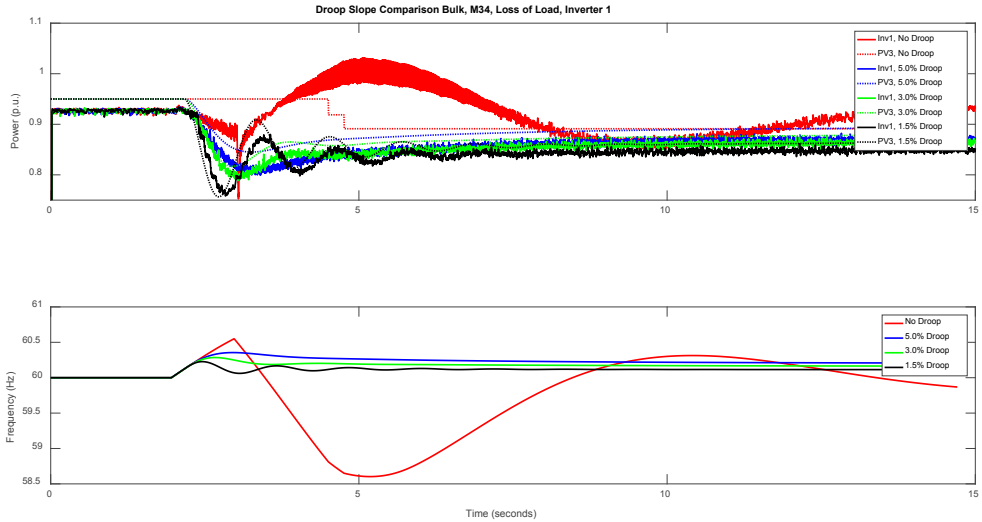
Findings:

- At the time of testing (2017), many (but not all) inverters could provide overfrequency response; most could not provide underfrequency response
- Manufacturers are currently updating products to align with 1547-2018
- Under-frequency load-shedding (UFLS) can make DER frequency response less effective

Outcomes:

- IEEE 1547-2018 allows for very fast frequency droop if needed
  - Very fast response may not be needed/desired in many cases (e.g. PJM)
- HECO now requires freq-watt for all new DERs

Example PHIL test of overfrequency event demonstrating DER inverters mitigating cascading event



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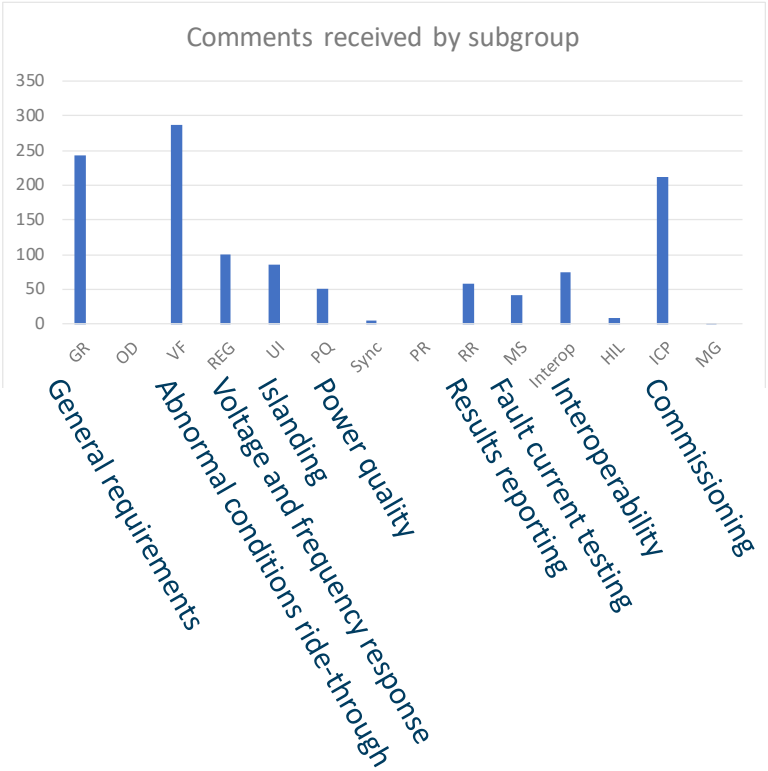
P1547.1 Subgroups (As of August 2019)

- General requirements
- Prioritization of DER Responses
- Abnormal voltage and frequency conditions tests
- Voltage and frequency regulation tests
- Unintentional islanding tests
- Power quality tests
- DER microgrid capabilities
- Synchronization tests
- Modeling and simulation
- Hardware-in-the-loop tests
- Interoperability tests
- Installation, commissioning, and periodic testing
- Results Reporting

Chair: Andy Hoke (emeritus: Sudipta Chakraborty)
Secretary: Jeannie Amber (Piekarz)
Treasurer: Charlie Vartanian
Vice Chairs: Tim Zgonena, Babak Enayati, Karl Schoder

P1547.1 Next Steps

- WG addressing 1300+ ballot comments
  - Goal: end of August
- Recirculate ballot and address new comments
  - Increase approval rate (indicates improved industry consensus)
- At least 2 (likely 3-4) recirculations needed
- Submit to IEEE RevCom for final approval and publication
  - Last 2019 RevCom deadline is Sept 17. Might have been possible (barely) to complete the necessary 2 recirculations by then, but quality and consensus would be sacrificed
  - Instead aim to complete all recirculations by late fall 2019
  - Submit for first 2020 RevCom deadline (January)



P1547.1 Tentative Timeline (as of Aug 2019)

Dates	Activities	Status
April 2018	**Milestone:** IEEE 1547-2018 published: New DER grid interconnection requirements established. In parallel: IEEE 1547.1 update in progress. (New test procedures to verify conformance to 1547-2018)	Complete
February 26-27, 2019	IEEE P1547.1 WG meeting – Draft 9.3 approved by Working Group	Complete
March 2019	Final pre-ballot edits to P1547.1	Complete
April 2019	**Milestone:** Final WG vote to send P1547.1 Draft 9.4 to IEEE-SA	Complete
April 2019	P1547.1 D9.4 sent to IEEE-SA for ballot invitation and MEC review	Complete
Q2-Q3 2019	IEEE-SA balloting and ballot resolution of P1547.1 (iterative)	In progress
Q3/Q4 2019	UL 1741 begin revision draft to incorporate new 1547.1 and 1547	
Q3/Q4 2019	**Milestone:** IEEE-SA ballot approval of P1547.1	
January 2020	IEEE RevCom review of P1547.1 In parallel: Finalize UL 1741 ballot document to incorporate new 1547.1.	
Q1/Q2 2020	**Milestone:** 1547.1 finalization and publication	
Q1/Q2 2020	UL Standards Technical Panel review and ballot updated UL 1741	
Q2/Q3 2020	**Milestone:** UL 1741 update published	
Q3 2020 – Q4 2021	Inverter manufacturers update and recertify products to UL 1741	
Q4 2020 – Q4 2021	UL 1741 / 1547-2018 compliant inverters expected to be available on market	

Thank you

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NREL/PR-5D00-74497

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Extra Slides

For further information on IEEE P1547.1, see
http://grouper.ieee.org/groups/scc21/1547.1_revision/1547.1_revision_index.html

How to test and verify requirements for P2800?

New IEEE P2800 will play a similar role to 1547, but for transmission-connected resources (and only for inverter-based plants)

How will the requirements for these very large inverter-based plants be verified?

- **The inverter terminals can be very remote from the transmission system interface**
- **What is the role of type testing?**
- **Will P2800.1, as an entity standard and a recommended practice (not a normative standard) manage to play a similar role to 1547.1?**
- **What is the role of design evaluations and commissioning? Simulation? HIL?**
- **Perhaps some requirements are "verified" through field experience?**