Highlights of IEEE Standard 1547-2018

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Webinar Presented to Arkansas DER Interconnection Stakeholders

October 28, 2019
(Revised 11/21/2019)

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.

NREL at a Glance

2,050

Employees,
plus more than
400
early-career researchers and visiting scientists

World-class
facilities, renowned technology experts

Nearly 820

Partnerships
with industry, academia, and government

Campus
operates as a living laboratory

NREL Core Capabilities: Foundation for Innovation

Systems Integration

Systems Engineering and Integration

Large-Scale User Facilities

Innovation and Application

Biological and Bioprocess Engineering

Chemical Engineering

Mechanical Design and Engineering

Power Systems and Electrical Engineering

Foundational Knowledge

Applied Materials Science and Engineering

Biological Systems Science

Chemical and Molecular Science

Crosscutting

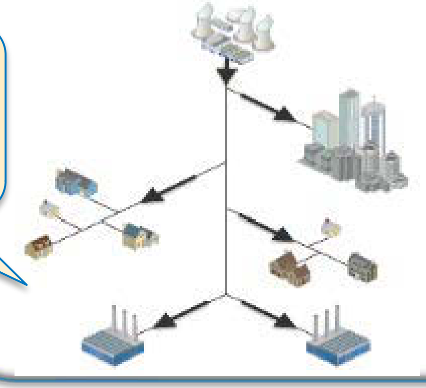
Advanced Computer Science, Visualization, and Data

Decision Science and Analysis

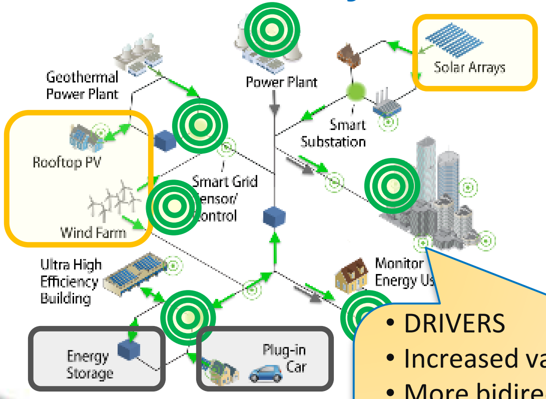
New DER Integration Challenges in a Modern Grid

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

Current Power System



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

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

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)

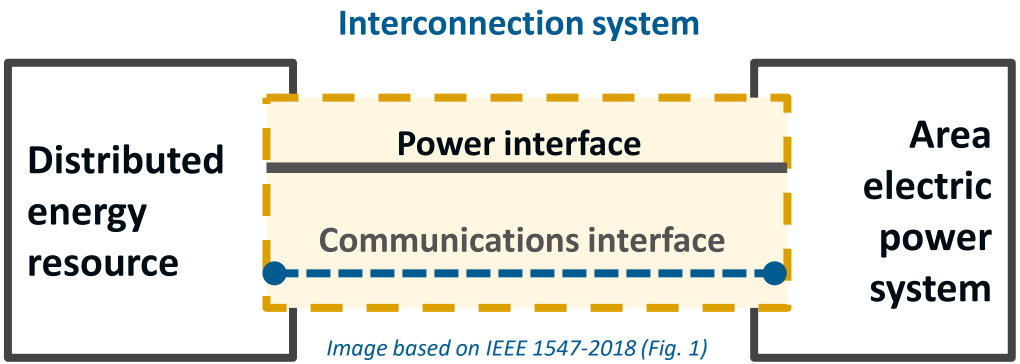


Image based on IEEE 1547-2018 (Fig. 1)

- Sponsored and published by the Institute of Electrical and Electronics Engineers (IEEE)
- Cited in federal law (EPACT 2005) for consideration as 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.)

IEEE 1547 Document Outline (Clauses)

1. Overview
2. Normative references
3. Definitions and acronyms
4. General specifications and requirements
5. Reactive power, voltage/power control
6. Response to area electric power system (EPS) 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).

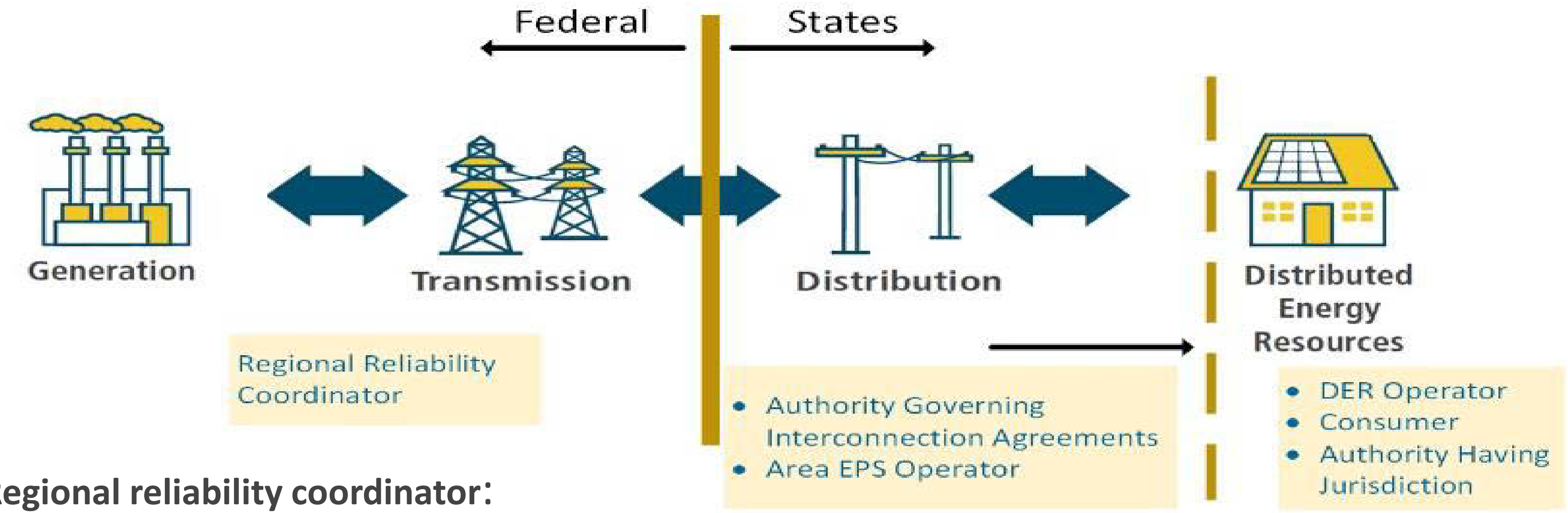
Limitations—it is *not*:

- 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.)

Key Terms and Entity Jurisdictional Boundaries



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

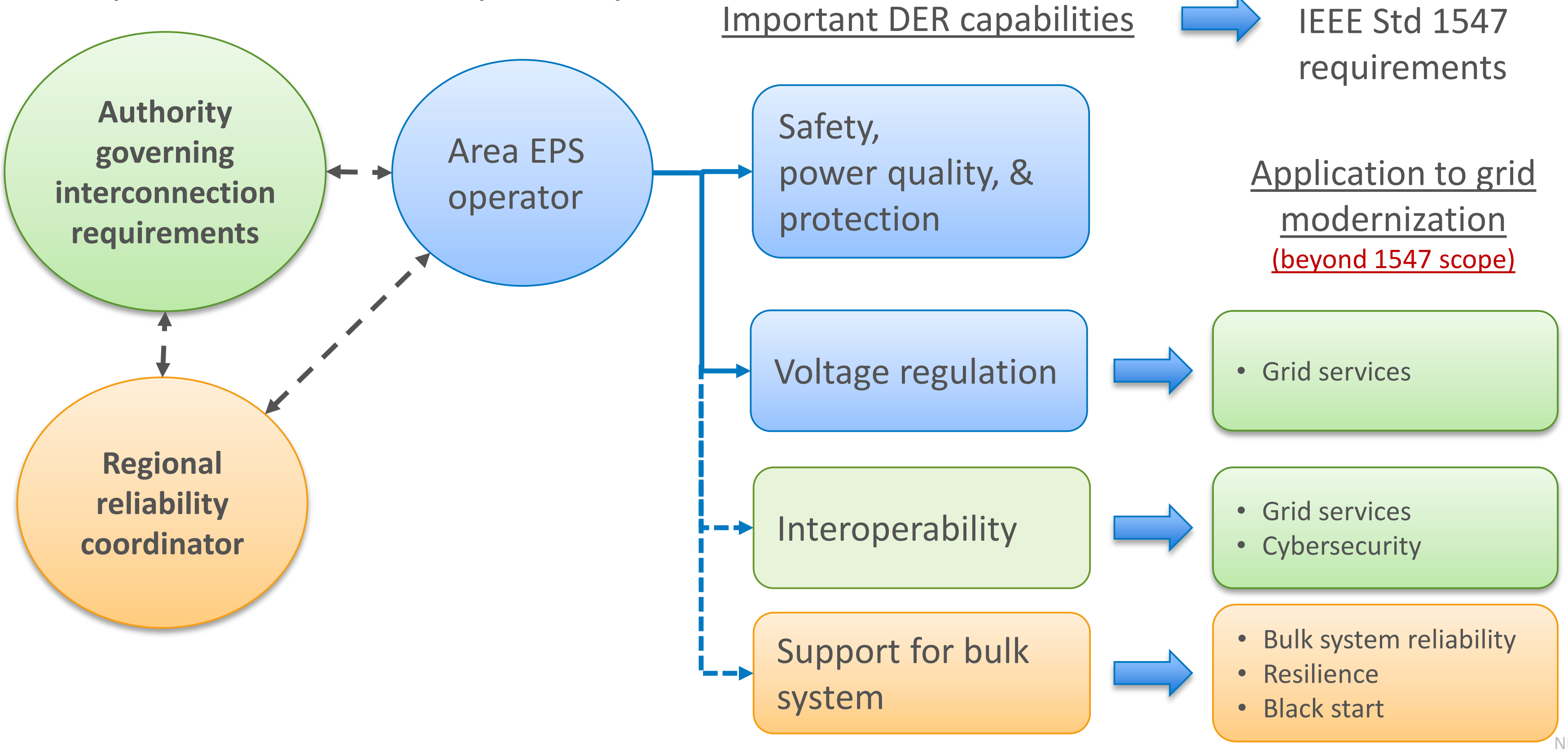
Authority governing interconnection requirements (AGIR): Codifies, communicates, administers, and enforces policies and procedures for allowing electrical interconnection of DERs to the grid.
Examples: State regulatory agency, public utility commission, municipality, cooperative board of directors

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

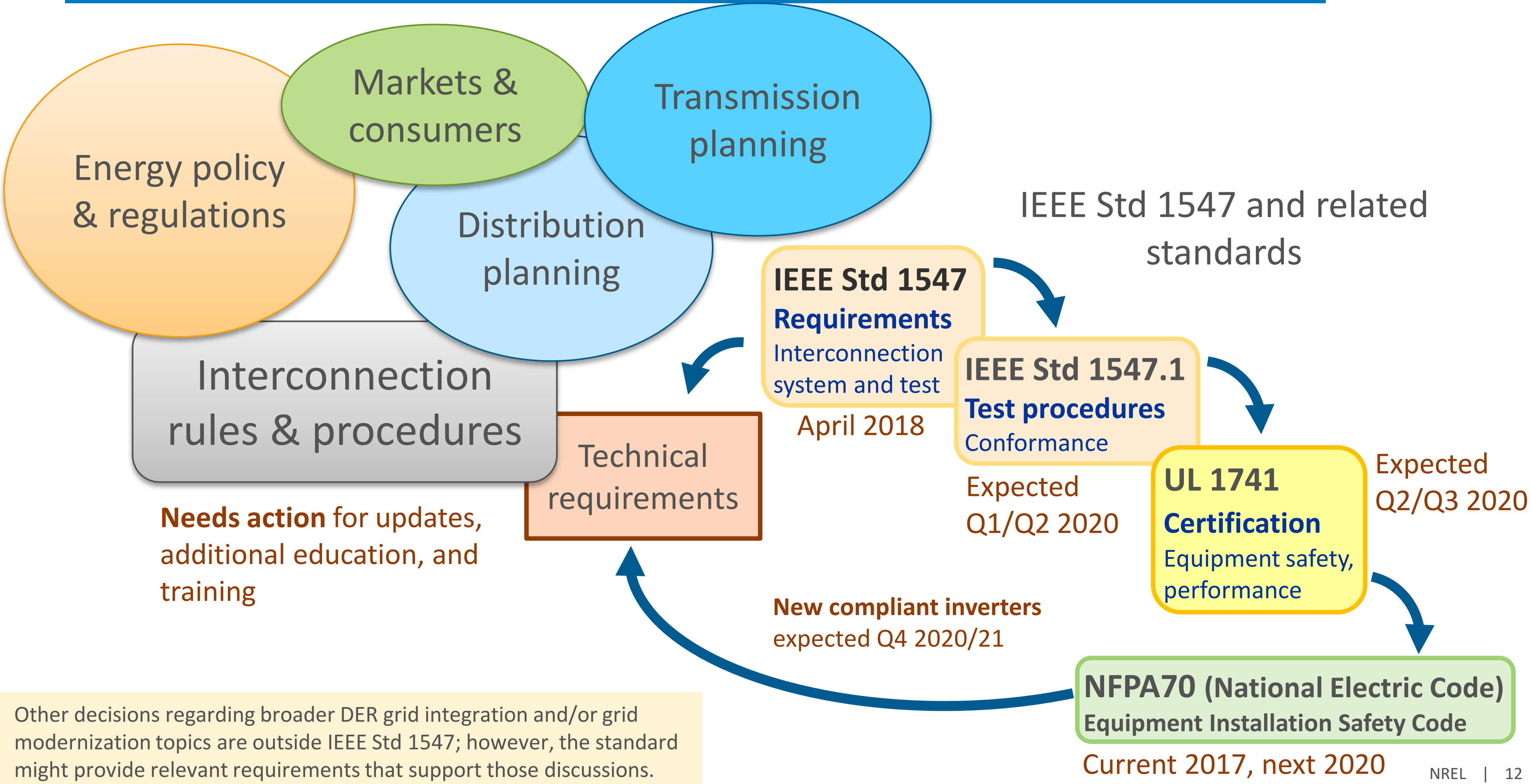
Images from DOE

Requirements Context

Input and decisions required by:



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.

Core Functions

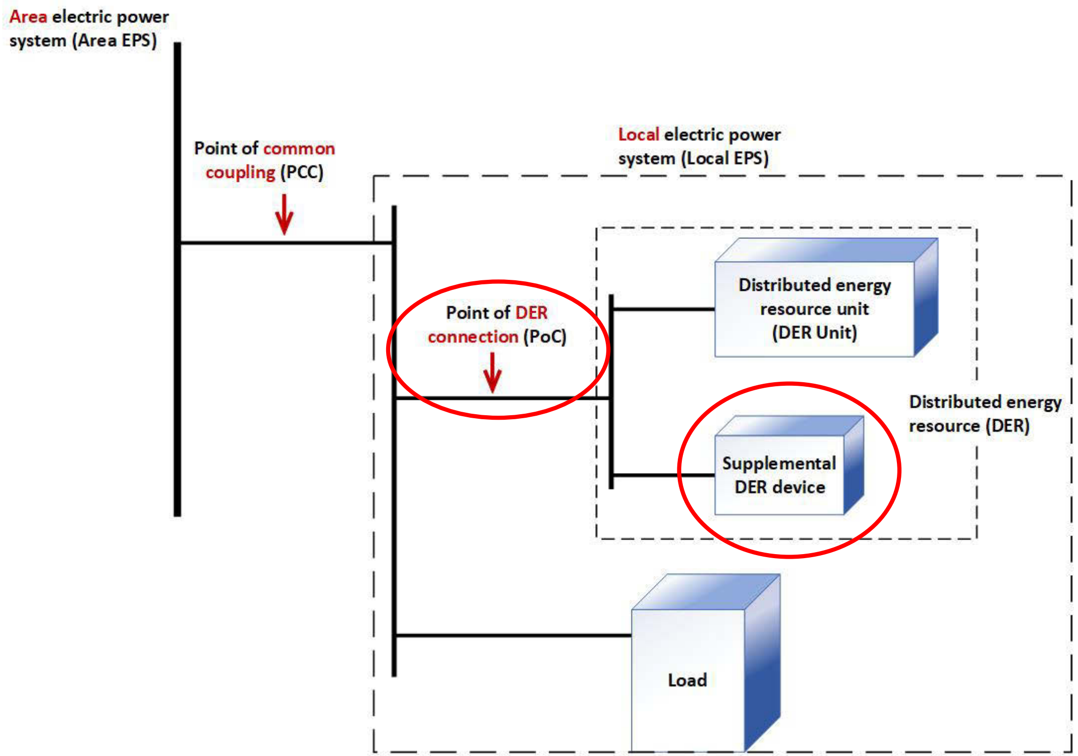
Topic Highlight

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." (IEEE Std 1547-2018)

Supplemental DER device: "Any equipment that is used to obtain compliance with some or all of the interconnection requirements of this standard." (IEEE Std 1547-2018)



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.

Energy Storage

Topic Highlight

Energy Storage

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

- Energy storage system (ESS) (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

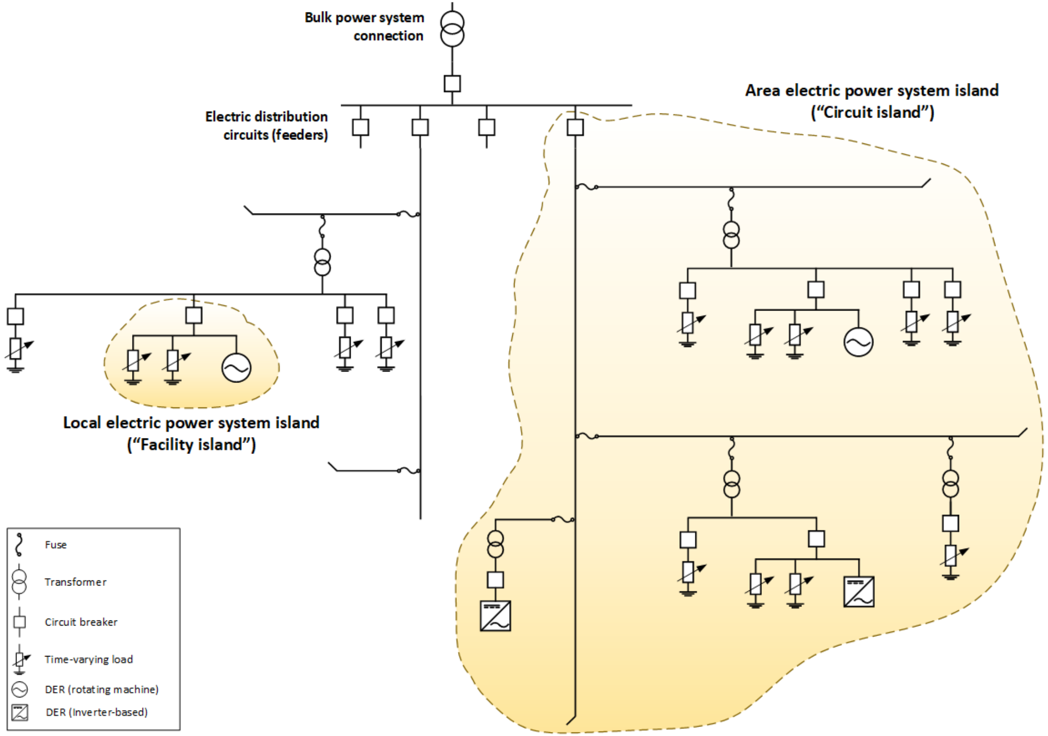
Intentional island: An electrical island that is capable of being energized by one or more local electric power systems (p. 23)

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").

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.



Interoperability

Topic Highlight

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)*

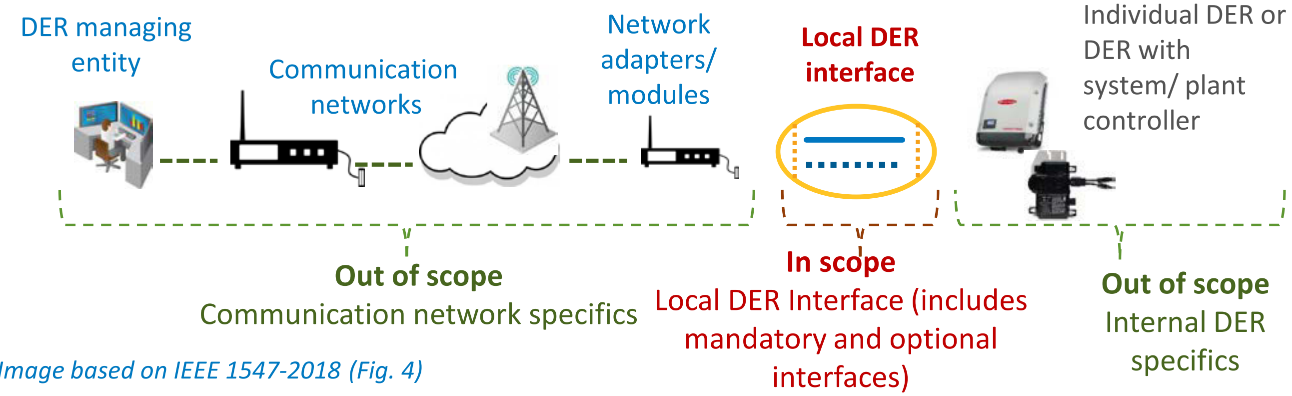


Image based on IEEE 1547-2018 (Fig. 4)

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)

Interoperability Requirements

IEEE Std 1547-2018 requirements:

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

The decision to use the *local DER communications interface* or to deploy a communications system shall be determined by the area EPS operator (**may need input from the AGIR**).

Potential stakeholders for communications/control/ monitoring:

- Area EPS operator
- DER aggregator
- DER operator
- DER owner
- Building/facility manager
- ISO/TSO/RTO?

Value of interoperability:

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

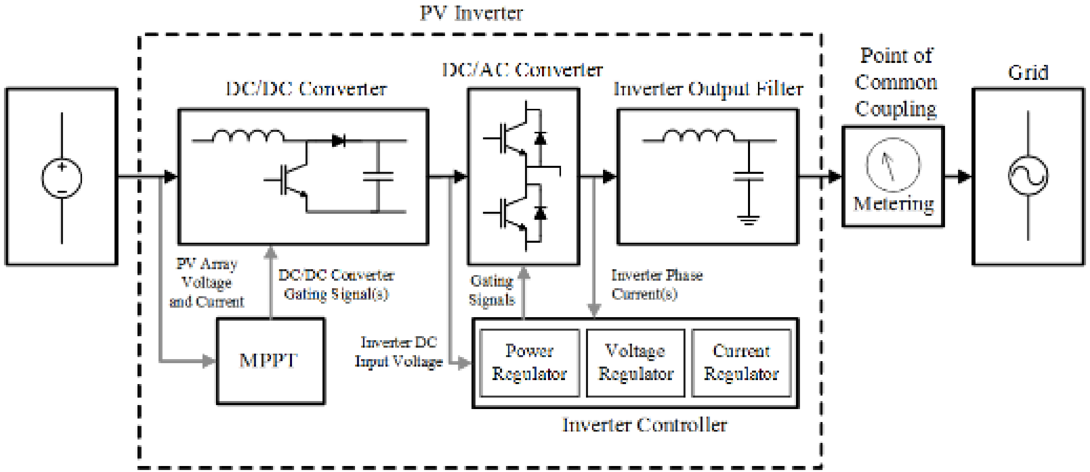
Grid Support

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



Simplified PV inverter block diagram showing key system components and control

Image courtesy of Dr. Barry Mather, NREL

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 CH4 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.

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 nontechnical issues and may require dialog among a broad range of stakeholders.

Voltage Regulation

Topic Highlight

Voltage Regulation

- IEEE Std 1547-2018 compliant DER shall have the capability to inject and absorb reactive power (overexcited and underexcited), 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	✓	✓	✓	✓	✓

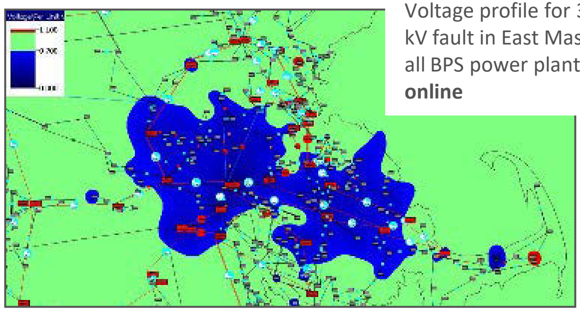
- *IEEE 1547-2018: “The DER shall provide voltage regulation capability by changes of reactive power. The approval of the Area EPS Operator shall be required for the DER to actively participate in voltage regulation.”*
- The area EPS operator shall specify the required voltage regulation control modes 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.

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., IEEE Std 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 Std 1547-2018 mandates *both*:

- Tripping requirements
- 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 of 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 of frequency (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 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 capability for DERs 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.

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 DERs to modulate active power in proportion to the rate of change of frequency.
Dynamic voltage support provides rapid reactive power exchanges during voltage excursions

Bulk Power System Considerations

Topic Highlight

PV Reliability Impacts in the Western U.S. Interconnection

North American Electric Reliability Corporation (NERC) Reports

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

Southern California Event: August 16, 2016, Published June 2017

- Key finding: mismeasurement 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 Western Electricity Coordinating Council Staff Report, Published 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

Published February 2017

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

Test & Verification

Topic Highlight

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 Std P1547.1 will address validation needs for distribution-connected systems.**

Slide courtesy Dr. Andy Hoke

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

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 Std 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

National Renewable Energy Laboratory – Golden, Colorado
Photo by Dennis Schroeder

Thank You

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

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