Workshop on: Applying IEEE Standard 1547-2018

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PV Systems Symposium
Albuquerque, NM
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Some materials provided by NREL:
Dave Narang, 1547 Chairman
Andy Hoke, 1547.1 Chairman
Getting Connected and Grid Integration with IEEE 1547-2018

- **Introductions / Objectives** - All

- **Overview** – Tom Key
  - Discussion on Scope and Application

- **Smart Inverters, Support Requirements** – Aminul Huque (P and Q, voltage and frequency ride thru)
  - Discussion on Applications and Settings

- **Islanding and Protection** – Michael Ropp

- **Certification Test to Commissioning** – Jesse Leonard
  - Discussion on verification processes

- **Connection Screening and Reviews** – Tom Key
Disclaimer & Acknowledgements

• This presentation on IEEE P1547 are the author’s views and are not the formal position, explanation or position of the IEEE.

• Many thanks to Project 1547 Officers, Working Group members, and balloters who contributed their time and efforts to develop this standard.
History of Electric Power Development in USA

- Edison Pearl Street Station (1882)
- First US Use of AC Transmission (1886)
- Rolling Blackouts in California Begin
- PURPA (1978)
- Government support of centralized power (TVA, REA, BPA, Hoover Dam)
- August 14, 2003 Northeast Blackout
- Norwest Blackout

More energy is produced and managed at distribution level...20-30%?
U.S. Generation Capacity Deployment (GW) up to now.
Changing Color of US Generation (GW) 2002-2016

U.S. utility-scale electric capacity additions and retirements (2002-16)
gigawatts

additions

retirements

net change in capacity (GW)

- natural gas
- coal
- wind
- solar


53 43 16 14 9 9 15 16 11 15 12 -4 7 -4 15
Distributed Energy Resources (DER) are Changing the Electric Grid

Combined Heat & Power
Demand Response
Home Energy Management
Rooftop Solar
Energy Storage
Electric Vehicles
Large-Scale Solar

For more information on-line at: EPRI, The Integrated Grid
Average sales price and shipments data source: P. Mints, SPV Market Research, www.spvmarketresearch.com

283,338 MW

IEEE 929-1990 for PV
IEEE 1001-1988 for DG
IEEE 929-1990 for PV

US PURPA 1978
NEC 690-1987 for PV installation
IEEE 1547-2003 limiting DG grid support


*Average sales price and shipments data source: P. Mints, SPV Market Research, www.spvmarketresearch.com
Operating the Grid – *Looking Forward*

More *Use of* Distributed Energy Resources (DER)

- Generation Becomes More Flexible
- T & D Becomes More Controllable and Resilient
- 2-way Power Flow
- Consumers Become Energy Producers
- Loads Become More Interactive and Dynamic

*A More Dynamic* End-to-End Power System
World-wide cumulative PV shipped GWp up to 2026

- Forecast to 2026 given annual growth of 45%/year 2007-2016
- This estimate assumes 5%/year 2017-2026

- IEEE 1547-2018 requires DER grid support
- IEEE 1547a-2014 allows DER grid support

Average sales price and shipments data source: P. Mints, SPV Market Research, www.spvmarketresearch.com
## Major Changes in 1547 Amendment

### IEEE 1547 – 2003
- DR shall not actively regulate the voltage at the PCC
- DR shall cease to energize if frequency > 60.5 Hz
- Tighter abnormal V/F trip limits and clearance times

### IEEE 1547a – 2014
- DR may actively participate to regulate the voltage by changes of real and reactive power
- DR shall be permitted to provide modulated power output as a function of frequency
- Much wider optional V/F trip limits and clearance times
- Under mutual agreement between the EPS and DR operators, other static or dynamic frequency and clearing time trip settings shall be permitted.
IEEE 1547a™-2014 allowed Grid Support Functions

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 1547-2018 Requires Grid Support
**IEEE 1547 Document Contents (Clauses)**

1. Overview
2. Normative references
3. Definitions and acronyms
4. General specifications and requirements
5. *normal grid* Reactive power, voltage/power control
6. Response to Area EPS abnormal grid conditions
7. Power quality
8. Islanding
9. Distribution secondary grid and spot networks
10. Interoperability
11. Test and verification
12. Seven new annexes (Informative)
Connecting to and integrating with the grid

“DER Interconnection” Deals with the individual DER performance capabilities and interface issues specific to the DER and focus of IEEE 1547

VS

“DER Integration” at PCC, larger picture dealing with whole power system and aggregate DG affect on a feeder and grid planning operation and protection. This is usually the main topic of technical screening and studies.
Balancing Distribution and Grid Operator Needs

The proposes draft standard balances the grid operations & planning challenges with distributed energy resources.

- Voltage/Reactive Power
- Power quality: voltage limits/power factor/harmonics
- Frequency/Active Power
- Stability
- Health & Safety: protection coordination/anti-islanding

IEEE P1547 adequately addresses bulk system and distribution system needs.
1.4 General remarks and limitations

- Applicable to all DERs connected at typical primary or secondary distribution voltage levels.
  - Removed the 10 MVA limit from previous versions.
  - **BUT:** Not applicable for transmission or networked sub-transmission connected resources.
- Specifies **performance** and **not design** of DER.
- Specifies **capabilities and functions** and **not utilization** of these.
- Does not address planning, designing, operating, or maintaining the Area EPS with DER.
- Emergency and standby DER are exempt from certain requirements of this standard.
  - E.g., voltage and frequency ride-through, interoperability and communications.
- Gives precedence to synchronous generator (SG) design standards for DER with SG units rated 10 MVA and greater.
  - E.g., IEEE Std C50.12, IEEE Std C50.13.
New Requirements

Important changes in the scope of IEEE Std 1547

IEEE Std 1547-2003
- Focused on distribution system aspects.
- Specifications for the “interconnection system” sufficiently achieve the standard’s objective.
- Meant as DER interconnection standard but mainly used for equipment listing.
- Limited to electrical requirements.

IEEE Std 1547-revised
- Focused on distribution and bulk system aspects.
- Specifications encompass the whole DER.
- For equipment as well as plant-level verification.
- Includes both electrical as well as interoperability/communications requirements.
Reference Point of Applicability and Related Normative Definitions

Reference Points of Applicability:

- **point of common coupling (PCC)**: The point of connection between the Area EPS and the Local EPS.
- **Point of DER connection (PoC)**: The point where a DER unit is electrically connected in a Local EPS and meets the requirements of this standard exclusive of any load present in the respective part of the Local EPS.
- Any mutually-agreed point between the PoC and PCC.

Depends on three criteria:

- Zero-sequence continuity (or not)
- Aggregate DER nameplate rating
- Annual average load demand

Source: P1547/D7.3  Draft Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
IEEE 1547 Interconnection Example Use in United States

IEEE 1547
Interconnection System and Test Requirements
- Voltage Regulation
- Ride-through
- Interoperability
- Islanding
- ....

IEEE 1547.1
Conformance Test Procedures
- Utility interactive tests
- Islanding
- Reconnection
- O/U Voltage and Frequency
- Synchronization
- DC injection
- ....

UL 1741 listing
Interconnection Equipment Safety, Performance Certification
- 1547.1 Tests
- Protection against risks of injury to persons
- Specific tests for various technologies
- ....

NFPA70 (NEC)
Installation Code
- Article 690 PV Systems
- Article 705: interconnection systems (shall be suitable per intended use per UL1741)
  (NEC info. Based on NEC 2011)

Local interconnection processes and procedures
Decision Tree for Reference Point of Applicability
(for Local EPS where zero sequence continuity is maintained)

Aggregate DER nameplate rating ≤ 500 kVA?

Yes: small-scale DER

No: medium or large-scale DER

% of annual average load > 10%?

Yes: generation embedded in customer

No: significant generation embedded in customer

Local EPS never exporting >500 kVA for >30 s?

Yes: insignificant generation embedded in customer

No: significant generation embedded in customer

Yes: insufficient generation embedded in customer

No: significant generation embedded in customer

Clause 5.2 & Clause 7 met?

Yes:

No:

Discount influence of Local EPS load

Point of DER Connection, PoC (DER terminals)

Yes:

No:

Point of Common Coupling, PCC
Sections 5 and 6 - Proposed New Requirements

Draft IEEE P1547 Performance Category Approach

IEEE Std. 1547rev

Category A
Category B
Category C
Category D
Category E
Category F
Category G
Category H
Category I
Category J
Category K
Category L
Category M
Category N
Category O
Category P
Category Q
Category R
Category S
Category T
Category U
Category V
Category W
Category X
Category Y
Category Z

Ride-Through Voltage Regulation

Control / trip settings
- Ranges of adjustability
- Default parameters

Impact Assessment
- Technical conditions: type & capacity & future penetration of DER, type of grid configuration, etc.
- Non-technical issues: DER use case, impacts on environment, emissions, and sustainability, etc.

1 State Regulator, Area EPS or bulk system operator, etc.

DER Vendors

Market Analysis
- Costs
- Market segment
- Etc.

Authorities Governing Interconnection Requirements (AGIR)
Minimum Reactive Power Injection and Absorption Capability

<table>
<thead>
<tr>
<th>Category</th>
<th>Injection Capability as % of Nameplate Apparent Power (kVA)</th>
<th>Absorption Capability as % of Nameplate Apparent Power (kVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (at DER rated voltage)</td>
<td>44</td>
<td>25</td>
</tr>
<tr>
<td>B (over the full extent of ANSI C84.1 range A)</td>
<td>44</td>
<td>44</td>
</tr>
</tbody>
</table>
Voltage – Reactive Power (Volt-var) Mode

The volt-var characteristics are allowed to be adjusted locally and/or remotely as specified by the area EPS operator.

**Voltage Lower Limit for DER Continuous operation**

**Voltage Upper Limit for DER Continuous operation**

### Voltage – reactive power parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Category A</th>
<th>Category B</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_L$</td>
<td>$V_M$</td>
<td>$V_{Ref} - 0.02 V_N$</td>
<td>$0.95 V_N$</td>
<td>$1.05 V_N$</td>
</tr>
<tr>
<td>$V_H$</td>
<td>$V_{Ref}$</td>
<td>$V_{Ref}$</td>
<td>$V_{Ref}$</td>
<td>$V_{Ref}$</td>
</tr>
<tr>
<td>$Q_L$</td>
<td>$0$</td>
<td>$0$</td>
<td>$100%$ of nameplate reactive power capability, absorption</td>
<td>$100%$ of nameplate reactive power capability, absorption</td>
</tr>
<tr>
<td>$Q_H$</td>
<td>$V_{Ref} + 0.02 V_N$</td>
<td>$V_{Ref} + 0.03 V_N$</td>
<td>$V_{Ref}$</td>
<td>$V_{Ref}$</td>
</tr>
</tbody>
</table>

Category A: $V_{Ref}$

Category B: $V_{Ref} + 0.03 V_N$
# Section 6 - Basis of Abnormal Grid Performance - Ride-Through

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Category</th>
<th>Foundation</th>
<th>Justification</th>
</tr>
</thead>
</table>
| **Voltage Ride-Through** | Category I               | German grid code for medium voltage-connected synchronous generator-based DER | • *Essential* bulk system needs.  
                          |                           |                                                                            | • Attainable by all state-of-the-art DER technologies. |
|                      | Category II              | NERC PRC-024-2 but w/o stability exception, extended LVRT duration for 65-88% $V_{\text{nom}}$ | • *All* bulk system needs.  
                          |                           |                                                                            | • Coordinated with existing reliability standards.  
                          |                           |                                                                            | • Considering fault-induced delayed voltage recovery. |
|                      | Category III             | CA Rule 21 and Hawaii, minor modifications                                | • All bulk system needs.  
                          |                           |                                                                            | • Considering fault-induced delayed voltage recovery.  
                          |                           |                                                                            | • Distribution system operation. |
| **Frequency Ride-Through** | All Categories (harmonized) | CA Rule 21 and Hawaii, exceeds PRC-024-2  
                          |                           |                                                                            | • All bulk system needs.  
                          |                           |                                                                            | • Low inertia grids.  

*Source: EPRI White Paper (May 2015)*
## Section 7 Power Quality Requirements

<table>
<thead>
<tr>
<th>PQ Section</th>
<th>1547 2003</th>
<th>1547 2017 PQ$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC injection Limit</td>
<td>.5% current</td>
<td>No change</td>
</tr>
<tr>
<td>Synchronization</td>
<td>±5% ΔV at PCC</td>
<td>Table for Δf, ΔV, ΔΦ$^2$</td>
</tr>
<tr>
<td>RVC</td>
<td>None</td>
<td>New ΔV MV-3%, LV-5%</td>
</tr>
<tr>
<td>Flicker</td>
<td>Shall not cause</td>
<td>New Pst &lt; .35, Plt &lt; .25</td>
</tr>
<tr>
<td>Harmonic Current</td>
<td>&lt;5% TDD</td>
<td>&lt;5% TRD, Relaxed Evens$^3$</td>
</tr>
<tr>
<td>Harmonic Voltage</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>OV Temporary</td>
<td>No disturbing GFO</td>
<td>New to 138% $V_{\text{Lg}}$ or $I_{\text{L}}$$^4$</td>
</tr>
<tr>
<td>OV “Cumulative Instantaneous”</td>
<td>None</td>
<td>New <a href="mailto:2pu@1.5ms">2pu@1.5ms</a> and 1.4pu@16ms</td>
</tr>
</tbody>
</table>

1. IEEE 1547 addresses limits at interconnection (PCC)
2. Compared to IEEE 519-2014 some small differences, including TRD instead of TDD and relaxation of higher even harmonics limits.
3. From IEEE/ANSI C62.92, and considering new C62.92-6

Acronyms: PCC=Point of Common Coupling, TDD=total demand distortion, RVC=Rapid Voltage Change, TRD=total rated distortion, GFO ground fault overvoltage
Interoperability Requirements Summary

capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely and effectively (IEEE 2030).

Mandatory communications capability
A DER shall have provisions for a local DER interface capable of communicating...

Information to be exchanged:
- Nameplate: as-built characteristics of the DERs (read)
- Configuration: present capacity and ability of the DERs to perform functions (read/write)
- Monitoring: present operating conditions of the DERs (read)
- Management: information to update the functional and mode settings for the DERs (read/write)

Communication performance requirements:
- Availability of communication (DER is operating in continuous or mandatory operation region)
- Information read response times ($\leq 30$ s, maximum amount of time to respond to read requests)

Communication protocol requirements:
- Shall support at least one of these protocols ...(IEEE Std 2030.5, IEEE Std 1815, SunSpec Modbus)

Cyber security:
- Of critical importance but out of scope (can be Mutual agreement, possible regulatory requirements)

help in Annex D (informative)
New Communications new Requirements

1547 Interface (mandatory)  Other Interfaces (optional)  Out of Scope

1547-approved standard protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Transport</th>
<th>Physical Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 2030.5 (SEP2)</td>
<td>TCP/IP</td>
<td>Ethernet</td>
</tr>
<tr>
<td>IEEE 1815 (DNP3)</td>
<td>TCP/IP</td>
<td>Ethernet</td>
</tr>
<tr>
<td>SunSpec Modbus</td>
<td>TCP/IP</td>
<td>Ethernet</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>RS-485</td>
</tr>
</tbody>
</table>
IEEE 1547 Uses

IEEE 1547 is:

• A technical standard—functional requirements for the interconnection itself and interconnection testing
• A single (whole) document of mandatory, uniform, universal, requirements that apply at the point of common coupling (PCC) or point of DER connection (PoC)
• Technology neutral—i.e., it does not specify particular equipment or type
• Should be sufficient for most installations

IEEE 1547 is not:

• A design handbook
• An application guide (see IEEE 1547.2)
• An interconnection agreement
• Prescriptive—i.e., it does not prescribe other important functions and requirements such as cyber-physical security, planning, designing, operating, or maintaining the area EPS with DER
Application of PV with Storage (Germany example)

- PV-storage with **self-consumption**: no improvement to limiting peak for grid integration

- PV-storage with **export limit**: federal incentive and advantage if peak pricing (over PV system lifetime)[1]

**Source:** [1] www.speichermonitoring.de
Important Terminology & Potential New Responsibilities

- **Area EPS Operator**: (distribution utility)
  - May specify technology-specific assignment of normal DER performance categories (reactive power requirements)
  - May specify functional settings, e.g., volt/var curve
  - May recommend / specifies technology-specific “preferred” and “custom” voltage and frequency trip settings
  - Performs DER interconnection screening

- **AGIR**: (e.g., state regulator)
  - May assign technology-specific DER performance categories
  - May specify method for trip settings other than “preferred”
  - May decide about certification for larger scale DER facilities

- **3rd party test & evaluation entity**: (e.g., by NRTL)
  - Type testing
  - DER evaluation (e.g., by consultant)
  - Certification, if required

- **Authority Having Jurisdiction**: (e.g., local inspectors)
  - Inspects and approves the design and construction of Local EPS

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**Federal Energy Regulatory Commission (FERC)**
- Order No. 827 (reactive power)
- Order No. 828 (ride-through)
- Transmission Providers to specify “Good Utility Practice” for SGIA

**North American Electric Reliability Corporation (NERC)**: Issues reliability guidelines for BPS-connected resources

**Regional Reliability Coordinator, i.e., NERC Reliability Coordinator (RTO/ISO)**
- May recommend technology-specific assignment of abnormal DER performance categories (ride-through)
- May recommend technology-specific “preferred” voltage and frequency trip settings

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**Generation**

**Transmission**

**Distribution**

**Distributed Energy Resources**

**Consumer / DER Developer**

**DER Operator / Local EPS Operator**

**3rd party test & evaluation entities**

**Authority Having Jurisdiction (AHJ)** (e.g., local inspectors)

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**Area EPS Operator** (distribution utility)

**Authority Governing Interconnection Requirements (AGIR)** (e.g., state regulator)

**Reference Point of Applicability**
# IEEE 1547/ CA Rule 21/ UL 1741-SA

<table>
<thead>
<tr>
<th>Function set</th>
<th>Advanced Functions</th>
<th>Interconnection Standards</th>
<th>State/ PUC Rules</th>
<th>Listing/ Certification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>Adjustable Trip Settings</td>
<td>√</td>
<td>‡</td>
<td></td>
</tr>
<tr>
<td>Controlling</td>
<td>Power Curtailment</td>
<td>‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp Rate Control</td>
<td>‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freq. Support</td>
<td>L/H Frequency Ride-Through</td>
<td>‡</td>
<td>‡</td>
<td>‡</td>
</tr>
<tr>
<td></td>
<td>ROCOF Ride-Through</td>
<td>‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frequency-Watt</td>
<td>X</td>
<td>√</td>
<td>‡</td>
</tr>
<tr>
<td></td>
<td>L/H Voltage Ride-Through (L/H VRT)</td>
<td>‡</td>
<td>‡</td>
<td>‡</td>
</tr>
<tr>
<td></td>
<td>Dynamic Voltage Support during L/H VRT</td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voltage Phase Angle Jump Ride-Through</td>
<td></td>
<td>‡</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fixed Power Factor</td>
<td>√</td>
<td>√</td>
<td>‡</td>
</tr>
<tr>
<td></td>
<td>Fixed Reactive Power</td>
<td>√</td>
<td>√</td>
<td>‡</td>
</tr>
<tr>
<td></td>
<td>Volt-Var</td>
<td>X</td>
<td>√</td>
<td>‡</td>
</tr>
<tr>
<td></td>
<td>Volt-Watt</td>
<td>X</td>
<td>√</td>
<td>‡</td>
</tr>
<tr>
<td></td>
<td>Watt-Var</td>
<td>X</td>
<td></td>
<td>‡</td>
</tr>
</tbody>
</table>

*Final requirements not confirmed.

Legend: X Prohibited, √ Allowed by Mutual Agreement, ‡ Capability Required, Δ Test and Verification Defined
Recent Updates to State Interconnection Standards – in USA

Year Updated
- 2009 or before
- 2010 - 2011
- 2012 - 2013
- 2014 - 2015
- 2016 - Update in Progress

Data: DSIRE
Hanna Terwilliger MPUC
May 1, 2017
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.

Contact Info:
Tom Key, tkey@epri.com

Thank You
New Requirements

Islanding
**island**: A condition in which a portion of an Area EPS is energized solely by one or more Local EPSs through the associated PCCs while that portion of the Area EPS is electrically separated from the rest of the Area EPS on all phases to which the DER is connected. When an island exists, the DER energizing the island may be said to be “islanding”.

**Unintentional island**: An unplanned island.
- DER must detect the island and trip within 2 seconds of the formation of an unplanned island (adjustable if needed up to 5 seconds)

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**area electric power system (Area EPS)**: An EPS that serves Local EPSs.

NOTE—Typically, an Area EPS has primary access to public rights-of-way, priority crossing of property boundaries, etc., and is subject to regulatory oversight

**local electric power system (Local EPS)**: An EPS contained entirely within a single premises or group of premises.
Intentional island
A planned electrical island that is capable of being energized by one or more Local EPSs. These:
1. have DER(s) and load,
2. have the ability to disconnect from and to parallel with the Area EPS,
3. include one or more Local EPS(s), and
4. are intentionally planned.

Intentional island systems can transition to an islanded condition in two ways:
Scheduled: Formed through DER operator or area EPS operator manual action or other operating dispatch means that triggers the transition to an islanded system.

Unscheduled: Formed autonomously from local detection of abnormal conditions at the interface(s) with the area EPS
intentional Local EPS island (also, “facility island”). An intentional island that is totally within the bounds of a Local EPS.

• When in grid-connected mode, supporting DER are subject to the requirements in the standard (with some exceptions)
intentional Area EPS island: An intentional island that includes portions of the Area EPS.

• Participating DER may have to adjust several control and protection settings (alternate settings given)

*Image source: IEEE Std 1547.4-2011*
**Intentional island-capable**: DER that can disable or modify its islanding detection function, and adjust settings.

**Black start-capable**: DER that can also energize an EPS that contains no other energy sources.

**Isochronous-capable**: DER that can independently regulate voltage and frequency to fixed setpoints.

**Uncategorized**: A DER not designed for intentional island operation may be allowed to participate in the intentional island if certain system criteria are met (examples in Annex C).
Revised Requirements

Test and Verification
### High-Level Test and Verification Process

<table>
<thead>
<tr>
<th><strong>Maintenance</strong></th>
<th><strong>Periodic</strong></th>
<th><strong>Commissioning Tests</strong></th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
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</tr>
</tbody>
</table>

- **Performed on site** at the time of commissioning
- **Basic**: visual check equipment, isolation device
- **Detailed**: check functionality and interoperability as a system

<table>
<thead>
<tr>
<th><strong>Post-installation review</strong></th>
<th><strong>As-Built Installation Evaluation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

- **Performed on site** at the time of commissioning
- **Basic**: check components and connections
- **Detailed**: engineering verification of components, may do modeling and simulation

<table>
<thead>
<tr>
<th><strong>Interconnection review</strong></th>
<th><strong>Design Evaluation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Desk study**
- Check equipment together meet requirements
- Typically done off-site before equipment is delivered and installed

<table>
<thead>
<tr>
<th><strong>Equipment conformance testing</strong></th>
<th><strong>Production Tests</strong></th>
</tr>
</thead>
<tbody>
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- **Done in** test lab, factory, or on equipment in field
- Tests on every unit of DER and interconnection
- **Verify** operability and document default function settings

<table>
<thead>
<tr>
<th><strong>Type Tests</strong></th>
<th><strong>Post-installation review</strong></th>
</tr>
</thead>
<tbody>
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</table>

- **Typically done in** test lab or factory
- Tests on representative DER Unit or DER system
- Type test from a DER within a product family of the same design

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**Slide:** NREL
The type of evaluation or testing needed for each requirement depends on the reference point of applicability and whether there are any supplemental DER devices.

- help in Annex F (informative) Discussion of Testing and Verification Requirements at PCC or PoC

1) As applicable, may depend on DER Design Evaluation.
**Disturbance performance terminology**

**Operation under normal conditions**
- **Continuous operation**

**Operation under abnormal conditions**
- **Ride-through**
- **Permissive operation**
  - Mandatory operation
  - Momentary cessation
- **Trip**
  - Momentary cessation
  - Restore output

**During Disturbance**
- **Mandatory operation**
- **Cease to energize**
- **Restore output**
- **Return to service**

**Post Disturbance**

- **Levels** of DER response showing hierarchy of terms/requirements:
  - Level 1
  - Level 2
  - Level 3
  - Level 4
  - Level 5
  - Level 6

- **Ride-through** – ability to withstand voltage or frequency disturbances
  - **Permissive operation** – DER may either continue operation or may cease to energize, at its discretion
    - Mandatory operation – required active and reactive current delivery
    - Momentary cessation – cessation of energization for duration of a disturbance with rapid recovery when voltage or frequency return to defined range
  - **Restore output** – DER recovery to normal output following a disturbance that does not cause a trip.
- **Trip** – cessation of output without immediate return to service; not necessarily disconnection
  - **Return to service** – re-entry of DER to service following a trip; equivalent to start-up of DER
Structure of Voltage Ride-through – Cat. II

Dashed lines indicate permissible range of trip adjustment, solid lines indicate default settings. Figure are approximate and solely for illustration, refer to IEEE P1547 for actual requirements.
Category III introduces *momentary cessation* requirement.

- Requires a relatively long zero voltage ride-through requirement (in *momentary cessation* mode).
- If feeder is faulted and tripped at the substation, then DER in momentary cessation will not energize the islanded feeder.
  - Voltage will remain zero and DER will eventually trip off.
**Frequency ride-through**

- Frequency is an interconnection-wide parameter
- Under-frequency tripping needs to be coordinated with UFLS
- IEEE P1547 allows wide range of must-trip settings to accommodate small, isolated grids
  - O/F: 61.8 – 66.0 Hz
  - U/F: 50.0 – 57.0 Hz
  - O/F: 61.0 – 66.0 Hz
  - U/F: 50.0 – 59.0 Hz

<table>
<thead>
<tr>
<th>Time</th>
<th>Frequency</th>
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</thead>
<tbody>
<tr>
<td>Short duration</td>
<td>0.16 – 1.0 s</td>
</tr>
<tr>
<td>Long duration</td>
<td>180 – 1000 s</td>
</tr>
</tbody>
</table>

- O/F: 61.8 – 66.0 Hz
- U/F: 50.0 – 57.0 Hz
- O/F: 61.0 – 66.0 Hz
- U/F: 50.0 – 59.0 Hz

- **Mandatory Operation**
- **Continuous Operation**
- **Must Trip**