Highlights of IEEE Standard 1547-2018

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PJM Technical Workshop on DER Integration with IEEE 1547/1547.1 Standards

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Acknowledgments

- Many thanks to the IEEE P1547 officers, working group members, and balloters who contributed their time and effort to developing the revised standard.

- Thanks also to the U.S. Department of Energy (DOE) Solar Energy Technologies Office for supporting the authors' participation in standards development.

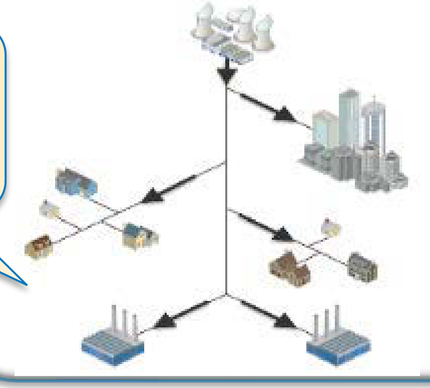
Presentation Topics

Day 1, July 30

11:00– 12:00	Overview (Part 1)
12:00 – 13:00	Lunch
13:00 – 13:45	Ride-through (Part II):

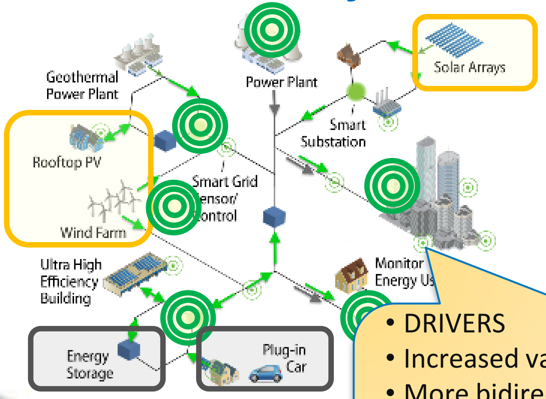
New DER Integration Challenges in a Modern Grid

Current Power System



- Carbon intensive
- Large generation
- Central control
- Highly regulated.

Future Power Systems



- DRIVERS
- Increased variable generation
- More bidirectional flow at distribution level
- Increased number of smart/active devices
- Evolving institutional environment.

Our evolving power system context:

- New energy technologies and services
- Increasing penetrations of variable renewables on grid
- New communications and controls (e.g., smart grids)
- Electrification of transportation
- Integrating distributed energy storage
- A modern grid needs increased system flexibility.
- Updated standards—e.g., IEEE 1547-2018 (distributed energy resources [DERs] as grid assets).

Slide courtesy of Dr. Ben Kroposki, NREL

IEEE Standard 1547

Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (https://standards.ieee.org/standard/1547-2018.html)

- Sponsored and published by the Institute of Electrical and Electronics Engineers (IEEE)
- Cited in federal law (EPACT 2005) as intended technical basis for local interconnection agreements, procedures, and best practices
- Follows IEEE's rigorous consensus-based standards development process (for 2018 revision: ~130 members of working group, >380 public balloters)
- All IEEE standards are voluntary. (Regulatory action from state energy commissions is needed to make part of local interconnection practice.)

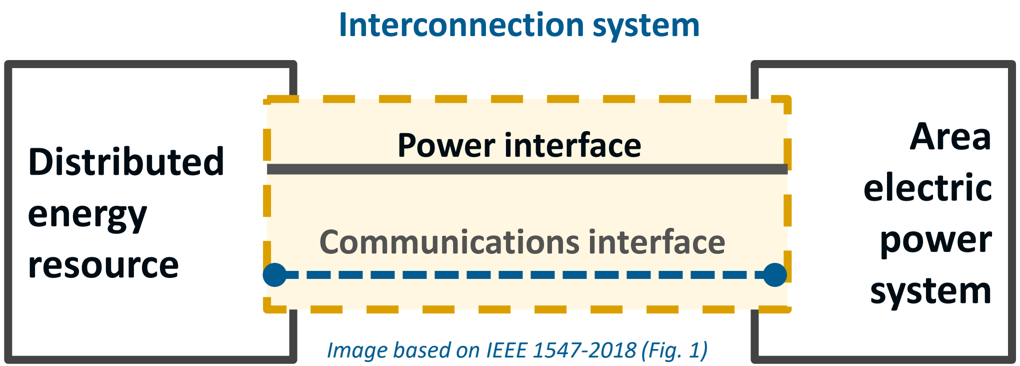


Image based on IEEE 1547-2018 (Fig. 1)

IEEE 1547 Document Outline (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 electric power system abnormal conditions
7. Power quality
8. Islanding
9. Distribution secondary grid and spot networks
10. Interoperability
11. Test and verification
12. Seven new annexes (informative)

Scope and Limitations

Scope:

- **Specifies functional requirements for all** DERs connected to typical primary or secondary distribution voltage levels
- **Applies regardless of type and size**—synchronous, induction, and inverter-based resources of ***any*** size
    - Gives precedence to synchronous generator design standards for DERs with synchronous generator units rated 10 MVA and greater (e.g., IEEE Std. C50.12, IEEE Std. C50.13).

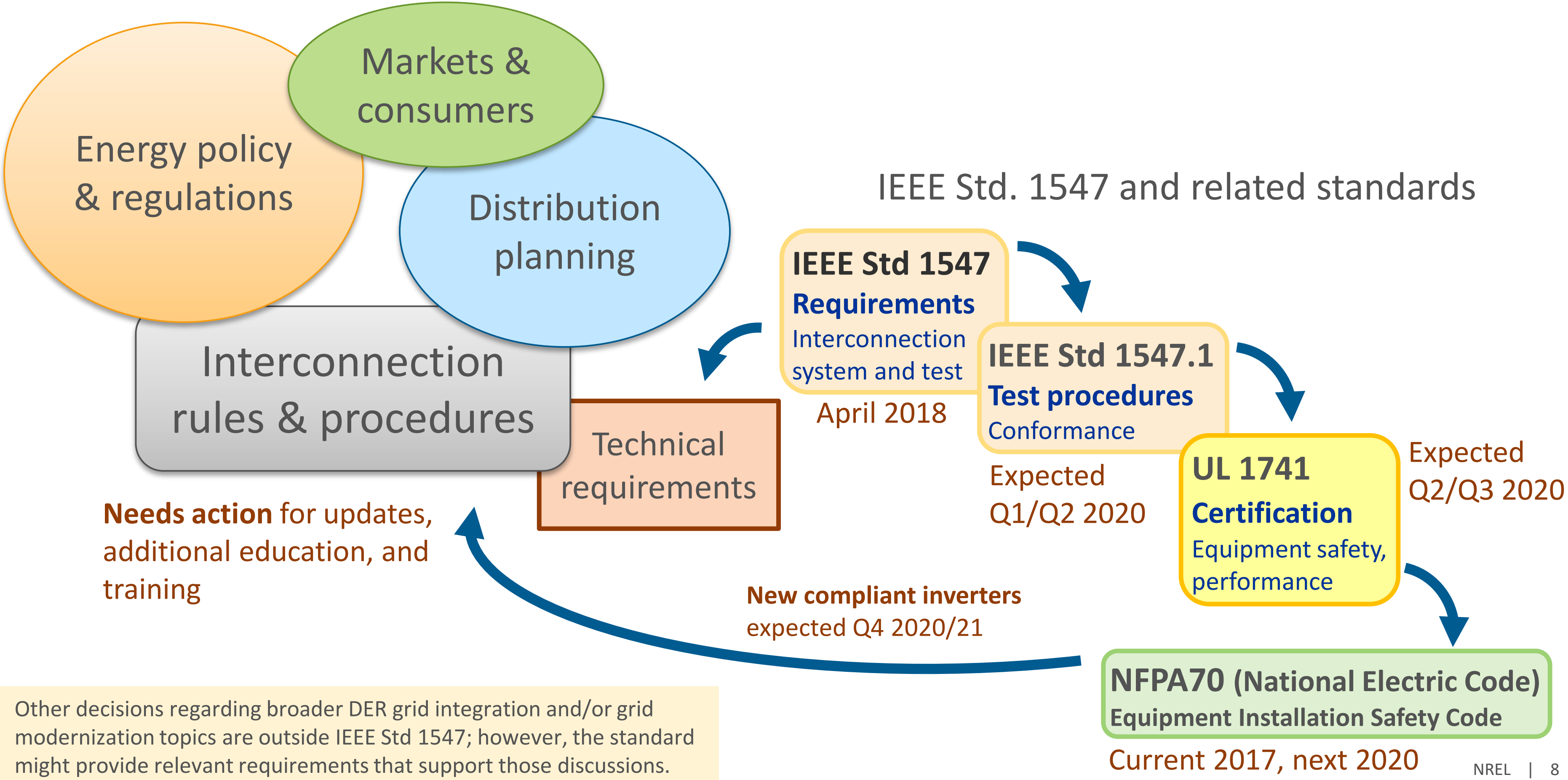
Limitations—it is *not*:

- A design handbook (specifies performance, not design of DERs)
- An application guide
- An interconnection agreement (specifies capabilities and functions, not utilization)
- Prescriptive—i.e., it does not prescribe other important functions and requirements (e.g., does not address planning, designing, operating, or maintaining the area EPS with DERs).

Exemptions for emergency and standby DERs—exempt from certain requirements of this standard (e.g., voltage and frequency ride-through, interoperability, and communications)

Does not apply to resources directly connected to the bulk power system (This is addressed by a recently started activity, IEEE P2800 for Transmission and Networked Sub-transmission Inverter-based Resources. https://standards.ieee.org/project/2800.html)

Context for Implementation



Other decisions regarding broader DER grid integration and/or grid modernization topics are outside IEEE Std 1547; however, the standard might provide relevant requirements that support those discussions.

New Expectations → New Requirements

reactive power support

AGIR

ride-through

interoperability

volt-var

LVRT

performance categories

communications protocols

ROCOF

area EPS faults

momentary cessation

power quality

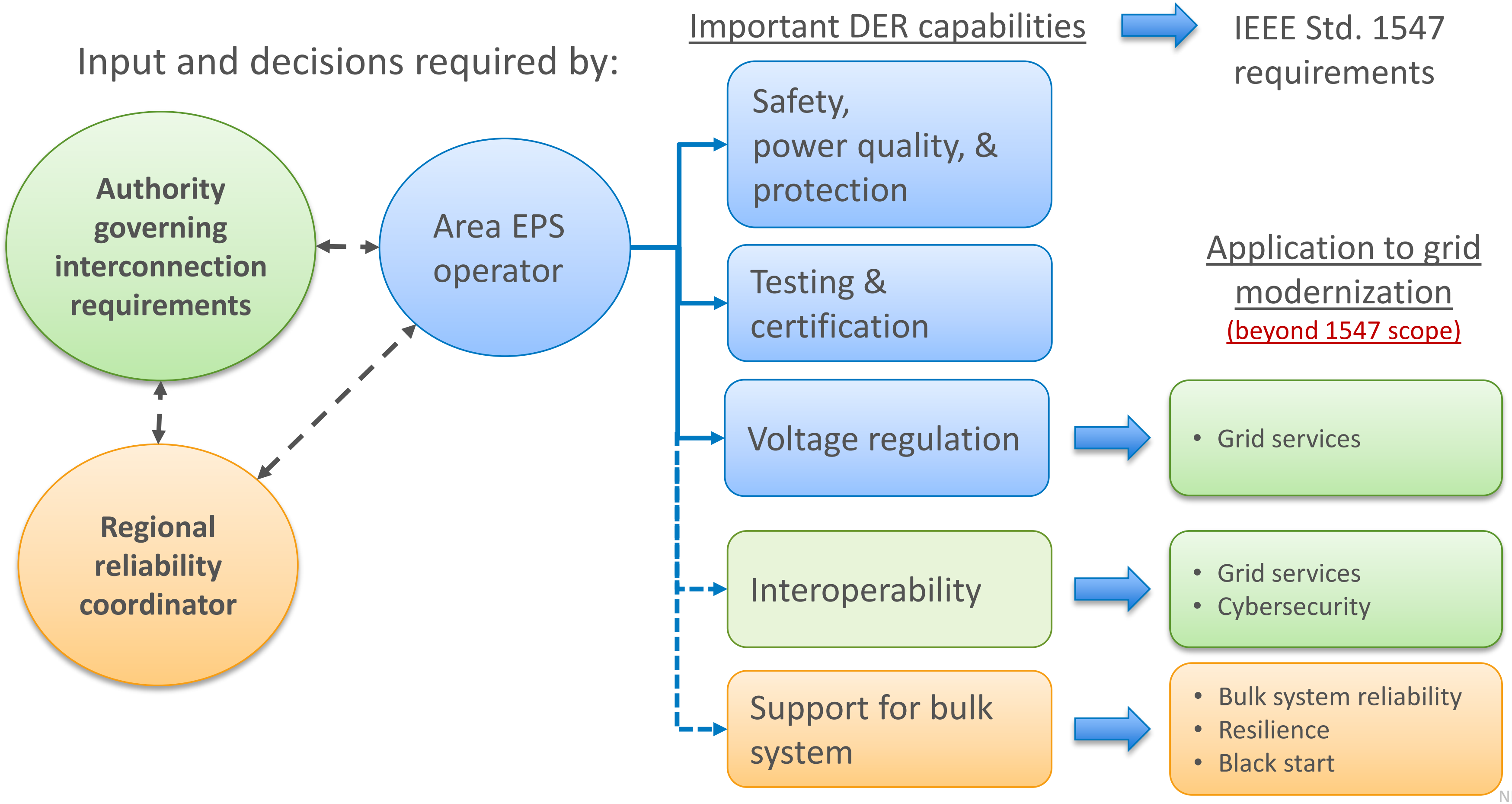
composite

constant power factor

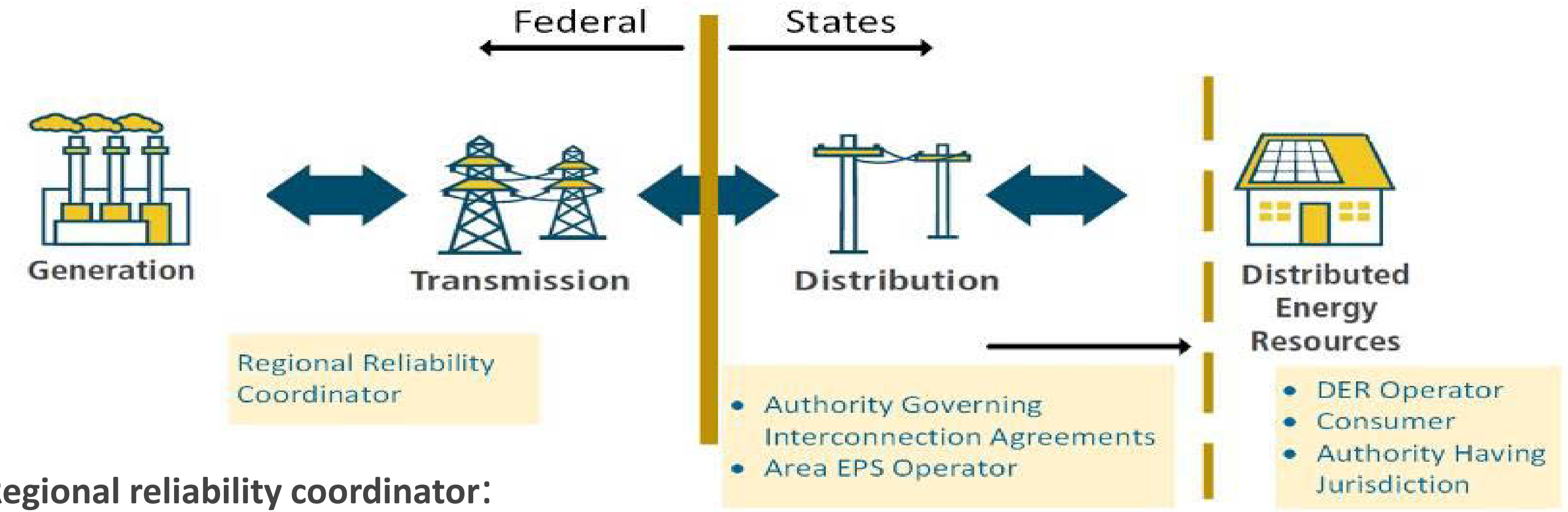
synchronization

Intentional islanding

Requirements Context



Key Terms and Entity Jurisdictional Boundaries



Regional reliability coordinator:
Maintains real-time operating reliability of bulk power system within a reliability coordinator area

Authority governing interconnection requirements (AGIR):
Codifies, communicates, administers, and enforces policies and procedures for allowing electrical interconnection of DERs to the grid.
Examples: State regulatory agency, public utility commission, municipality, cooperative board of directors

Authority having jurisdiction: Has rights to inspect and approve of the design and construction. Examples: City or county inspectors

Images from DOE

Core Functions

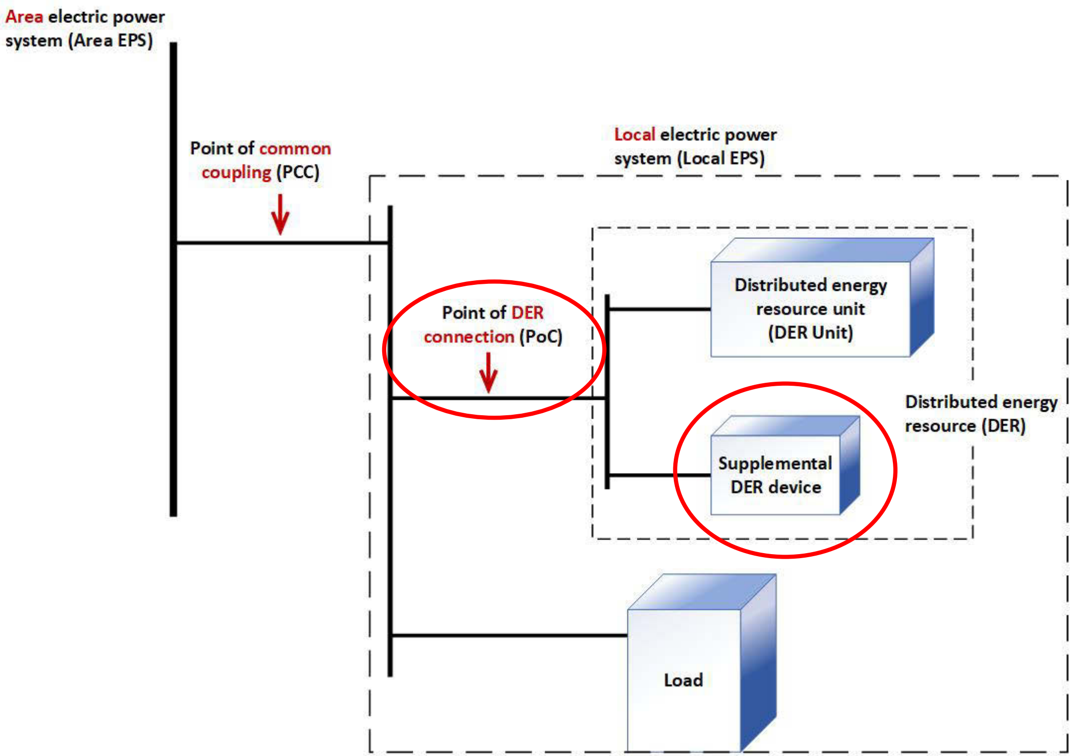
Topic Highlight

Example of New Terms in the Revised Standard

Definitions from IEEE Std 1547-2018

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."

Supplemental DER device: "Any equipment that is used to obtain compliance with some or all of the interconnection requirements of this standard."



New Requirements (General Provisions)

- **General provisions**
  - Measurement accuracy (root mean square [RMS] voltage, frequency, active power, reactive power)
  - Cease to energize capability
  - Enter service criteria
  - Control capability—limit active power
  - Permit service disable (within 2 seconds, primarily for bulk).

- **Exemptions for emergency and standby DER**

Reinforced "Good Citizen" Behavior

Safety

- Visible-break isolation device
- Anti-islanding
- Inadvertent energization of area EPS.

Tripping & reclose coordination

- Short-circuit faults
- Open phase conditions
- Coordination with area EPS circuit reclosing.

General

- Interconnect integrity
    - Protection from electromagnetic interference
    - Surge withstand.
- Integration with area EPS grounding
- Synchronization limits for frequency, voltage, and phase angle (IEEE 67 criteria okay for some types of synchronous generators[1]).

Power quality

- Limitation of DC current injection
- Limitation of DER-caused voltage fluctuations
    - Flicker (revised method)
    - Rapid voltage changes (new).
- Limitation of current distortion
- Limitation of overvoltage contribution
    - Temporary overvoltage
    - Transient overvoltage.
- Harmonics.

[1]For example, round rotor synchronous generators with ratings 10 MVA and larger and salient pole synchronous generators with ratings 5 MVA and larger may use the synchronization criteria described in IEEE 67, which are tighter than the ones specified here, and can therefore meet the requirements of this standard.

Power Quality Reinforcements—Flicker

Flicker: Defined in IEEE Std. 1547-2018 as "The subjective impression of fluctuating luminance caused by voltage fluctuations."

- Assessment and measurement methods for flicker are defined in IEEE 1453 and International Electrotechnical Commission (IEC) 61000-3-7.
- E_{Pst} – Emission limit for the short-term flicker severity. If not specified differently, the Pst evaluation time is 600 s.
  - In IEEE Std. 1547-2018 (Table 25), the minimum individual DER flicker emission limit for E_{Pst} is 0.35.
- E_{Plt} – Emission limit for long-term flicker severity. If not specified differently, the Plt evaluation time is 2 h.
  - In IEEE Std. 1547-2018 (Table 25), the minimum individual DER flicker emission limit for E_{Plt} is 0.25.

See Clause 7.2.3 for complete details.

Slide original by Dr. Babal Enayati, with modifications

Power Quality Requirements—Limitation of Current Distortion

- Table 26 and Table 27 (Clause 7.3) specify maximum harmonic current distortion limits for odd and even harmonics.
- Harmonic current distortion and total rated-current distortion at the RPA shall not exceed the limits stated in Table 26 and Table 27.
- The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the area EPS without the DER connected.

Slide original by Dr. Babal Enayati, with modifications

Power Quality Requirements—Limitation of Overvoltage Contribution

Limitation of overvoltage over one fundamental frequency period

The DER shall not contribute to instantaneous or RMS overvoltages with the following limits:

a) The DER shall not cause the fundamental frequency line-to-ground voltage on any portion of the area EPS that is designed to operate effectively grounded, as defined by IEEE Std C62.92.1, to exceed 138% of its nominal line-to-ground fundamental frequency voltage for a duration exceeding one fundamental frequency period.

b) The DER shall not cause the line-to-line fundamental frequency voltage on any portion of the area EPS to exceed 138% of its nominal line-to-line fundamental frequency voltage for a duration exceeding one fundamental frequency period.

Limitation of cumulative instantaneous overvoltage

The DER shall not cause the instantaneous voltage on any portion of the area EPS to exceed the magnitudes and cumulative durations shown in Figure 13. The cumulative duration shall include only the sum of durations for which the instantaneous voltage exceeds the respective threshold during a 1-minute time window.

See Clause 7.4 for complete details.

Slide original by Dr. Babal Enayati, with modifications

Energy Storage

Topic Highlight

Energy Storage

IEEE Std. 1547 definition of DER includes energy storage technologies capable of exporting active power to the electric power system (IEEE Std. 1547-2018 p. 22) … The entire standard applies.

- ESS: energy storage system (p. 27)
- Cease to energize (ESS may continue charging) (p. 22)

Specifically called out in these clauses:

- 4.10.3 Performance during entering service (p. 34)
- 5.4.2 Voltage-active power mode
  - Table 10 (p. 41)
- 6.5.2.1 General requirements and exceptions
  - Frequency disturbance ride-through (p. 55)
- 6.5.2.3.2 Low-frequency ride-through performance (p. 57)
- 6.5.2.4.2 High-frequency ride-through performance (p. 57)
- Frequency-power (frequency droop) during low- and high-frequency conditions
  - Table 23 (p. 59): footnote 104: can use energy storage to provide positive or negative active power
- 10.5 Monitoring information
  - Table 29: operational state of charge 0% to 100% of operational energy storage capacity (p. 71).

Intentional Islanding

Topic Highlight

Islanding Definitions

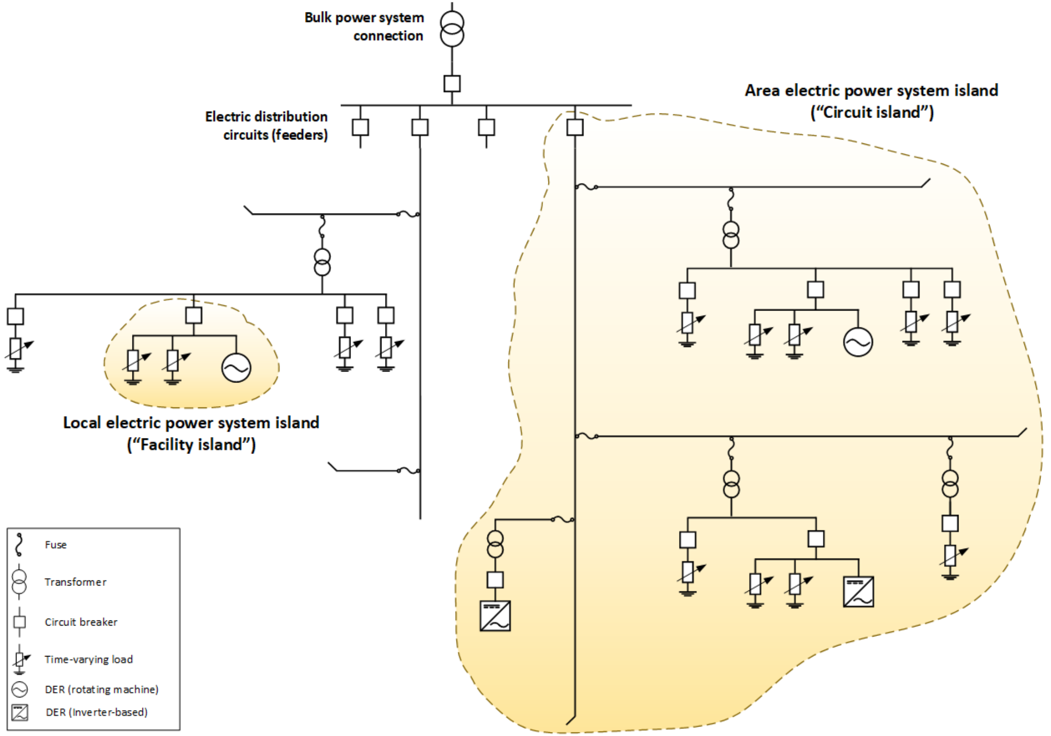
Intentional island: An electrical island that is capable of being energized by one or more local electric power systems (p. 23)

Characteristics:

- Possesses generation (DER(s)) and load (load cannot be only energy storage)
- Possesses the ability to disconnect from and to parallel with the area EPS
- Includes at least one local EPS
- Is intentionally planned.

Varieties of intentional islands:

- Local EPS island is totally within the boundary of a local EPS (aka "facility island").
- Area EPS island includes parts of the area EPS (e.g. "circuit island").



DER Categories for Intentional Islands

Intentional island-capable: DER that can disable or modify its islanding detection function and adjust settings as in 8.2.7 (p. 67)

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

Isochronous-capable: Black-start-capable and can regulate V and f in an EPS that does contain other sources

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

Transitioning to an Island

Two ways to transition to an islanded condition (p66)

Scheduled: formed through manual action of DER or area EPS operator or through other dispatch means

- **Conditions** for scheduled transition to islanded operation include reliability, economic dispatch (self-supply or power exchange with area EPS), in advance of inclement weather

Unscheduled: formed through automatic action due to local detection of abnormal conditions at the interface(s) with the area EPS

Conditions for unscheduled transition to islanded operation include:

- Meeting any of the exception conditions in 6.4.2.1 and 6.5.2.1
- Meeting any of the trip conditions in Clause 6 that allow or mandate tripping
- If the DER has detected an island (under 8.1), the DER may enter into intentional island mode instead of ceasing to energize the area EPS (as long as it doesn't energize any part of the area EPS outside the defined boundary of the intentional island)

Other Standards: IEEE Std 1547.4

IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems (IEEE Std 1547.4™-2011)

- Island system configurations and functionality, general considerations for DER island systems and specific considerations for area EPS islands
- Planning and engineering, including load, EPS, DER requirements, types of studies,
- Testing and commissioning, periodic review and maintenance
- Operation of DER island systems, including system management and transition, control strategies, restoration after disturbances,
- Safety and protection considerations
- Interoperability considerations (monitoring, information exchange and control
- Informative annex on contractual and regulatory considerations

Other Standards: IEEE Std 2030.7

IEEE Standard for the Specification of Microgrid Controllers (IEEE Std 2030.7™-2017)

- General considerations, including core functions and control system.
- Functional requirements of the control system.
- Dispatch of the microgrid, including description, features, functional specification of the dispatch function, metrics and testing scenarios.
- Transition from grid-connected to islanded mode, including description, features and specification of the transition function, metrics and scenarios for testing.
- Three informative annexes on microgrid description, objectives of the microgrid and control system, and implementation of control system functions.

Other Standards: IEEE Std 2030.8

IEEE Standard for the Testing of Microgrid Controllers (IEEE Std 2030.8™-2018)

- Microgrid control system core function testing, including context and purpose, general consideration, development of test scenarios, testing conditions, conceptual flowchart of the test procedure.
- Testing of the dispatch and transition functions
- Metrics for responses, including general considerations, requirements for steady-state and transient voltage and frequency, real and reactive power.
- Compliance testing procedure
- Eight informative annexes on testing and compliance considerations, microgrid control system features, description and characterization of core functions, field and laboratory data collection, defining operating requirements and ranges, and test environments and platforms.

Other Standards: IEC

IEC Technical Subcommittee 8B (SB 8B): Decentralized electrical energy systems Work Program

- IEC TS 62898-3-1 ED1: Microgrids – Technical Requirements – Protection
- IEC TS 62898-3-2 ED1: IEC/TS 62898-3-2 Microgrids – Technical requirements – Energy Management Systems
- IEC TS 62898-3-3 ED1: Microgrids – Technical requirements – Self-regulation of dispatchable loads
- IEC 63189-1 ED1: Virtual Power Plants- Part 1: Architecture and Functional Requirements
- IEC TS 63189-2 ED1: Virtual Power Plants – Part 2: Use Cases

Interoperability

Topic Highlight

Interoperability Requirements

Value of interoperability:

- Situational awareness/monitoring
- Control and advanced control (integration with DER management tools, aggregation)
- Supports modeling and simulation.

IEEE Std 1547-2018 requirements:

- Communications requirements
- Identified functions to communicate
- Scope of interoperability
- Protocols.

Stakeholders and Interoperability

Potential stakeholders for communications/control/monitoring

- Area EPS Operator
- DER Aggregator
- DER Operator
- DER Owner
- Building/Facility Manager
- …ISO/TSO/RTO?

Communications Requirements

- A DER shall have provisions for an interface capable of communicating (local DER communications interface) to support the information exchange requirements specified in this standard for all applicable functions that are supported in the DER.
- Under mutual agreement between the area EPS operator and DER operator, additional communications capabilities are allowed.
- The decision to use the *local DER communications interface* or to deploy a communications system shall be determined by the area EPS operator.

Interoperability Scope and Requirements Summary

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

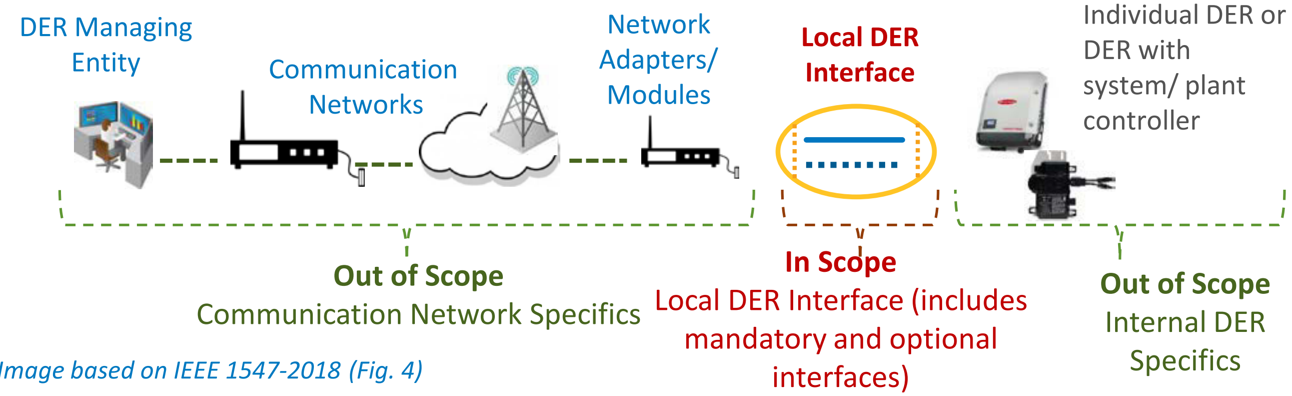


Image based on IEEE 1547-2018 (Fig. 4)

Interoperability Capability Requirements	
Communications capability	**Mandatory**: "A DER shall have provisions for a local DER interface capable of communicating…"
Communications protocol	**Shall support at least one of these protocols** …(IEEE Std 2030.5, IEEE Std 1815, SunSpec Modbus)
DER information exchange	**Nameplate**: (read) as-build characteristics **Monitoring**: (read) present operating conditions **Configuration**: (read/write) present capacity and ability to perform functions **Management**: (read/write) updates to functional and mode settings
Communications performance	**Availability of communications**: (DER is operating in continuous or mandatory operation region) **Information read response times**: (≤ 30 s, maximum amount of time to respond to read requests)
Cybersecurity: Of critical importance but out of scope (can be mutual agreement, possible regulatory requirements)	

DER Cybersecurity

Topic Highlight

Cybersecurity Considerations

Critical, but considered out of scope for current version of 1547 due to:

- Scope of IEEE Std 1547
- Scope and complexity of cybersecurity requirements
- System architecture flexibility
- Testability

Cybersecurity Considerations

- **Exposure, attack surface, vulnerabilities**
  - Physical security (DER front panel)
  - DER network
  - List of deployed assets
    - Tracking and configuration management during life cycle
  - Communications paths (hard wire (twisted pair, fiber…), wireless (radio, cellular, …)
  - Communications protocols (one of the three in 1547 or other?)
- **Risk assessment**
- **Resilience**
  - Response to attack
  - Recovery
- **Testing and certification**
- **Monitoring!!!!**

Cyber-Related Guidance and Standards

1. IEC 62351-12 (http://www.iec.ch/)
2. NISTIR 7628 (https://csrc.nist.gov/publications/detail/nistir/7628/rev-1/final)
3. IEEE P1547.3 (upcoming)

Ongoing Efforts in DER Cybersecurity

- U.S. Department of Energy (DOE)
  - DOE Office of Cybersecurity, Energy Security, and Emergency Response (https://www.energy.gov/ceser/office-cybersecurity-energy-security-and-emergency-response)
- U.S. Department of Commerce
  - National Institute of Standards and Technology (NIST) Cybersecurity for smart grid systems: https://www.nist.gov/programs-projects/cybersecurity-smart-grid-systems
- National laboratories
  - Sandia National Laboratories
  - Idaho National Laboratory
  - National Renewable Energy Laboratory
- Research and consulting
  - Electric Power Research Institute (EPRI)
- Industry
- Universities
- Standards
  - IEEE
  - SunSpec

Voltage Regulation

Topic Highlight

IEEE 1547 Evolution of Grid Support Functions

IEEE 1547-2003

- **Shall NOT** actively regulate voltage
- **Shall trip** on abnormal voltage/frequency.

IEEE 1547a-2014 (Amendment 1)

- **May** actively regulate voltage
- **May** ride-through abnormal voltage/frequency
- **May** provide frequency response[1] (frequency droop).

IEEE 1547-2018

- **Shall be capable of** actively regulating voltage
- **Shall be capable of** frequency response[2]
- **Shall ride-through** abnormal voltage/frequency
- **May** provide inertial response.[3]

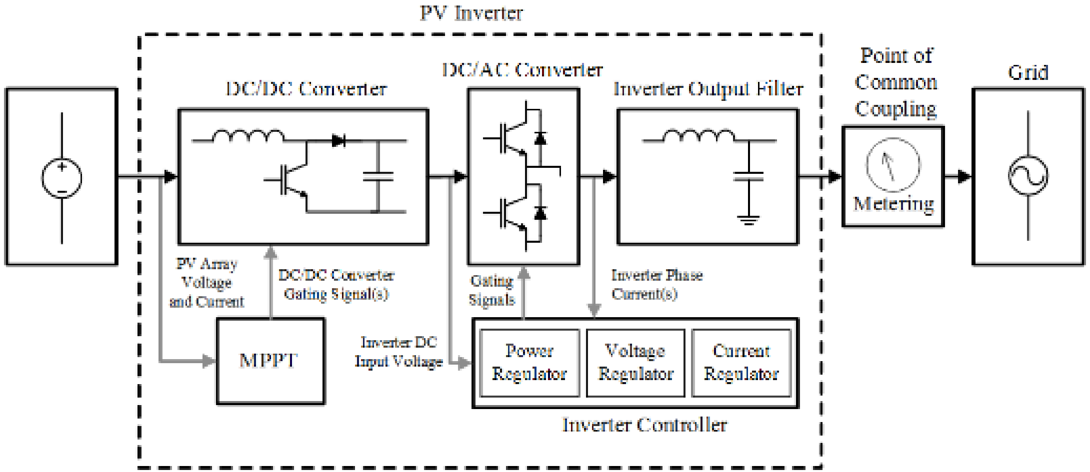
[1]Frequency response is the capability to modulate power output as a function of frequency.
[2]Mandatory capability for Categories II and III under high-frequency conditions, mandatory for Categories II and III under low-frequency conditions, optional for Category 1
[3]Inertial response is the capability for DERs to modulate active power in proportion to the rate of change of frequency.

Modern PV Inverters Have New Capabilities for Grid Support

Micro inverter
(Source: enphase)

String inverter
(Source: Fronius)

Central inverter (Source: SMA)



Simplified PV inverter block diagram showing key system components and control

Image courtesy Dr. Barry Mather, NREL

Voltage Regulation

- IEEE Std 1547-2018 compliant DER shall have the capability to inject and absorb reactive power (over-excited and under-excited), within certain limitations.

- Voltage regulation ***capability*** is mandatory, but the utilization is at the discretion of the area EPS operator (and potentially other stakeholders, such as the AGIR).

See tables 6, 7 on p. 37 of the standard (Clause 5.2) for details.

IEEE 1547-2018 Active Voltage Regulation Requirements

Performance Categories (Grid support under normal grid conditions)		Mandatory Voltage Regulation **Capabilities**				
		Constant Power Factor Mode	Constant Reactive Power Mode ("reactive power priority")	Voltage-Reactive Power Mode ("volt-VAR")	Active Power-Reactive Power Mode ("watt-VAR")	Voltage-Active Power Mode ("volt-watt")
Category A	Meets minimum performance capabilities needed for area EPS voltage regulation Reasonably attainable by all state-of-the-art DER technologies	✓	✓	✓	Not required	Not required
Category B	Meets all requirements in Category A plus: Supplemental capabilities for high DER penetration, where the DER power output is subject to frequent large variations Attainable by most smart inverters	✓	✓	✓	✓	✓

- *IEEE 1547-2018: "The DER shall provide voltage regulation capability by changes of reactive power. The approval of the Area EPS Operator shall be required for the DER to actively participate in voltage regulation."*
- The area EPS operator shall specify the required voltage regulation control modes and the corresponding parameter settings. Modifications of the settings and mode selected by the EPS operator shall be implemented by the DER operator (min 44% injecting, 25% absorption (low), 44% (high)).
- Settings can be adjusted locally or remotely.

Voltage–Reactive Power (Volt/VAR)

Category A and B DER

In this mode, the DER actively controls its ***reactive power*** output as a function of ***voltage***

- Intended to supply VAR only when needed, push local voltage back toward nominal.

Please refer to clause 5.3.3 and table 8 for details, and figure H-4 for an example

Active Power–Reactive Power (Watt-VAR, P-Q)

Category B DER

In this mode, the DER actively controls the ***reactive power*** output as a function of the ***active power*** output.

See clause 5.3.4 and table 9 for details, and figure H-5 for an example

Voltage–Active Power (Volt-Watt)

Category B DER

In this mode, the DER actively ***limits*** the DER maximum ***active power*** as a function of the ***voltage***.

- This mode can reduce the prevalence of very high voltages.

See Clause 5.4.2 and table 10 for details, and figure H-6 for an example

Test & Verification

Topic Highlight

High-Level Test and Verification Process

Maintenance

Periodic

- Scheduled or other criteria
- **Reverification** needed on important system changes

Post-installation review

Commissioning Tests

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

As-Built Installation Evaluation

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

Interconnection review

Design Evaluation

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

Equipment conformance testing

Production Tests

- 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

Type Tests

- 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

Slide: NREL

DER versus Composite Compliance

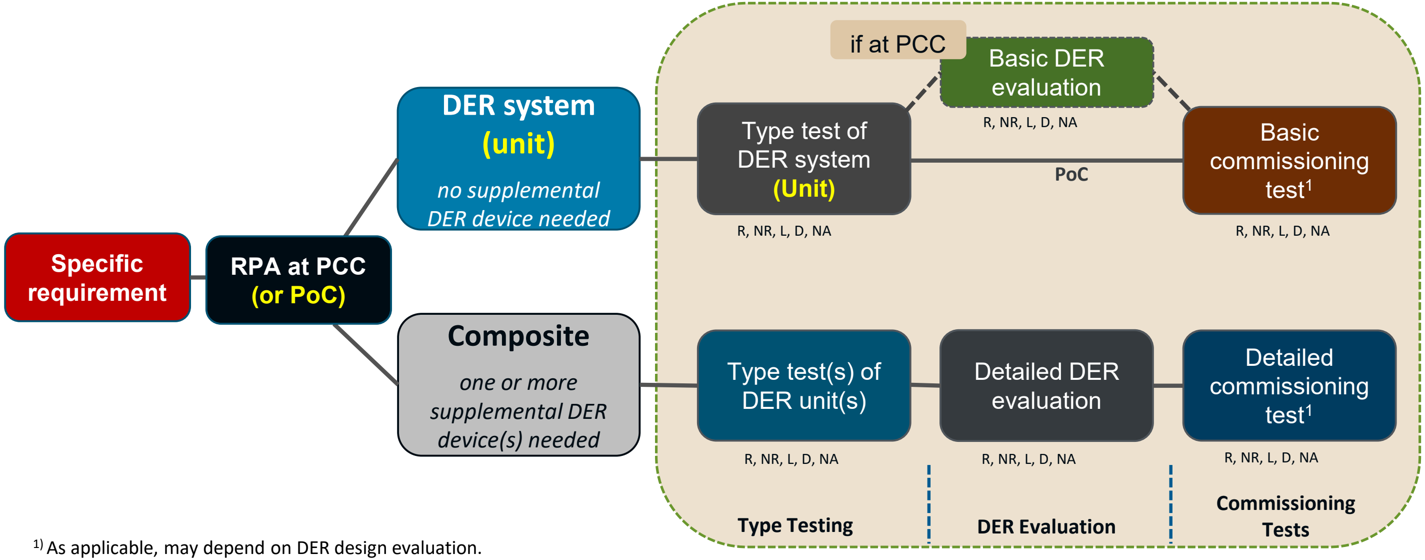
- For DER system that shall meet requirements at PCC:
  - DER system: DER system is fully compliant at PCC
    - *No supplemental DER device needed.*
  - Composite: composite of partially compliant DER that is fully compliant at PCC
    - May need one or more supplemental DER devices.

- Examples for supplemental DER devices: capacitor banks, STATCOMs, harmonic filters that are not part of a DER unit, protection devices, plant controllers

Determination of Requirements Testing

What's the requirement? → Where's the reference point of applicability? → Are supplemental DER device(s) needed? → Category of test and verification needed

- **R:** Required
- **NR:** Not required
- **L:** Limited
- **D:** Depends on DER design eval.
- **NA:** Not applicable



[1)] As applicable, may depend on DER design evaluation.

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

Periodic Tests and Verifications

- According to scheduled time period or other criteria:
  - Confirm already interconnected device or combination of devices meet interconnection and interoperability requirements
- Provided by interconnection equipment manufacturers and system integrators
- Approved by AGIR or area EPS operator
- Periodic test reports or log for inspection
- Area EPS operator might require commissioning test at any time to verify adherence to the standard.

Reverification of interoperability requirements of this standard might be required when any of the following events occur:

- *Functional software or firmware* changes have been made on the DER
- Any *hardware component* of the DER has been *modified* in the field or has been *replaced or repaired with parts that are not substitutive components* compliant with this standard.
- *Protection settings have been changed* after factory testing.
- *Protection functions have been adjusted* after the initial commissioning process.

Summary and Takeaway

- RPA and compliance with or without supplemental DER device(s) determines the verification requirements.
- Detailed verification requirements are specified in Table 43 and Table 44 of IEEE P1547.
- Type testing can be performed on a DER unit or a DER system.
- A composite of DER unit(s) and supplemental DER device(s) requires a detailed DER evaluation.
- DER evaluation and commissioning test might be either basic or detailed.

Thoughts on Testing and Certification

- **As power systems come to depend on DERs for essential functions and services, more thorough testing and validation are needed.**
  - Must balance this need with the burden of testing. UL estimates more than 700 test files are produced to certify a single inverter model under UL 1741 SA.
- **IEEE P1547.1 will address validation needs for distribution-connected systems.**
- **It is possible that IEEE P1547 and P1547.1 frameworks/procedures could be leveraged for bulk system requirements with some modification.**
  - In practice, many transmission-connected inverters today are tested to IEEE 1547.1 (though this may not be an appropriate use of the standard).

Slide courtesy Dr. Andy Hoke

Impacts of IEEE 1547 on Interconnection Screens Used by Some Utilities

- System protection (supplemental review and full-impact studies)
- Anti-islanding protection screens might need to be revised
- System DER hosting capacity
- Modeling advanced DERs. Lack of modeling tools that are widely used by the utilities for protection and load-flow studies
- Interconnection study time and cost.

Slide courtesy Dr. Babal Enayati

Major Achievements in 2018 Revision

- Consensus standard: 120+ industry experts in working group, 4-year effort
- Robust public balloting: 389-member public ballot pool, 1,500+ comments resolved
- 93% approval (75% required).

- More coordinated operation under normal conditions
- Maintain grid safety
- Grid support under abnormal conditions
- New guidance for interoperability and open communications
- New guidance for intentional islands
- Strikes a balance between needs for large and small installations.

NREL Project: Stakeholder Educational Materials

- Develop website for IEEE 1547-2018 educational materials.
- Conduct gap analysis of existing educational materials.
- Develop new educational materials, as needed.
- Prepare guide for authorities governing interconnection requirements.
- Provide direct technical assistance.

Provide your input to the gap analysis:
https://www.surveymonkey.com/r/IEEE-1547-2018

Presentation Part II:

Grid Support

IEEE 1547 Evolution of Grid Support Functions

Standard	Requirements
IEEE 1547-2003	• **Shall NOT** actively regulate voltage • **Shall trip** on abnormal voltage/frequency.
IEEE 1547a-2014 (Amendment 1)	• **May** actively regulate voltage • **May** ride through abnormal voltage/frequency • **May** provide frequency response[1] (frequency droop).
IEEE 1547-2018	• **Shall be capable of** actively regulating voltage • **Shall be capable of** frequency response[2] • **Shall ride through** abnormal voltage/frequency • **May** provide inertial response.[3]

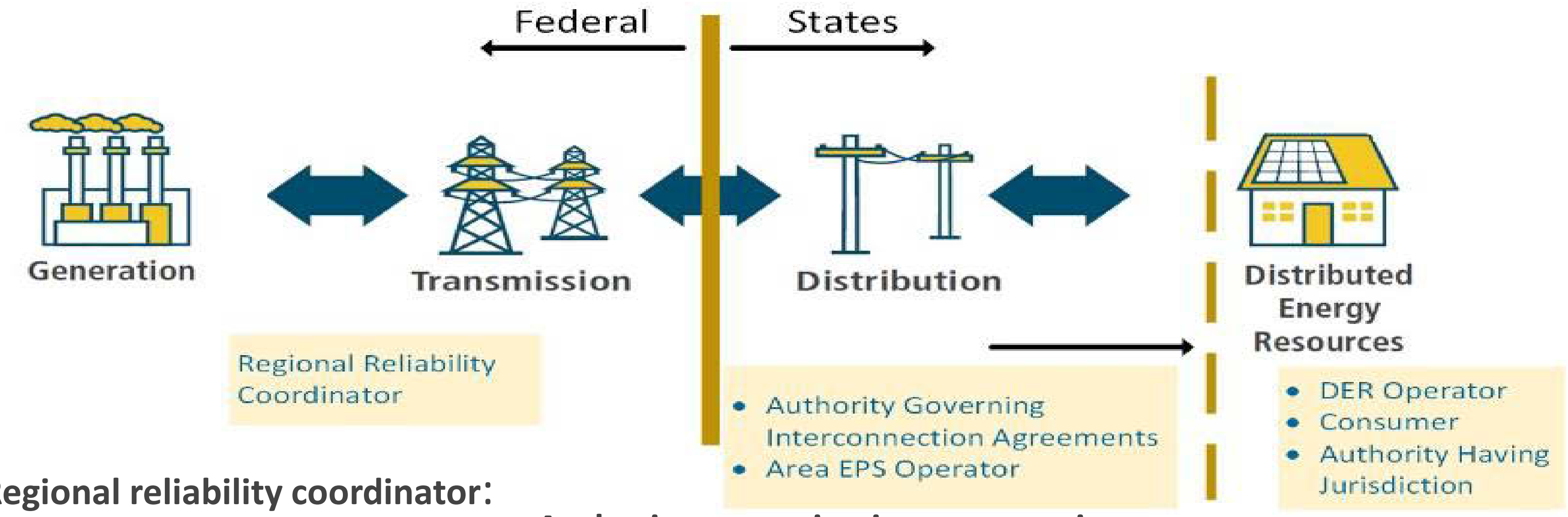
[1]Frequency response is the capability to modulate power output as a function of frequency.
[2]Mandatory capability for Categories II and III under high-frequency conditions, mandatory for Categories II and III under low-frequency conditions, optional for Category 1
[3]Inertial response is the capability for DERs to modulate active power in proportion to the rate of change of frequency.

Performance Categories

- Not all desirable DER technologies can meet the full extent of reactive power and/or ride-through compatible with bulk power system requirements.
  - Synchronous generators have stability issues with some reactive power and/or low-voltage ride-through (LVRT).
  - Some “prime mover” or “energy source” systems can also have potential issues.
  - Example of desirability: engine converting landfill CH_4 to energy.

- Solution: define “disturbance performance categories”
  - AGIR decides which performance category will be met by each DER type and application.
  - Technical criteria: type, capacity, future penetration of DER, type of grid configuration, etc.
    - AGIR may also limit cumulative capacity allowed to meet “lower-level” requirements.
  - Nontechnical criteria: DER use case, impacts on environment, emissions, and sustainability, etc.
    - Making nontechnical judgements is outside the purview of IEEE standards.

Key Terms and Entity Jurisdictional Boundaries



Regional reliability coordinator:
Maintains real-time operating reliability of bulk power system within a reliability coordinator area

Authority governing interconnection requirements (AGIR):
Codifies, communicates, administers, and enforces policies and procedures for allowing electrical interconnection of DERs to the grid.
Examples: State regulatory agency, public utility commission, municipality, cooperative board of directors

Authority having jurisdiction: Has rights to inspect and approve of the design and construction. Examples: City or county inspectors

Images - DOE

Assignment of New IEEE 1547 Performance Categories

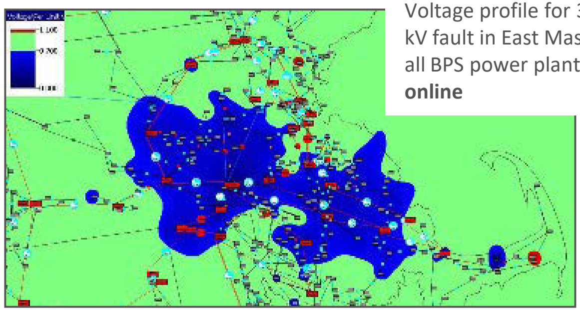
Decisions on adoption of normal and abnormal performance categories could require consideration of topics outside the specific scope of IEEE Std 1547. These considerations may include technical and non-technical issues and may require dialog among a broad range of stakeholders.

Ride-Through

Topic Highlight

Driver for New Ride-Through Requirements: Potential for Widespread DER Tripping

- Transmission faults can depress distribution voltage over very large areas.
- Sensitive voltage tripping (i.e., 1547-2003) can cause massive loss of DER generation.
- Resulting bulk power system event could be greatly aggravated.



Voltage profile for 345-kV fault in East Mass., all BPS power plants **online**

Source: ISO-New England

- System frequency is defined by the balance between load and generation.
- Frequency is the same across entire interconnection; all DERs can trip simultaneously during disturbance.
- Impact is the same whether or not DER is on a high-penetration feeder.

IEEE 1547-2018 mandates BOTH:

- Tripping requirements, and
- Ride-through requirements.

Ride-through is not a "setting"; it is a capability of the DER:

- i.e., it is the DER's robustness.

Tripping points are adjustable over an allowable range.

- Range does not allow DER tripping to seriously compromise BPS security.
- Tripping points are specified by the area EPS operator (utility) within constraints of the regional reliability coordinator.

Slide courtesy Dr. Jens Boemer

New Grid Support Requirements–Abnormal Grid Conditions

Ride-through:

ability to withstand voltage or frequency disturbances

Required

1. Voltage ride-through
2. Frequency ride-through
3. Rate-of-change (ROCOF)
4. Voltage phase angle change
5. Frequency droop.[1][2]

Other allowed capabilities

- Inertial response[3]
- Dynamic voltage support[4]

[1]Frequency response is capability to modulate power output as a function of frequency.

[2]Mandatory capability for Categories II and III under high frequency conditions, Mandatory for Categories II and III under low frequency conditions, optional for Category 1

[3]Inertial response is capability for DER to modulate active power in proportion to the rate of change of frequency.

[4]Dynamic voltage support provides rapid reactive power exchanges during voltage excursions.

Abnormal Operating Conditions Performance Categories

Category I

- ✓ Essential bulk system needs
- ✓ Attainable by all state-of-the-art DER technologies.

Foundation/harmonization: German grid code for medium-voltage-connected synchronous generator-based DERs

Category II

- ✓ Full coordination with all bulk system power system stability/reliability needs
- ✓ Coordinated with existing reliability standards to avoid tripping for a wider range of disturbances (than Category I)

Foundation/harmonization: North American Electric Reliability Corporation (NERC) PRC-024-2, adjusted for distribution voltage differences (delayed voltage recovery), extended low-voltage ride-through duration for 65%–88% Vnom | & Based on EPRI white paper (May 2015).

Category III

- ✓ Designed for all bulk system needs and distribution system reliability/power quality needs
- ✓ Coordinated with existing requirements for very high DER levels

Foundation/harmonization: California Rule 21 and Hawaii, minor modifications

IEEE 1547-2018 Ride-Through Requirements

Performance Categories (Grid support under abnormal grid conditions)		Mandatory Ride-Through Capabilities						
		Voltage Ride-Through	Frequency Ride-Through	Rate-of-Change-of-Frequency (ROCOF) Ride-Through	Voltage Phase Angle Change Ride-Through	Frequency Droop (freq-power)	Inertial Response	Dynamic Voltage Support
Category I	Essential bulk system needs Attainable by all state-of-the-art DER technologies	✓	✓	✓ (.5 Hz/s)	✓	Low freq. optional	Permitted	Permitted
Category II	Full coordination with all bulk system power system stability/ reliability needs (e.g., NERC) Coordinated with existing reliability standards to avoid tripping for a wider range of disturbances (than Category I)	✓	✓	✓ (2.0 Hz/s)	✓	✓	Permitted	Permitted
Category III	Designed for all bulk system needs and distribution system reliability/power quality needs Coordinated with existing requirements for very high DER levels (e.g., CA, HI)	✓	✓	✓ (3.0 Hz/s)	✓	✓	Permitted	Permitted

[1]Frequency response is the capability to modulate power output as a function of frequency.
[2]Mandatory capability for categories II and III under high-frequency conditions, mandatory for categories II and III under low-frequency conditions, optional for Category 1
[3]Inertial response is the capability for the DER to modulate active power in proportion to the rate of change of frequency.
Dynamic voltage support provides rapid reactive power exchanges during voltage excursions

IEEE 1547-2018 Voltage Ride-Through Requirements

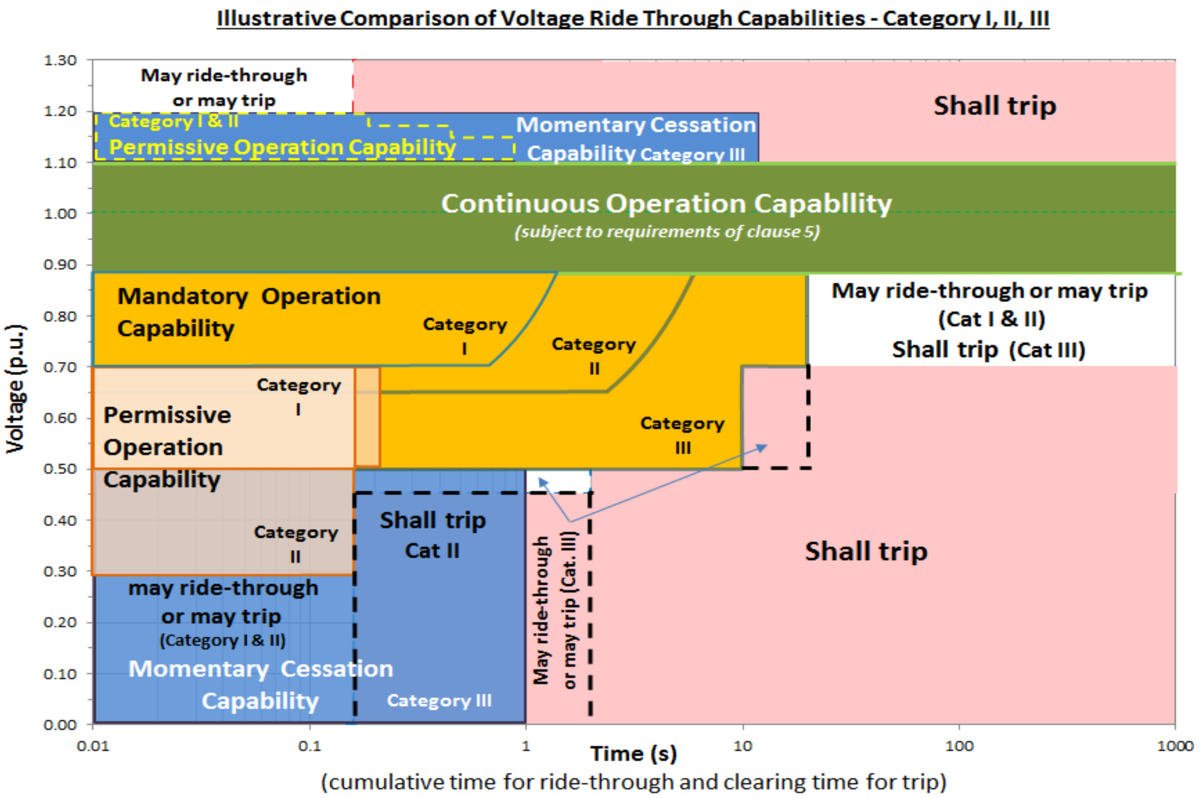


Figure based on IEEE 1547-2018 (Fig. H.7, H.7, H.8). Please see the original for details.

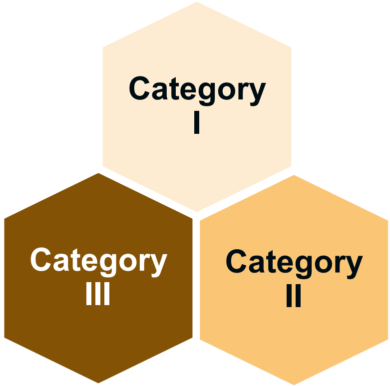
"The Area EPS Operator, as guided by the AGIR who determined applicability of the performance categories as outlined in 4.3, shall specify which of abnormal operating performance category I, category II, or category III performance is required.*" (IEEE 1547-2018)

**This may be subject to regulatory requirements that are outside the scope of this standard and may consider DER type, application purpose, future regional DER penetration, and the Area EPS characteristics.*

Key takeaways:

- Performance categories
- Modes of operation
- Requires coordination with bulk power system.

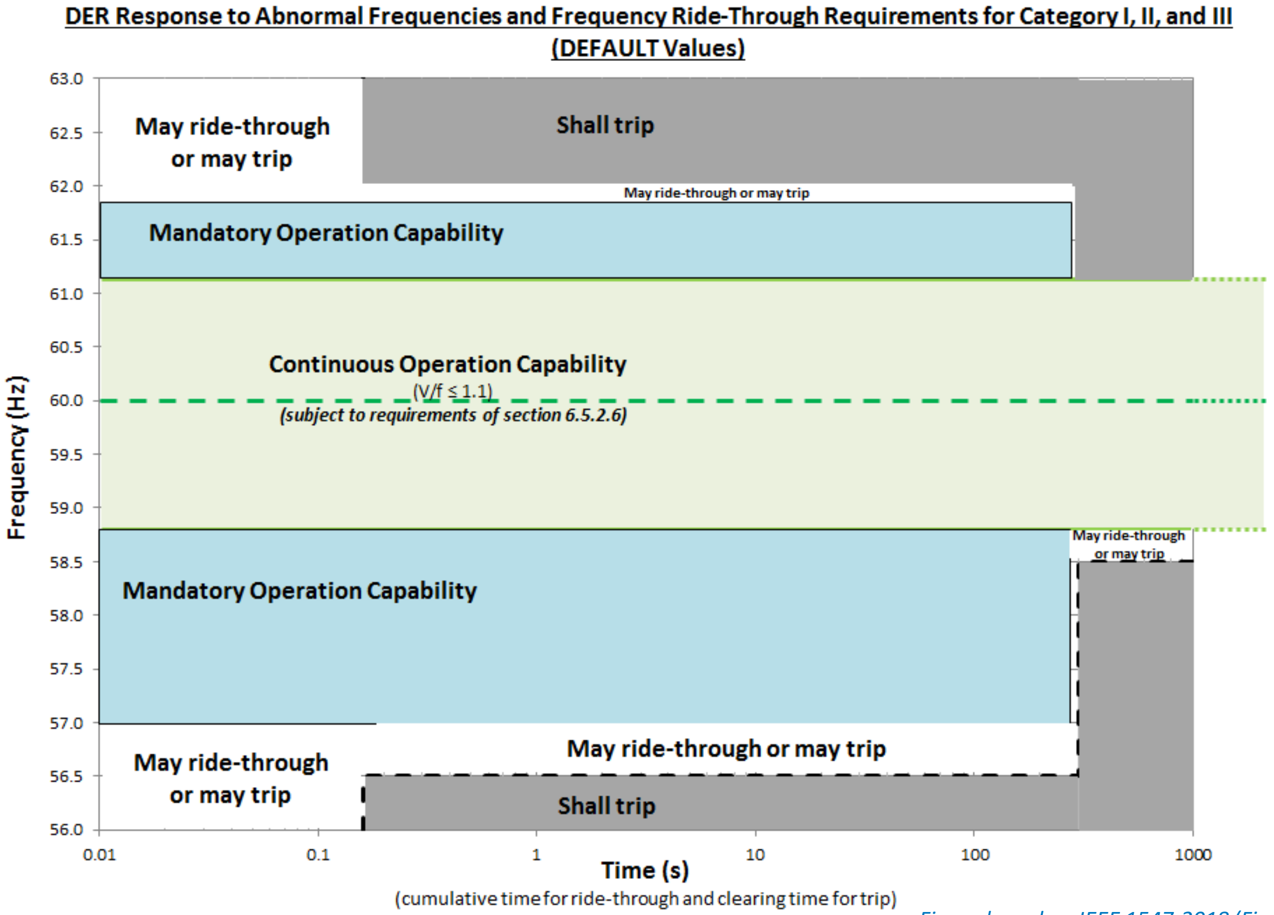
Frequency Ride-Through



- ✓ All categories (harmonized)
- ✓ All bulk system needs
- ✓ Low-inertia grids.

Foundation/Harmonization: California Rule 21 and Hawaii, exceeds PRC-024-2 | & Based on EPRI white paper (May 2015).

IEEE 1547 Frequency Ride-Through Requirements



"Area EPS operators may specify values within the specified range subject to the limitations on frequency trip settings specified by the regional reliability coordinator" (NERC)

Key takeaways:

- Performance categories
- Modes of operation
- Requires coordination with bulk power system.

Figure based on IEEE 1547-2018 (Fig. H.10) Please see the original for details.

Bulk Power System Considerations

Topic Highlight

PV Reliability Impacts in the Western U.S. Interconnection

NERC Reports

"**1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report**"

Southern California 8/16/2016 Event, June 2017

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

"**900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report**"

Southern California Event: October 9, 2017 Joint NERC and WECC Staff Report, February 2018

- Key finding: no erroneous frequency measurements, continued use of momentary cessation, interpretation of voltage trip requirements, phase-locked loop operation…

"**Distributed Energy Resources: Connection Modeling and Reliability Considerations**", February 2017

- Report outlines potential impacts of DER on bulk system reliability.
- Recommends specific modeling methods and data requirements for DERs.

National Renewable Energy Laboratory – Golden, Colorado
Photo: Dennis Schroder

Thank You

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