IEEE Draft Standard P1547.1 Status Update

Validating Conformance to IEEE 1547-2018

Jesse Leonard (Clemson Univ.)
Co-chair HIL subgroup of IEEE P1547.1

PV Systems Symposium
Albuquerque, NM
May 2, 2018

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Disclaimer & Acknowledgements

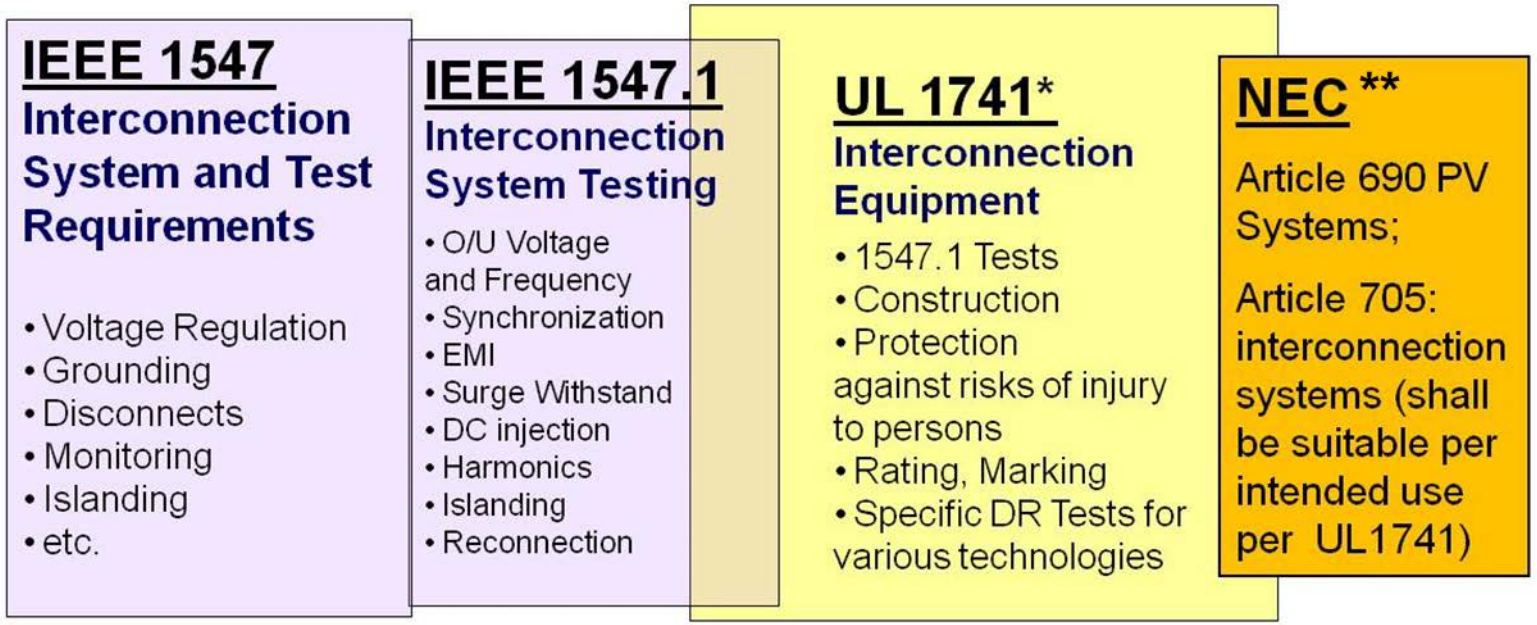
- *This presentation and discussion here on IEEE 1547-2018 and P1547.1 are the author's views and are not the formal explanation or position of the IEEE.*

- Personal thanks to Andy Hoke (chair P1547.1) for providing valuable inputs and materials

Motivation for IEEE P1547.1

- In many locations the power system **depends on DER support** 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 from “just get out of the way” to “stay connected (within limits) and support voltage and frequency”
- 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
- Other power systems failed to recognize this in time, sometimes at great cost.
  - North America has a chance to get it right the first time!

IEEE 1547 Standards Example Use in U.S.



- Content list is for 1547-2003. Same relationship will exist for 1547-2018 and future revisions of 1547.1, 1741, and NEC.
- 1547-2018 cannot be fully applied until after revised P1547.1 is published!
- Note: 1547-2018 contains many new requirements that are not fully verified through lab testing

  → DER evaluations and commissioning tests become more important

IEEE 1547 Content Growth

	1st Edition		2nd Edition
1547 technical content:	13 pages	→	127 pages
1547.1 technical content:	54 pages	→	??? pages (currently ~200)

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

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P1547.1: Full Revision

Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces.

Scope: This standard specifies 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.

Purpose: Standardized test and evaluation procedures are necessary to establish and verify compliance with those requirements. These test procedures shall provide both repeatable results, independent of test location, and flexibility to accommodate a variety of DER technologies and functions.

P1547.1: Full Revision

- What needs to be revised?
- What needs to be added?
- What needs to be external to P1547.1?

- ***Goal**: to come up with P1547.1 contents that fulfill the PAR scope and purpose: addressing revised requirements in IEEE 1547*

IEEE 1547.1-2005 CONTENTS

1. **Overview**
2. **Normative references**
3. **Definitions and acronyms**
4. **General requirements**
5. **Type tests**
6. **Production tests**
7. **Commissioning test**
8. **Periodic interconnection tests**

Annex A (normative) Test signals

Annex B (informative) Bibliography

P1547.1 Overview

- IEEE P1547.1 provides conformance test procedures to establish and verify compliance with the requirements of revised IEEE 1547
- IEEE P1547.1 is not just for type testing; conformance may be established through combination of type (aka “design” tests), production tests, design evaluation, installation evaluation, commissioning tests, and periodic tests
- Like 1547, applies to all DERs (not just PV, and not just inverter-based)
- Does not cover testing for safety
- Although this standard does not define a certification process, these P1547.1 tests can be used as part of such a process – e.g. UL 1741
- Need to keep objectives technically precise for P1547.1 – this is not a design guide, recommended practice, business, tariff, contractual, regulatory, or policy document

P1547.1: Types of Verification Methods

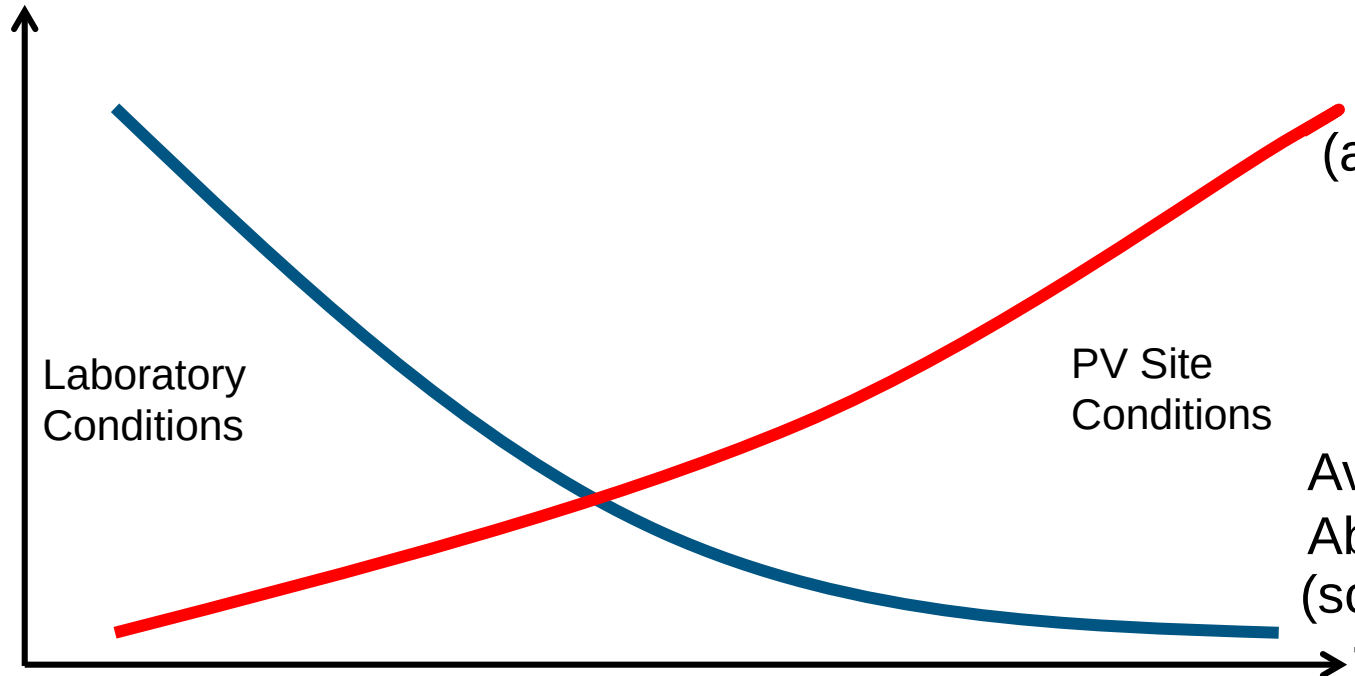
Test and evaluations in 1547.1 show how to achieve compliance at PoC and PCC through various verification methods

- **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

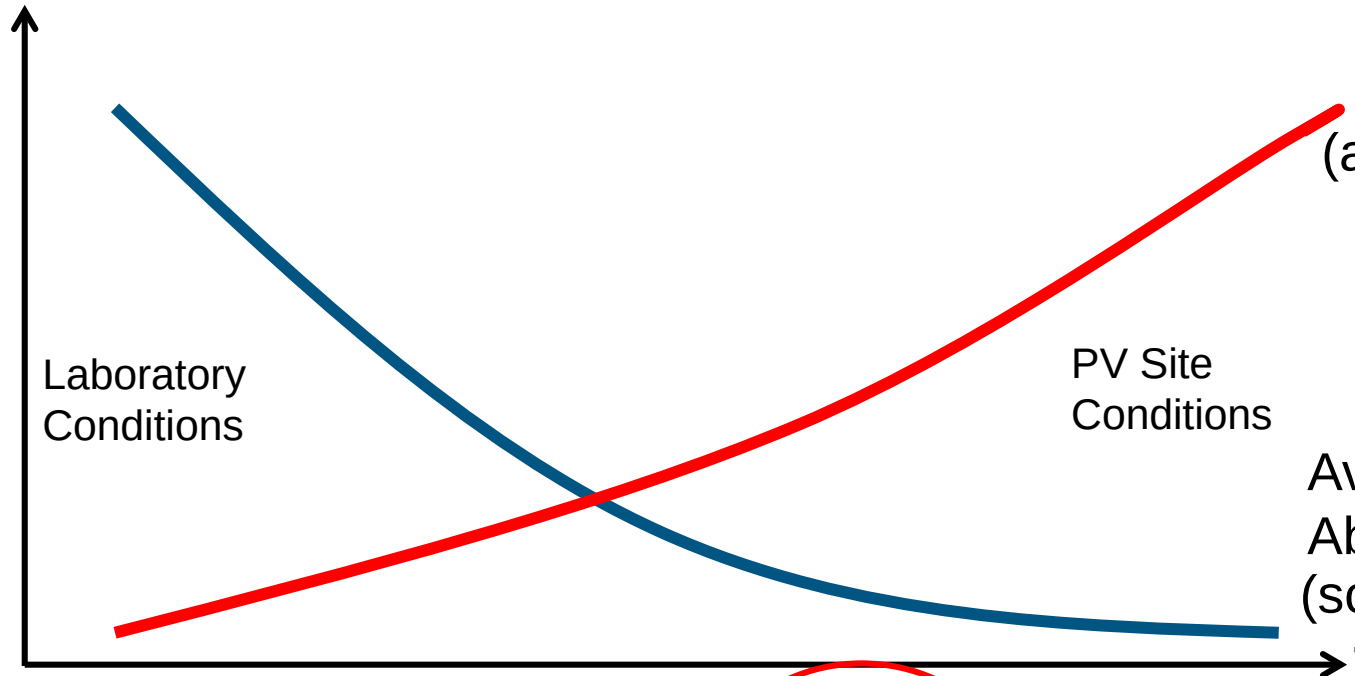
Feasibility of Testing Over DER Lifecycle



Method for validation to 1547 req.	Type **Tests**	Production (end of line) **tests**	Design Evaluation	Installation Evaluation	Commissioning and periodic **tests**
DER Lifecycle	Prototype Unit	Production Units	Site Design, Procurement	Installed Units + any Support Equip.	

Note: line trajectories are for illustrative purposes based on testing experience, hard numbers difficult to quantify

Where does screening fit in?



Cost of DER terminal testing (amount of DER equipment under test)

Availability of test equipment, Ability to control DER terminal V,F (scope of tests)

Method for validation to 1547 req.	Type **Tests**	Production (end of line) **tests**	Design Evaluation	Installation Evaluation	Commissioning and periodic **tests**
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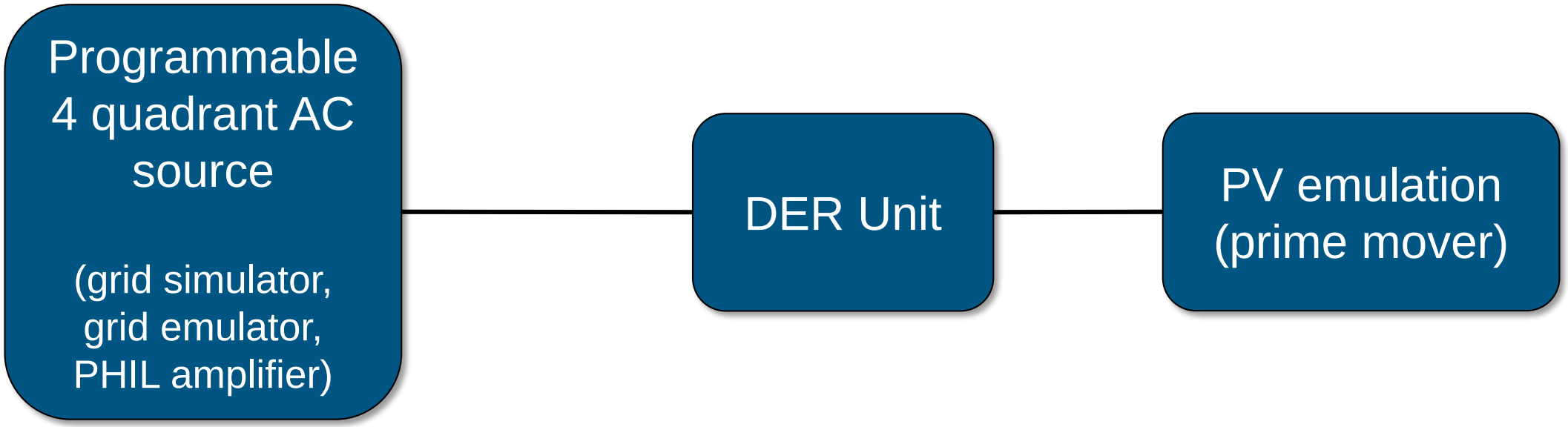
Test Equipment for Most Full Power Type Tests



Test Equipment for Most Full Power Type Tests

Looking at existing UL1741 SA – circuit suitable for all but one test

SA8	Anti-islanding	(needs RLC circuit)
SA9	L/HVRT Low and High Voltage Ride-through (and trip)	
SA10	L/HFRT Low and High Frequency Ride-through (and trip)	
SA11	Ramp rates: normal and soft-start	
SA12	Specified Power Factor (SPF)	
SA13	Volt/Var	
SA14	Frequency-Watt	
SA15	Volt-Watt	

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4Q AC source changing, DER responding

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SA15	Volt-Watt	

4Q AC source fixed, DER changing

Voltage Ride-through & Trip Cat II,III

Table 12—DER response (shall trip) to abnormal voltages for DER of abnormal operating performance Category II (see Figure H.8)

Shall trip—Category II				
Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Voltage (p.u. of nominal voltage)	Clearing time (s)	Voltage (p.u. of nominal voltage)	Clearing time (s)
OV2	1.20	0.16	fixed at 1.20	fixed at 0.16
OV1	1.10	2.0	1.10–1.20	1.0–13.0
UV1	0.70	10.0	0.0–0.88	2.0–21.0
UV2	0.45	0.16	0.0–0.50	0.16–2.0

Table 13—DER response (shall trip) to abnormal voltages for DER of abnormal operating performance Category III (see Figure H.9)

Shall trip—Category III				
Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Voltage (p.u. of nominal voltage)	Clearing time (s)	Voltage (p.u. of nominal voltage)	Clearing time (s)
OV2	1.20	0.16	fixed at 1.20	fixed at 0.16
OV1	1.10	13.0	1.10–1.20	1.0–13.0
UV1	0.88	21.0	0.0–0.88	21.0–50.0
UV2	0.50	2.0	0.0–0.50	2.0–21.0

Reference: IEEE 1547-2018

Voltage Ride-through & Trip Cat II,III

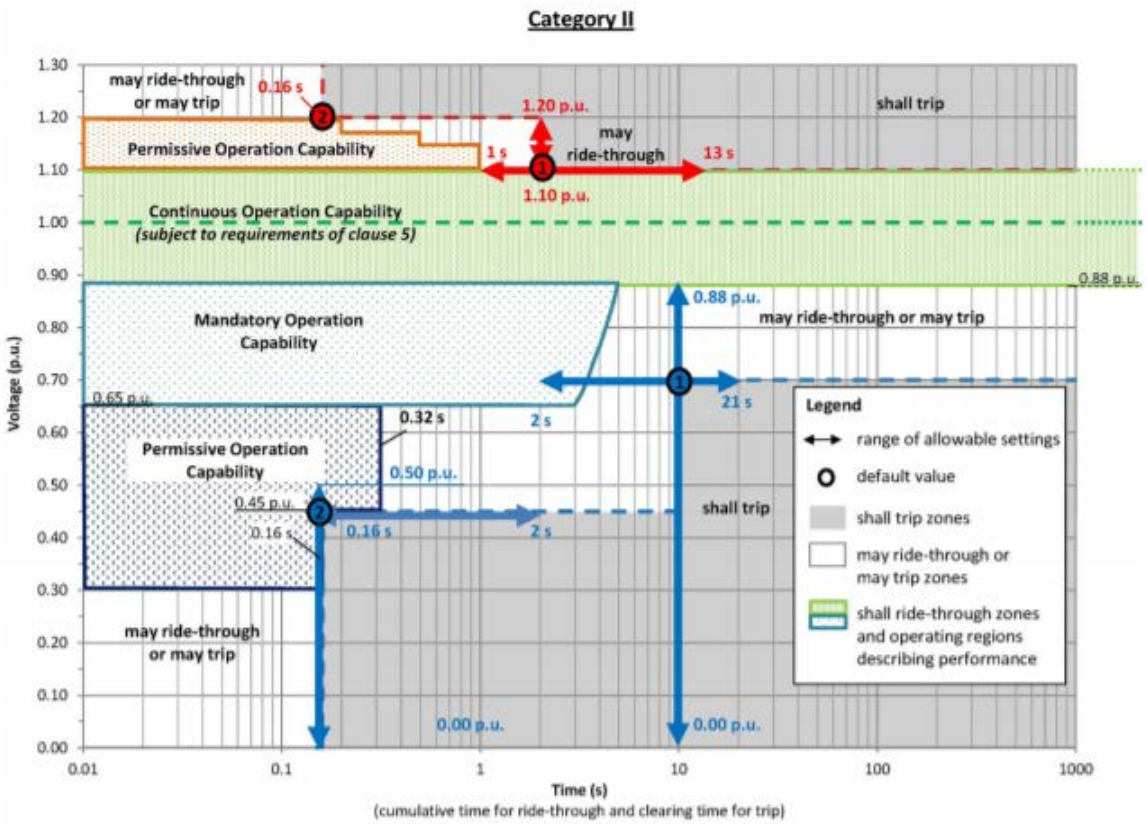

Figure H.8—DER response to abnormal voltages and voltage ride-through requirements for DER of abnormal operating performance Category II

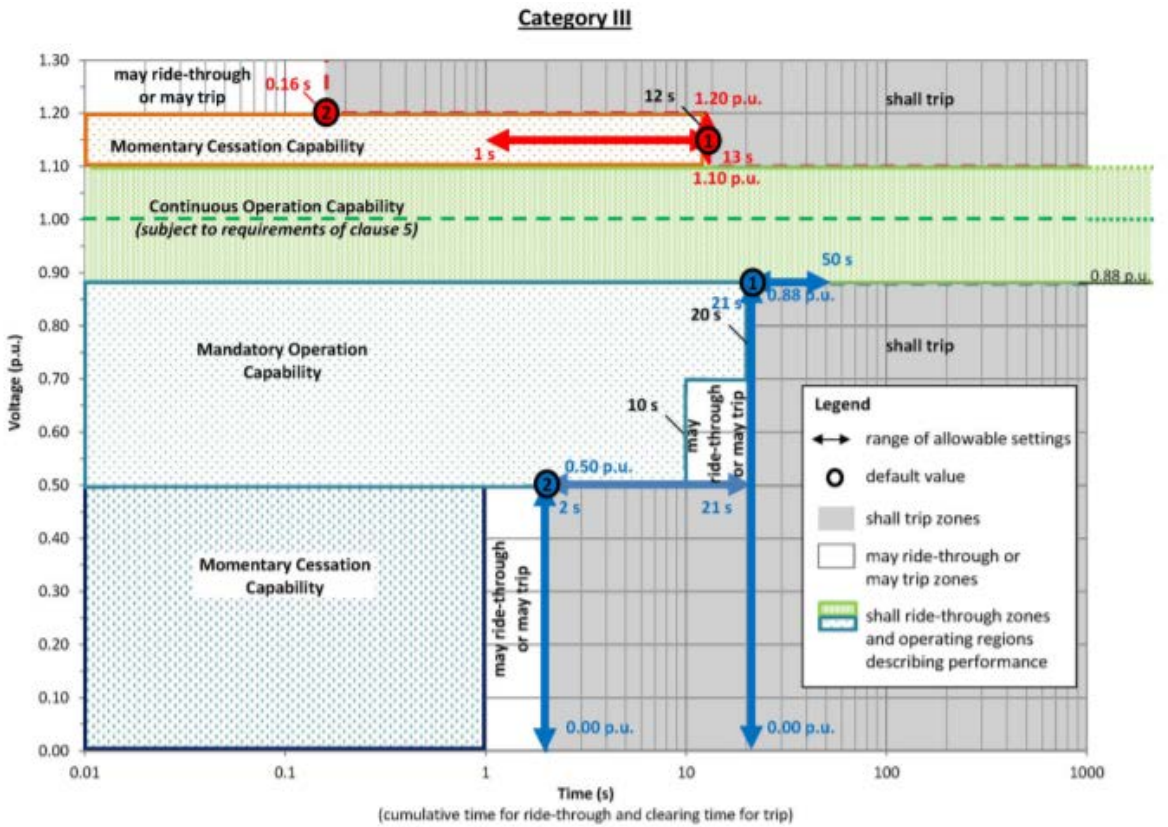

Figure H.9—DER response to abnormal voltages and voltage ride-through requirements for DER of abnormal operating performance Category III

Reference: IEEE 1547-2018

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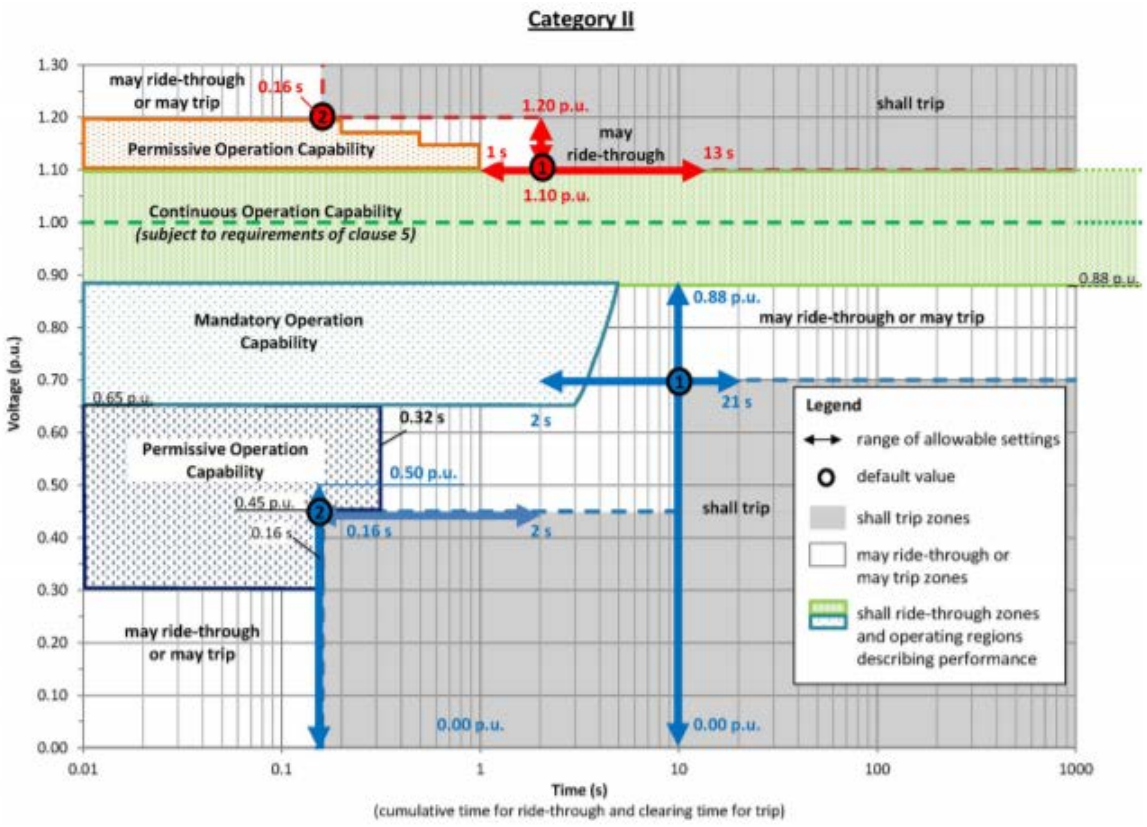
Voltage Ride-through & Trip Cat II,III



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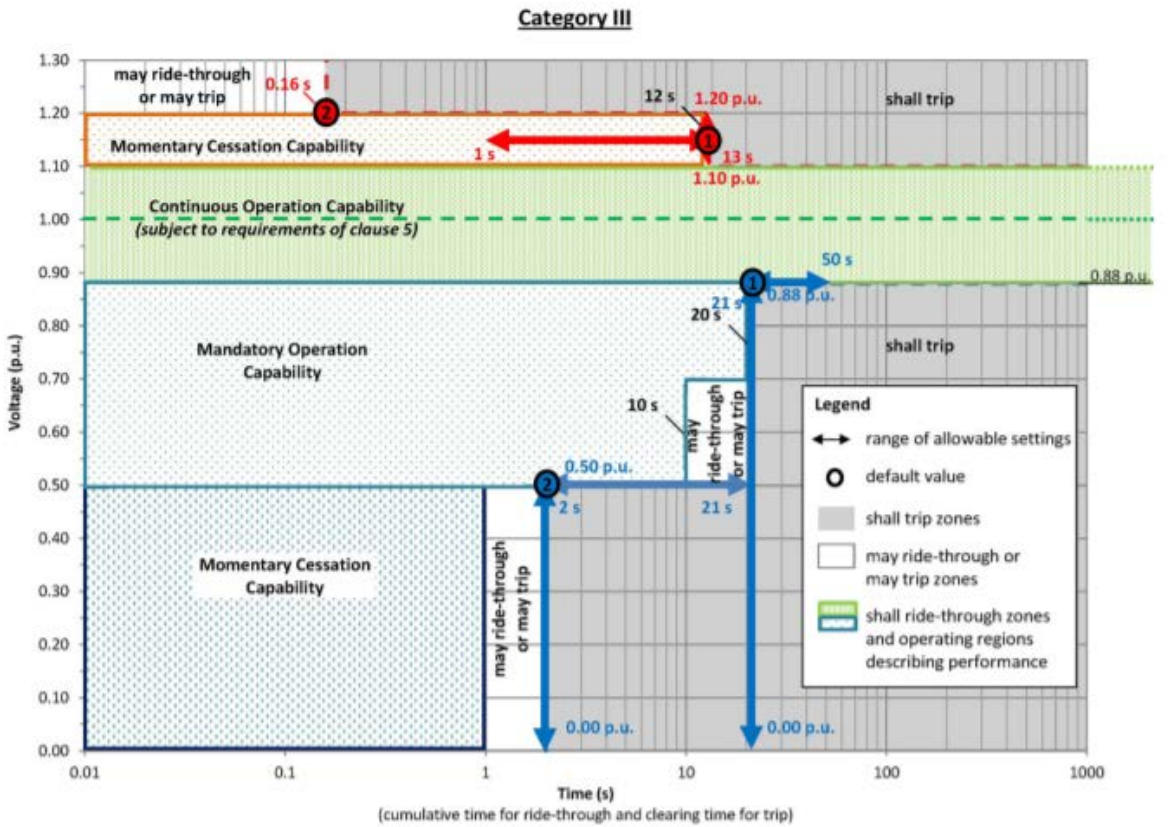

Figure H.9—DER response to abnormal voltages and voltage ride-through requirements for DER of abnormal operating performance Category III

Reference: IEEE 1547-2018

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Frequency Ride-through & Trip Cat I,II,III

Table 18—DER response (shall trip) to abnormal frequencies for DER of abnormal operating performance Category I, Category II, and Category III (see Figure H.10)

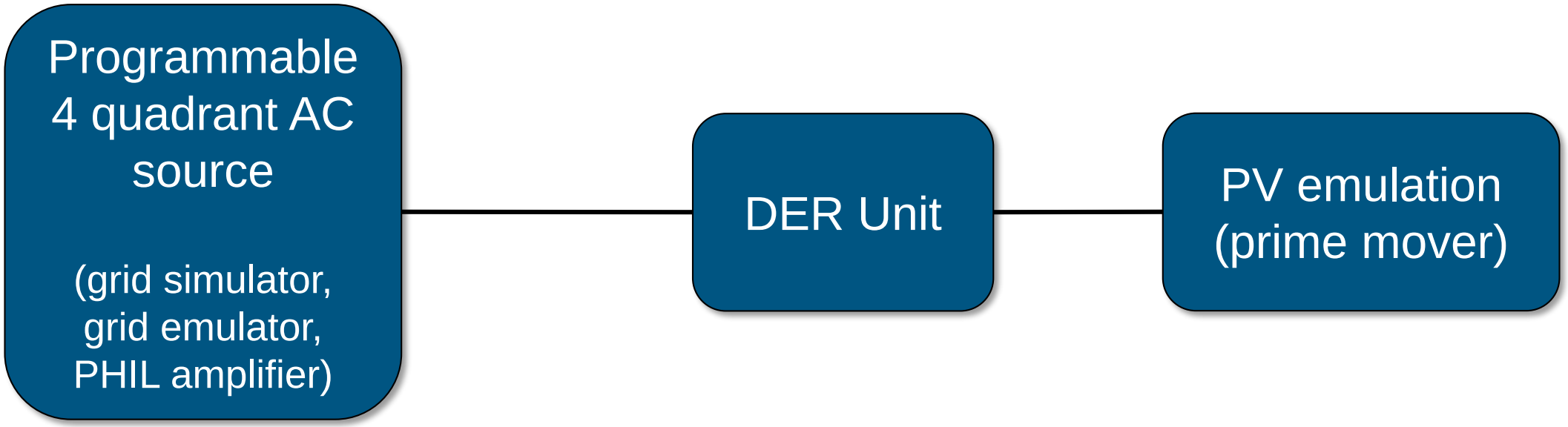
Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Frequency[c] (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s)
OF2	62.0	0.16	61.8–66.0	0.16–1 000.0
OF1	61.2	300.0	61.0–66.0	180.0–1 000.0
UF1	58.5	300.0[c]	50.0–59.0	180.0–1 000
UF2	56.5	0.16	50.0–57.0	0.16–1 000

Table 19—Frequency ride-through requirements for DER of abnormal operating performance Category I, Category II, and Category III (see Figure H.10)

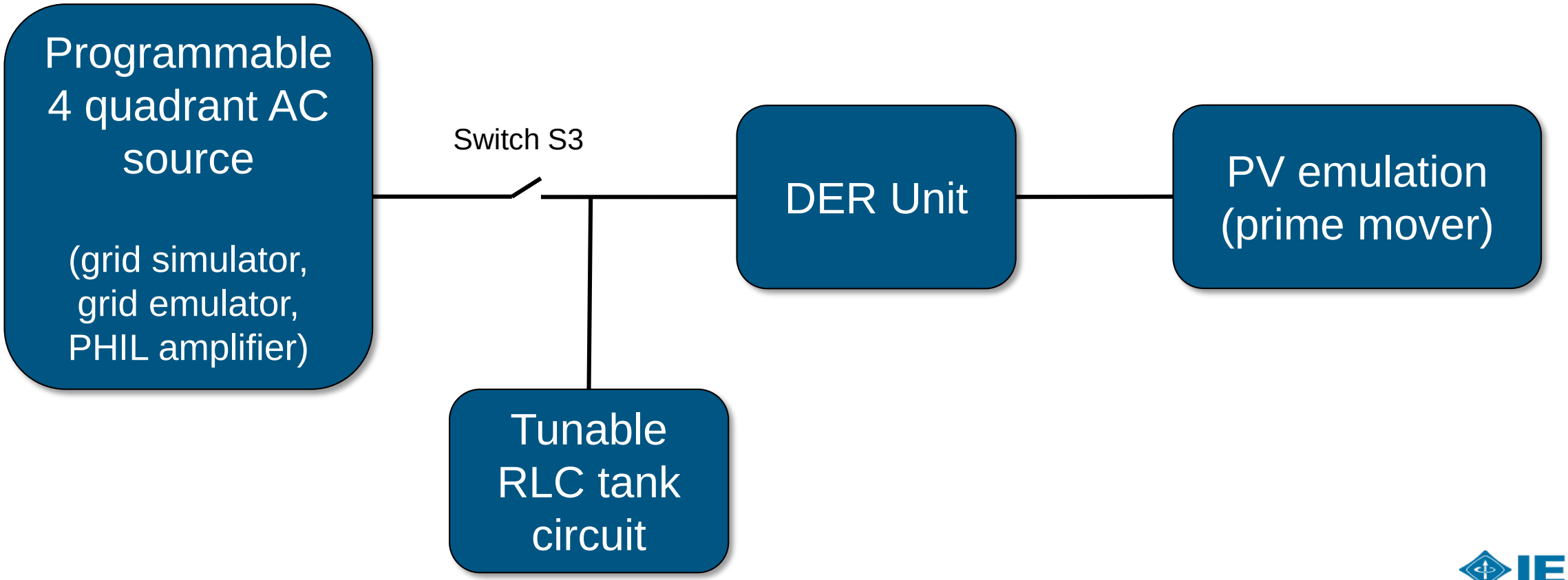
Frequency range (Hz)	Operating mode	Minimum time (s) (design criteria)
$f > 62.0$	No ride-through requirements apply to this range	
$61.2 < f \leq 61.8$	Mandatory Operation[a]	299
$58.8 \leq f \leq 61.2$	Continuous Operation[a,b]	Infinite[c]
$57.0 \leq f < 58.8$	Mandatory Operation[b]	299
$f < 57.0$	No ride-through requirements apply to this range	

Reference: IEEE 1547-2018

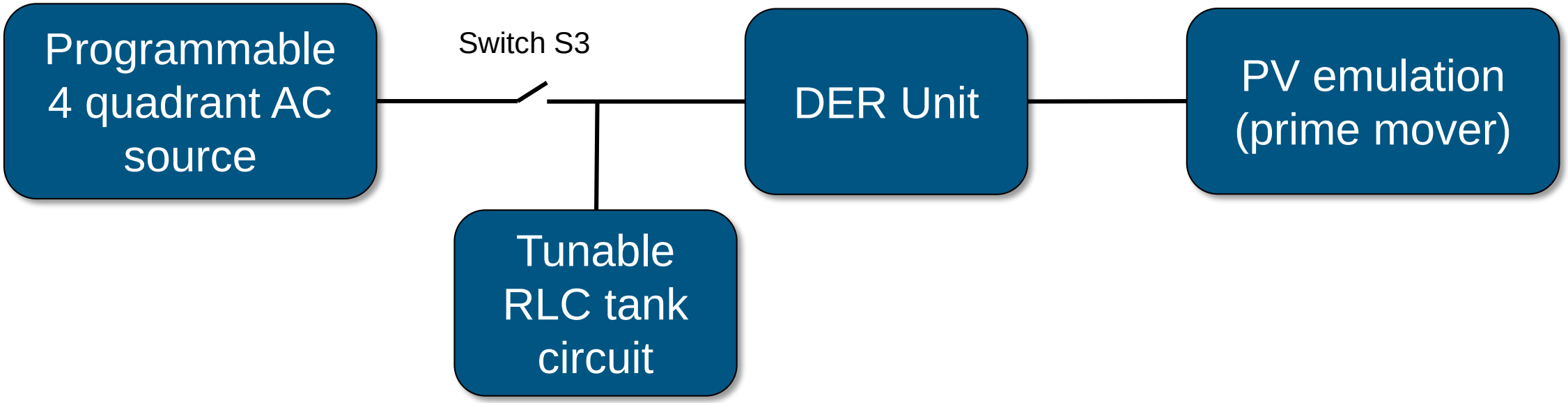
Modifying Test Circuit for Anti-Islanding Test



Modifying Test Circuit for Anti-Islanding Test



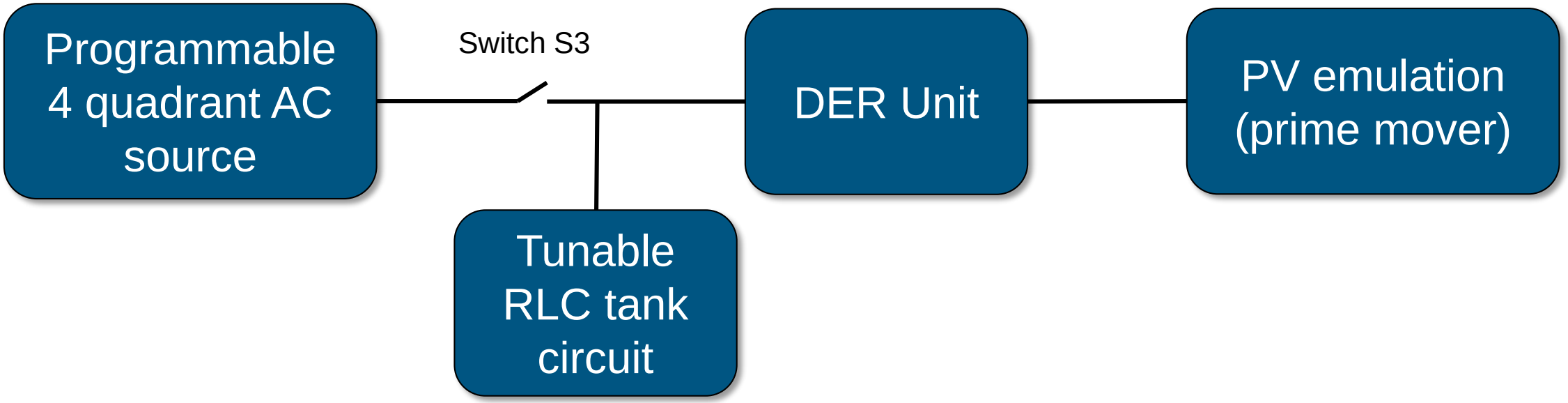
Scope of Tests Presently in UL1741 SA



- Power setpoints: 33%, 66%, 100%
- Settings groups
  - VRT, FRT enabled
  - VRT, FRT, SPF, RR, FW enabled
  - VRT, FRT, Volt-VAR, RR, FW enabled
- -5%, 0%, +5% off-tune in 1% increments. Expands until ROT's decrease
- Replicates

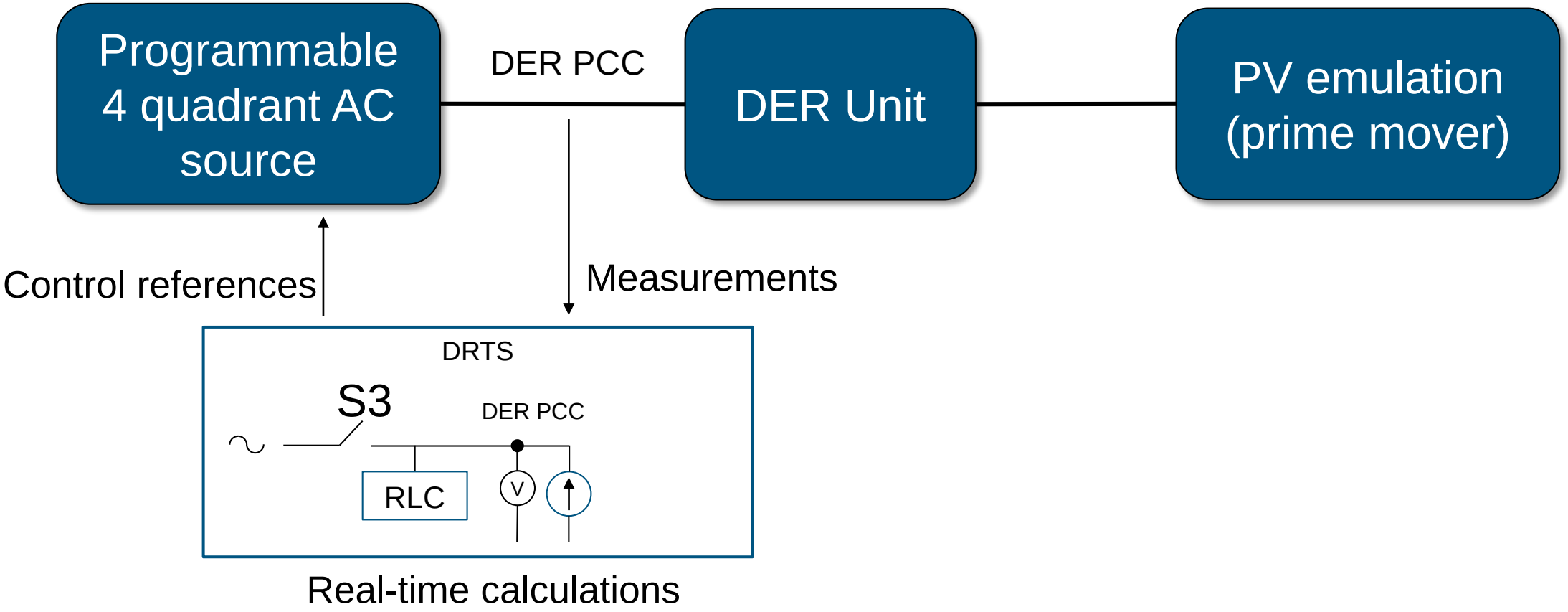
>100 tests,
difficult to automate,
difficult to tune,
generates lots of heat and cost

Approach to Improve in P1547.1



- Power setpoints: **two setpoints**
- Test with UI disabled: verify tuned circuit instead of 2% I_{rated} through S3
  - If DER runs on, RLC is in tune, can proceed

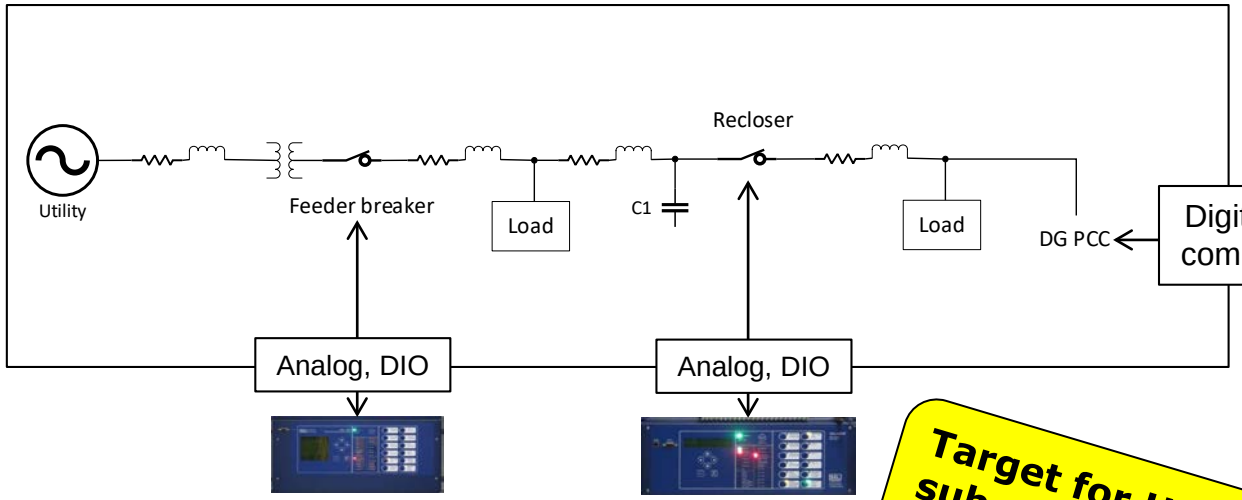
Applying Hardware-In-the-Loop Methods



DRTS – digital real-time simulator
Vendor-agnostic term being used in IEEE P2004 – Recommended Practice for Hardware-In-the-Loop (HIL)

Ongoing work to validate HIL methodology

DRTS – digital real-time simulator



PHIL interface

(4160V 3ph)

4Q AC Source

50 kW inverter + inverter controllers

PV emulation

- DRTS for feeder circuit emulation
- Test with commercial available inverters

Target for HIL subgroup this 1547.1 revision

Test method validation: physical RLC vs. PHIL RLC on small inverter

PHIL RLC

Off tune RLC, DER settings combinations

(1547.1)

PHIL Feeder

Feeder load P, Q

machine loads, etc.

DER location

Iterating method on different inverters (higher power)

Validation

Expanded and automated design of experiments (doe) capabilities with PHIL

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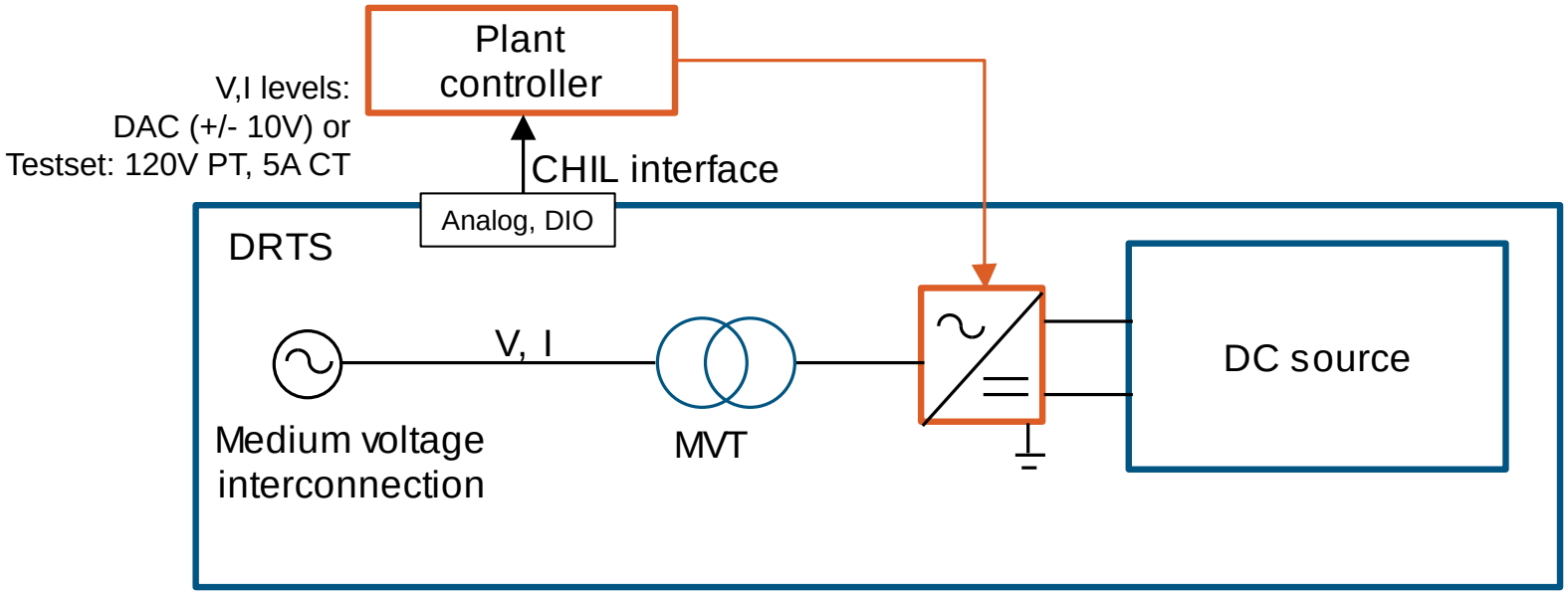
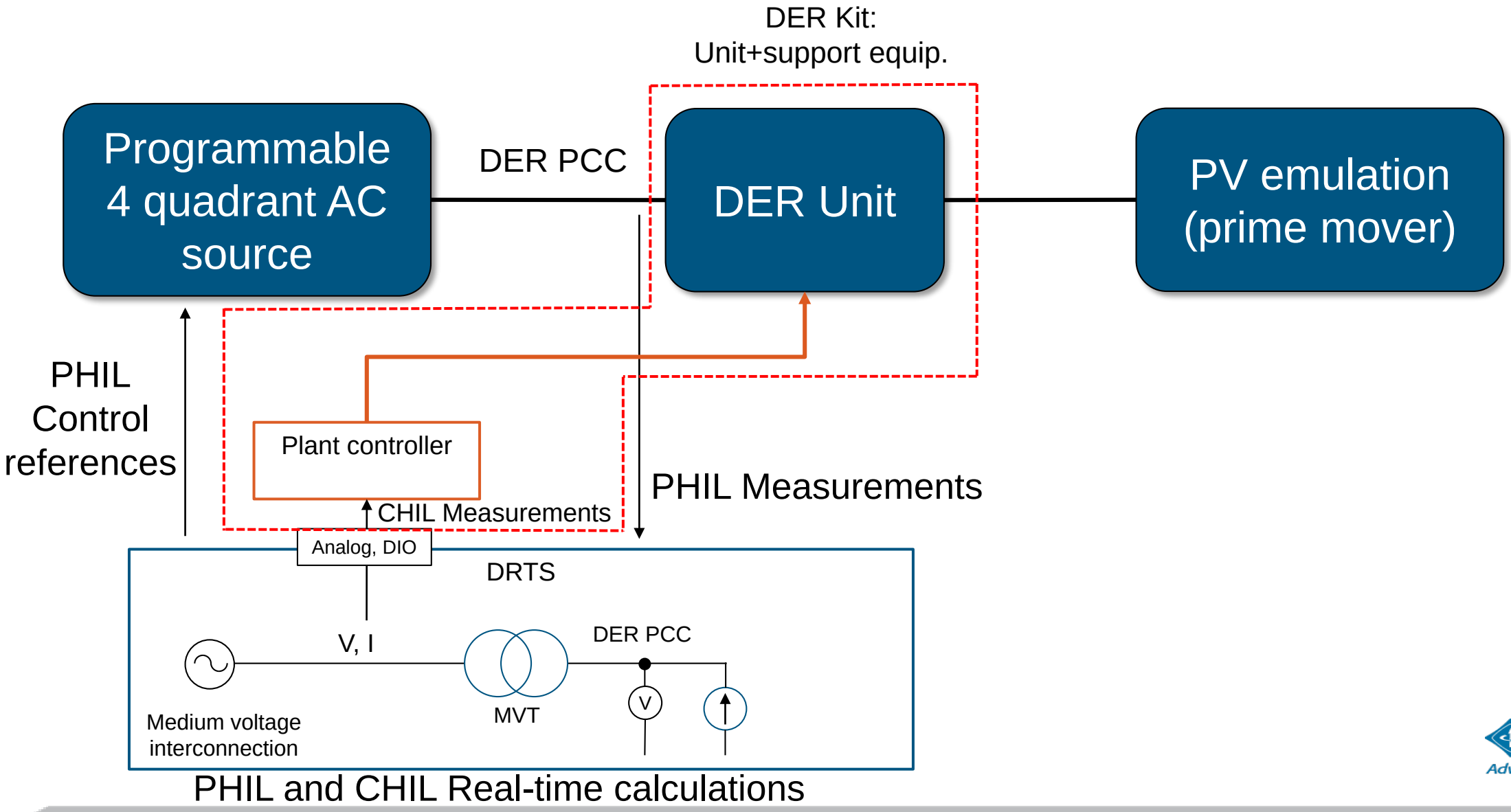
Other HIL opportunities: plant control testing



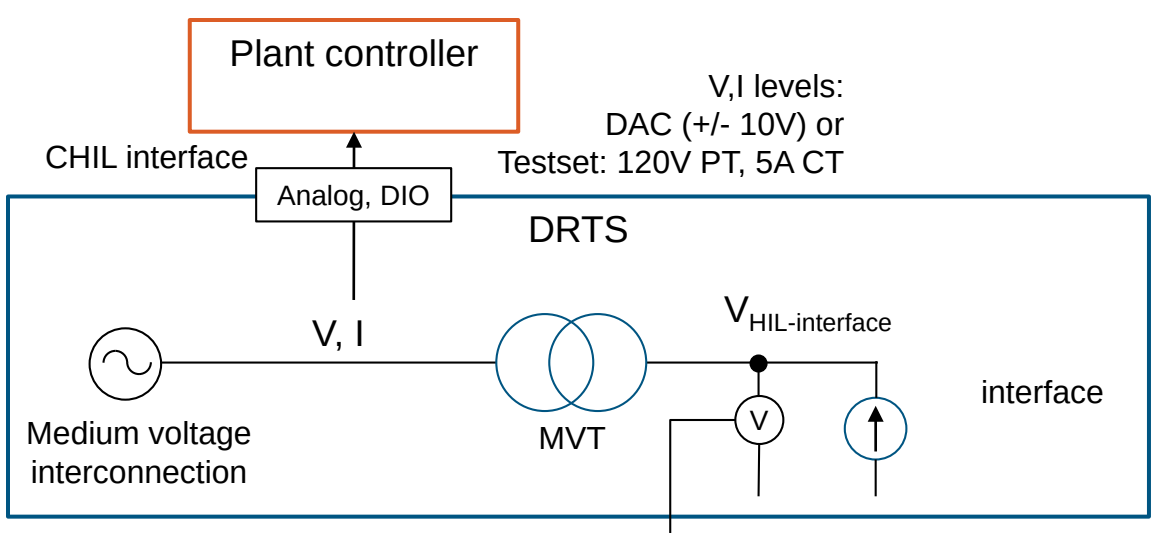
CHIL – controller hardware in the loop

Controller being physical PLC, relay, etc. interfaced at its native sensing V,I inputs

Applying HIL to DER “kit”



Other HIL opportunities: DER “kit” testing



DRTS – digital real-time simulator (calculations)

Idea of kit brought in 1547 WG: group of components all pre-tested as a kit.
Could this bypass some **design evaluation** or **commissioning tests**

Design Evaluation

PoC vs PCC and DER Support Devices

- **Design evaluation** – A “paper study” evaluating a proposed DER installation
- **Ex. residential rooftop inverter** – system installer has “paper study” verifying use of Listed components and NEC compliance. Type and production tests verified PoC compliance, in this case is also the PCC. Only thing left for “paper study” is utility screening (ideally not an expensive study).
- **Ex. central/string inverter plant >500kW export** – Type and production tests verified PoC compliance, but this plant must comply at PCC, addition of transformers, cap banks, plant controllers may require coordination. EPC/other performs plant “paper study”, utility does screening then maybe “paper study”.
- 1547.1 ICP subgroup balancing specificity of content with need for flexibility for all plant designs and requirements at PoC, PCC and various support devices

What dictates majority of installed DER behavior?

It's all in the software settings!

- **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

Installation Evaluation

- **Ex. residential rooftop inverter** – system installer verifies use of the right "grid code" settings – manufacturers have various methods for applying settings profiles, ex. Rule 21, or maybe soon to be 1547 Cat III, B.
  Idea being the electrical contractor/certified installer can do this, no new parties.
  (P1547.1 WG working on how best to limit number of profiles needed to fit every utility's specific requirements within range of allowable settings)

- **Ex. central/string inverter plant >500kW export** – Trip and ride-through settings, Volt-Var settings, etc. may be implemented across multiple devices.
  Settings need to be checked along with physical aspects of plant – components used, workmanship, etc.
  (and maybe rechecked at a later date)

P1547.1 Subgroup Leaders (As of April 2018)

Subgroup	General requirements	Overall Document	Abnormal voltage and frequency conditions tests (ride-through and trip)	Prioritization of DER Responses	Reporting of test results	Voltage and frequency regulation tests	Unintentional islanding tests	Power quality tests	Synchronization tests	Fault current characterization tests	Hardware-in-the-loop for 1547.1 applications	Interoperability (communications) tests	Installation, commissioning, and periodic testing	DER microgrid capabilities and microgrid interconnection devices
Subgroup Chair(s)	Andy Hoke	Andy Hoke	John Berdner	Bob White	John Berdner	Jon Ehlmann	Sig Gonzalez	Marcelo Algrain	Marcelo Algrain	Mike Ropp	Karl Schoder	Brian Seal	Mark Siira	Babak Enayati
		Mark Siira	Marcelo Algrain	Haile Gashaw		Aminul Huque	Greg Kern			Jeannie Amber	Jesse Leonard	Bob Fox	Wayne Stec	
			Jens Boemer				John Berdner							

To join any of the subgroups, please contact a subgroup chair directly, or contact andy.hoke@nrel.gov

P1547.1 Tentative Timeline to Ballot (As of April 2018)

Dates	Activities	Status
June 16, 2016	P1547.1 WG meeting – Draft 1 initiated	Done
October 27-28, 2016	P1547.1 WG meeting – Draft 1 discussed	Done
March 2, 2017	P1547.1 WG meeting – Draft 2 discussed	Done
June 20-21, 2017	P1547.1 WG meeting – Draft 3 discussed	Done
November 14-16, 2017	P1547.1 WG meeting – Draft 4 discussed	Done
February 2018	P1547.1 Draft 5 posted for WG meeting	Done
March 6-8, 2018	P1547.1 WG meeting – Draft 5 discussed	Done
May 25, 2018	Subgroups deliver Draft 6 content	
June 1, 2018	Draft 6 posted for WG review	
June 12-14, 2018	P1547.1 WG meeting – Draft 6 discussed	
June - August 2018	Subgroups finalize pre-ballot draft content (D7)	
September 2018	Pre-ballot draft to WG for review	
October 1, 2018	WG comments on D7 to subgroups	
October 9-11, 2018	P1547.1 WG meeting – Finalize and approve D7	
November 2018	IEEE MEC review, IEEE-SA ballot pool formation	
Dec 2018 - Jan 2019	P1547.1 IEEE-SA ballot	
Feb - June 2019	Ballot resolution	
Q3 2019	IEEE RevCom review	
Q4 2019 – Q1 2020	1547.1 Publication	

National Grid, Waltham MA, June 12-14, 2.5 days

Conclusions

- IEEE 1547-2018 will help standardize “smart DERs” and accelerate state of the art. It can provide **high value** to the power industry.

- IEEE 1547-2018 Working Group agreed on and specified **safe, reliable,** and **cost-effective** new interconnection and interoperability **requirements** for DERs.

- Specification of **test and verification** requirements is under way in P1547.1.
  - Interim solutions via UL1741-SA exist. ➔ support offered in EPRI project

- IEEE 1547-2018 and P1547.1 will provide a solid and widely-accepted **technical basis for regulatory proceedings**.
  - Action required from state regulators, et al.

For More Information

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

Sign up for the ListServ to receive occasional communications, including meeting information. Instructions are at the website above.

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Karl Schoder, Florida State University | schoder@caps.fsu.edu (HIL subgroup co-chair)

Andy Hoke, NREL | andy.hoke@nrel.gov

Jeannie Amber, National Grid | Jeannie.Amber@nationalgrid.com

Thank You