Highlights of IEEE Standard 1547-2018 Implementation Considerations

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Acknowledgments

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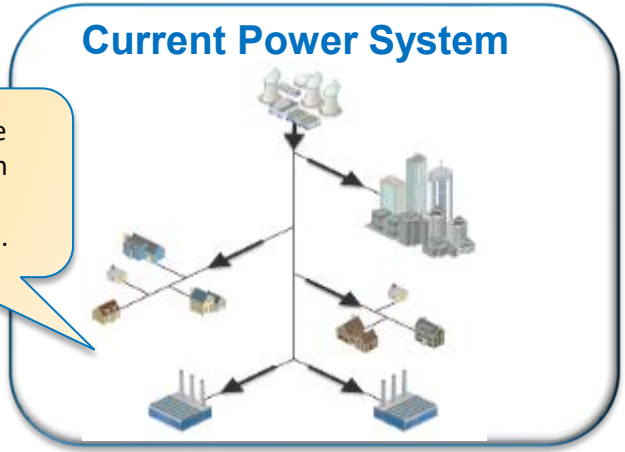
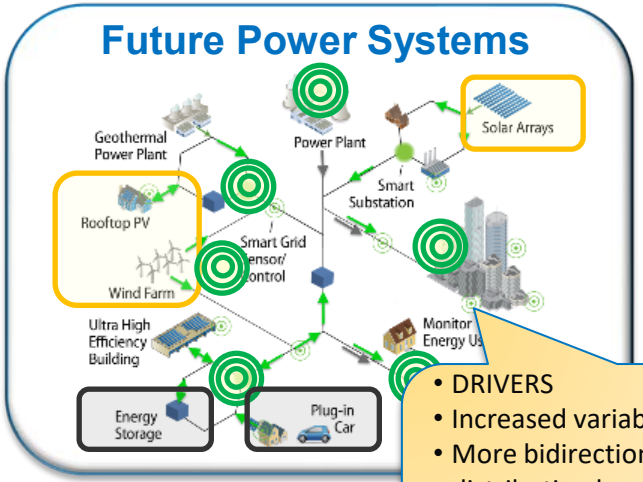
- Thanks also to the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office for supporting the authors' participation in standards development.

New DER Integration Challenges in a Modern Grid



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



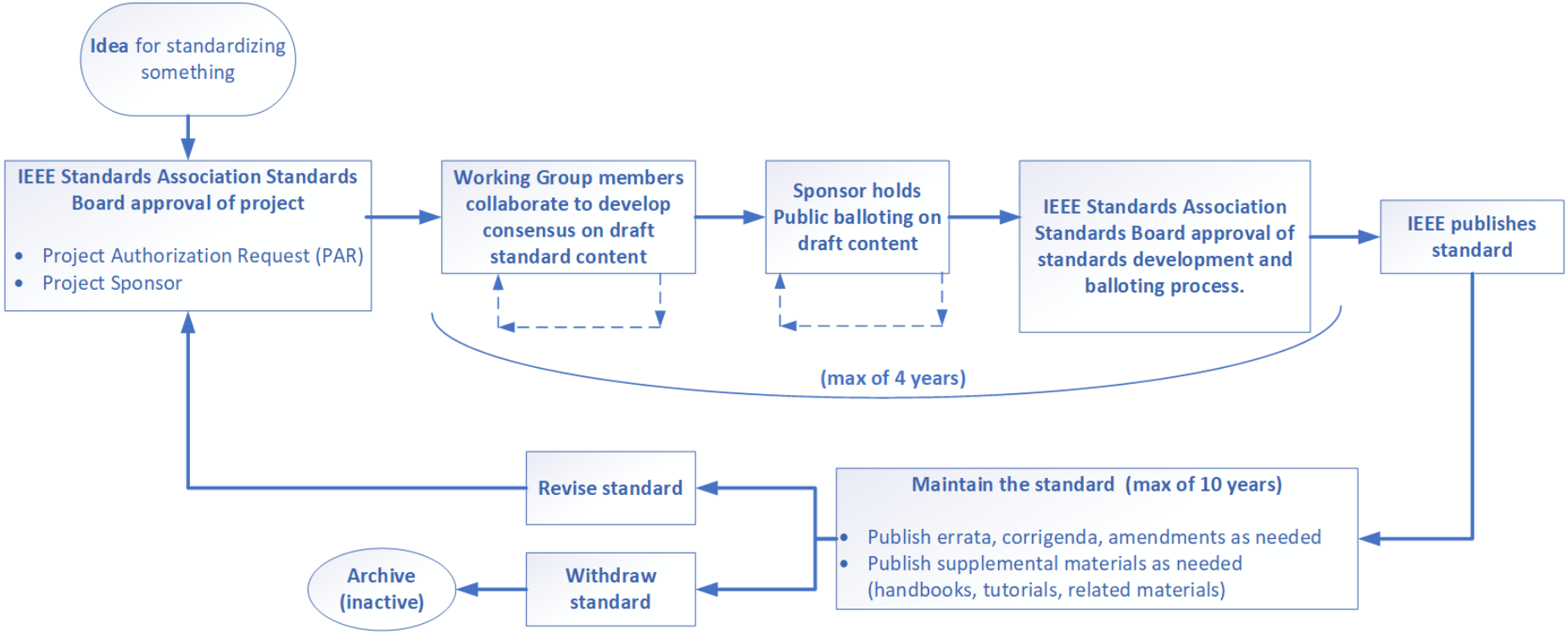
- DRIVERS
- Increased variable generation
- More bidirectional flow at distribution level
- Increased number of smart/active devices
- Evolving institutional environment.

Our evolving power system context:

- New energy technologies and services
- Increasing penetrations of variable renewables on the 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 Std 1547-2018 (distributed energy resources [DERs] as grid assets).

Slide courtesy of Dr. Ben Kroposki, NREL

IEEE Standards Development Life Cycle



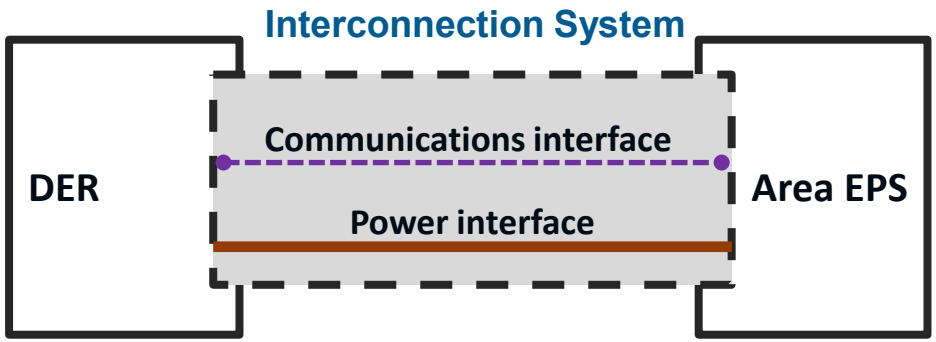
Source: based on https://standards.ieee.org/develop/develop-standards/process.html

IEEE standards process overview: https://standards.ieee.org/develop/index.html

IEEE Std 1547-2018 Scope and Purpose

Title: *Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

Scope: *This standard establishes criteria and requirements for the interconnection of DERs with electric power systems (EPS) and associated interfaces.*



Interconnection system: The collection of all interconnection equipment and functions, taken as a group, used to interconnect DERs to an area EPS. Note: In addition to the power interface, DERs should have a communications interface.

Interface: A logical interconnection from one entity to another that supports one or more data flows implemented with one or more data links.

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

Purpose*: This document provides a uniform standard for the interconnection and interoperability of DERs with the EPS. It provides requirements relevant to the interconnection and interoperability performance, operation, and testing and safety, maintenance, and security considerations.*

1547 is:

- A technical standard—**functional requirements**
- A single (whole) document of **mandatory, uniform, universal requirements** applied at the point of common coupling or the point of DER connection
- **Technology neutral**—i.e., it does not specify particular equipment or type.

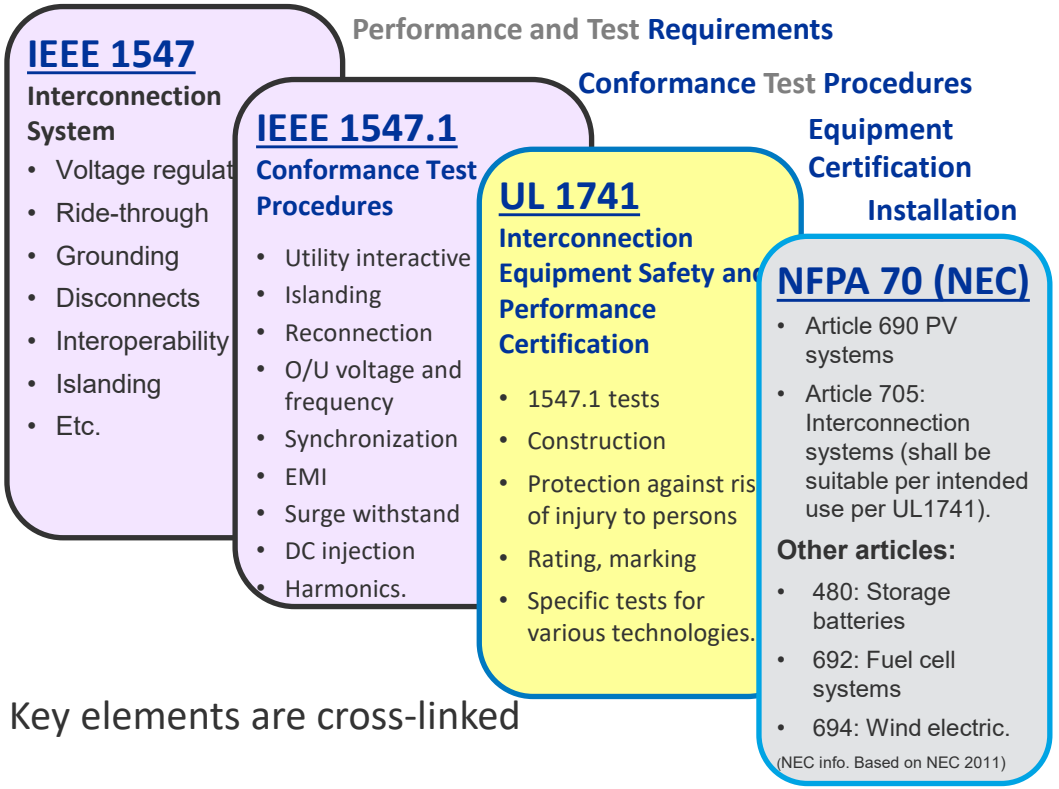
1547 is NOT:

- A design handbook
- An application guide
- 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 DERs.

IEEE Std 1547 Intended Use in the United States

Content of IEEE Std 1547-2018:

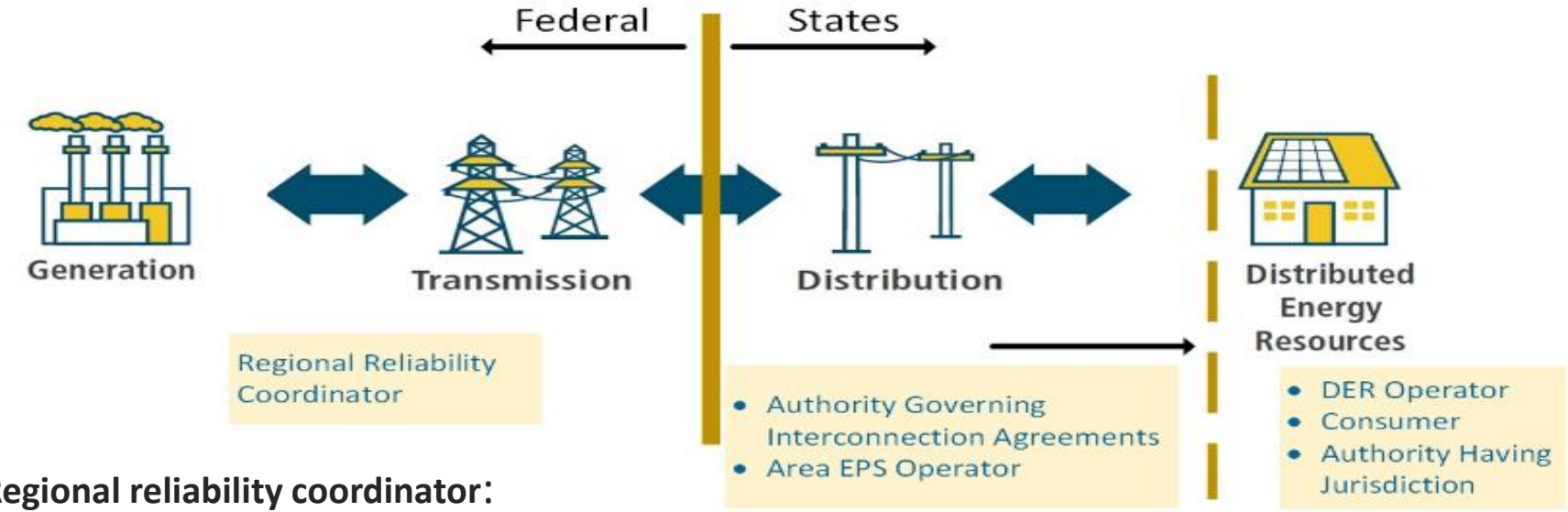
1. Overview
2. Normative references
3. Definitions and acronyms
4. General specifications and requirements
5. *[normal grid]* Reactive power, voltage/power control
6. Response to area EPS abnormal conditions
7. Power quality
8. Islanding
9. Distribution secondary grid and spot networks
10. Interoperability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



Key elements are cross-linked

Local interconnection processes and standards

Key Terms and Entity Jurisdictional Boundaries



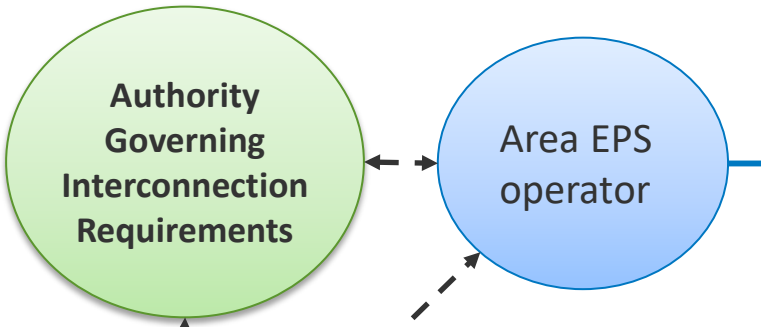
Regional reliability coordinator:
Maintains real-time operating reliability of bulk power system within a reliability coordinator area

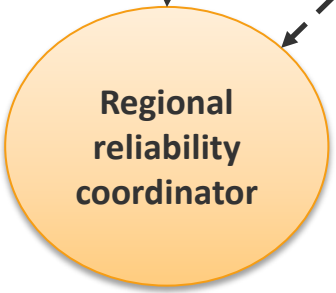
Authority Governing Interconnection Requirements (AGIR):
Codifies, communicates, administers, and enforces policies and procedures for allowing electrical interconnection of DERs to the grid.
Examples: State regulatory agency, public utility commission, municipality, cooperative board of directors

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

Images from DOE

IEEE Std 1547-2018 Requirements Context





IEEE Std 1547-2018 Requirements

Decisions (sample)

Adoption of 1547-2018!

- **Safety power quality protection**
  - Item
  - Protection settings
- **Testing & certification**
  - Type testing
  - Study, evaluation
- **Voltage regulation**
  - Perf. category
  - V. reg. mode
- **Interoperability**
  - Utilization
  - Com. protocols
- **Support for bulk system (ride-through)**
  - Perf. category
  - Trip settings
  - Ride-through settings

Application to Grid Modernization

(beyond 1547 scope)

- Grid services
- Grid services
- Cybersecurity
- Bulk system reliability
- Resilience
- Black start

Examples of Improved DER Capabilities Enabled in IEEE Std 1547-2018

Topic Highlight

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.

IEEE Std 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.

IEEE Std 1547-2018 Ride-Through Requirements

Performance Categories (Grid support under abnormal grid conditions) *Ride-through: ability to withstand voltage or frequency disturbances*		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	Meets essential bulk system needs Attainable by all state-of-the-art DER technologies	✓	✓	✓ (.5 Hz/s)	✓	Low freq. optional	Permitted	Permitted
Category II	Achieves 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	Most "robust": 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.
[4] Dynamic voltage support provides rapid reactive power exchanges during voltage excursions

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)*

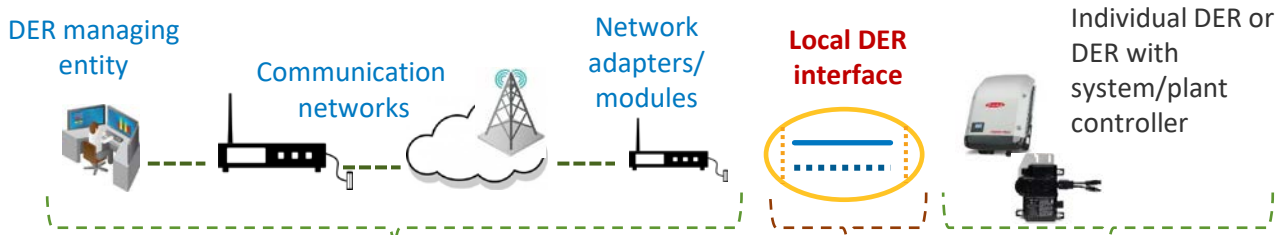
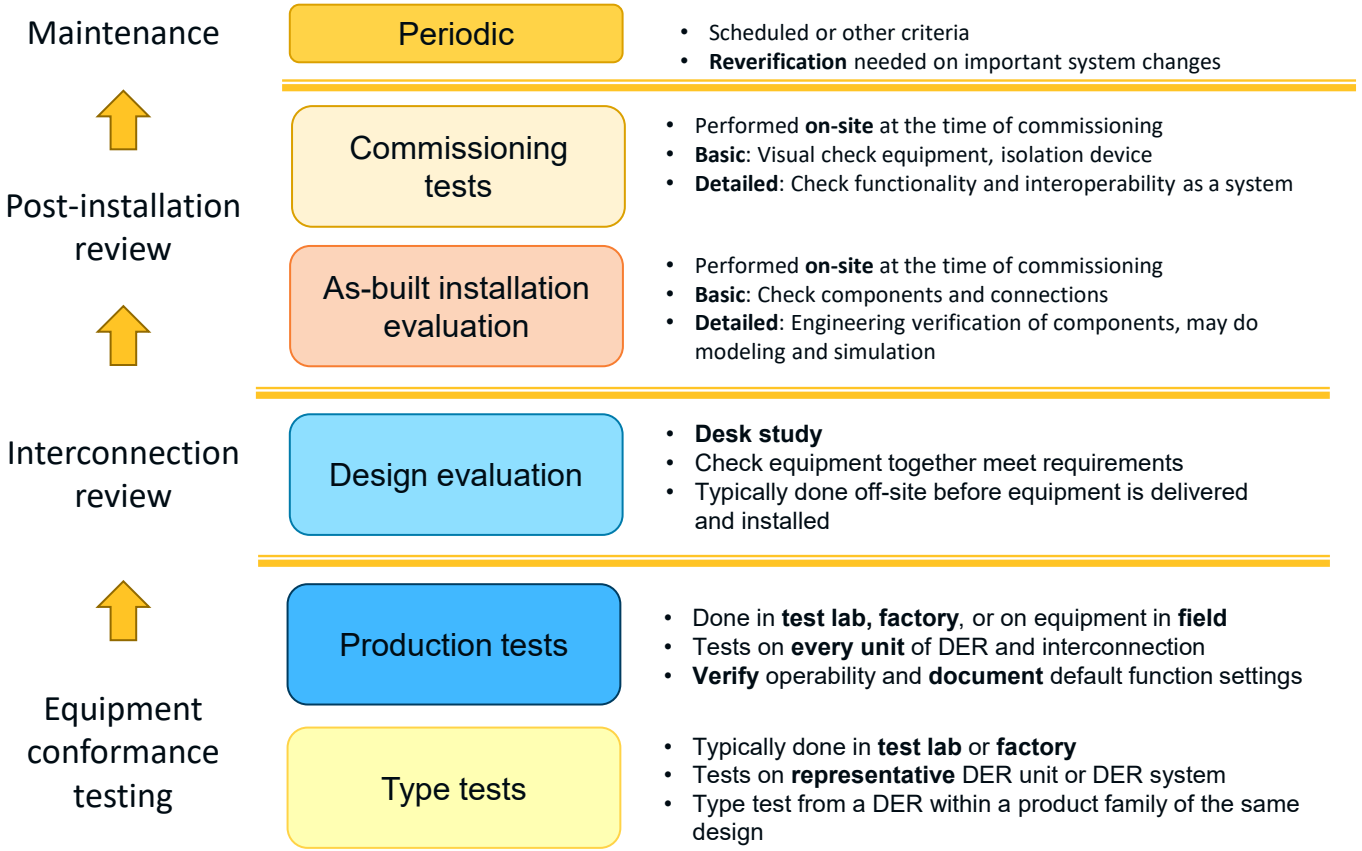


Image based on IEEE 1547-2018 (Fig. 4)

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)	

High-Level Test and Verification Process

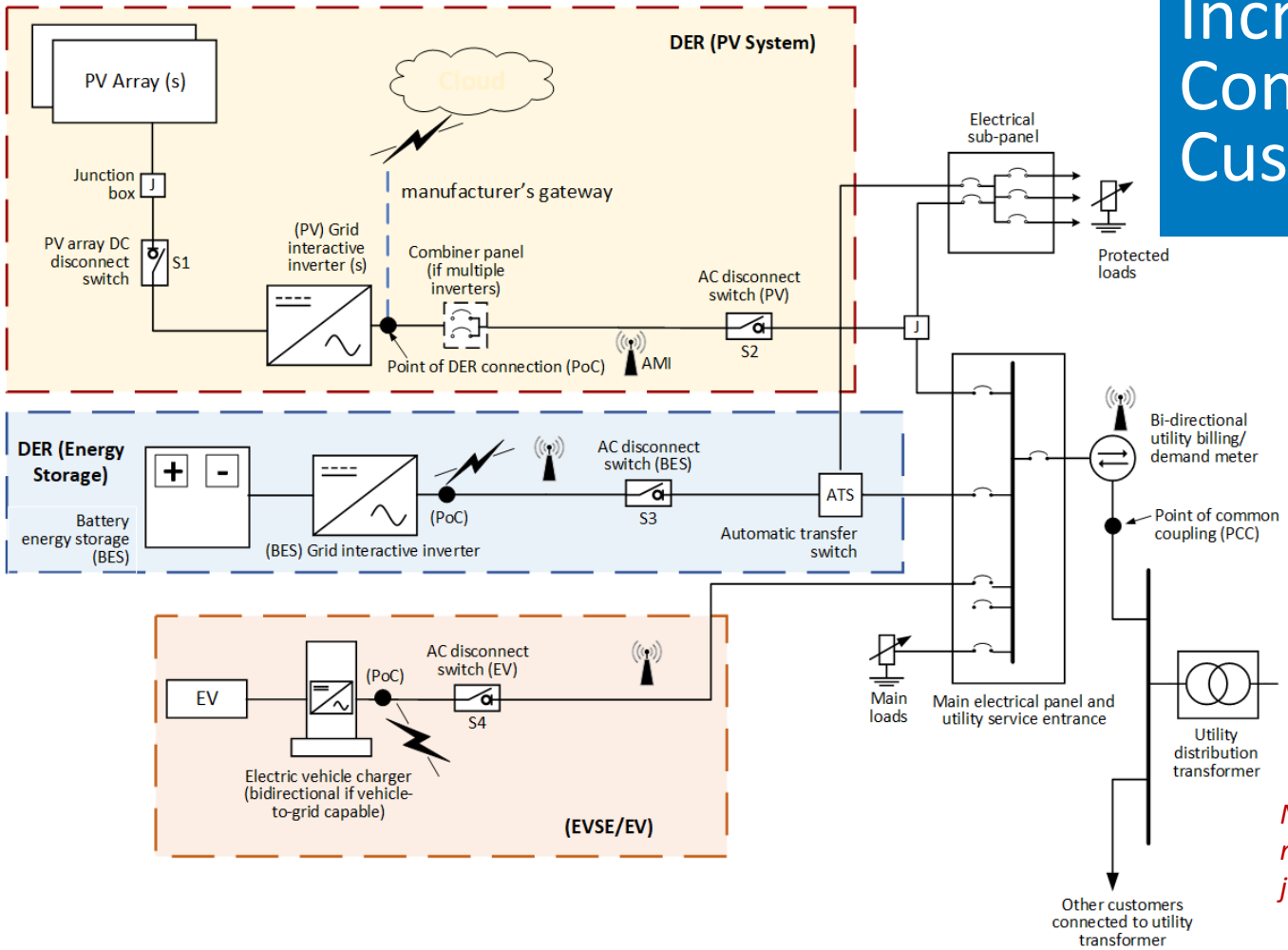


Examples of Increased Complexity to Be Considered

Topic Highlight

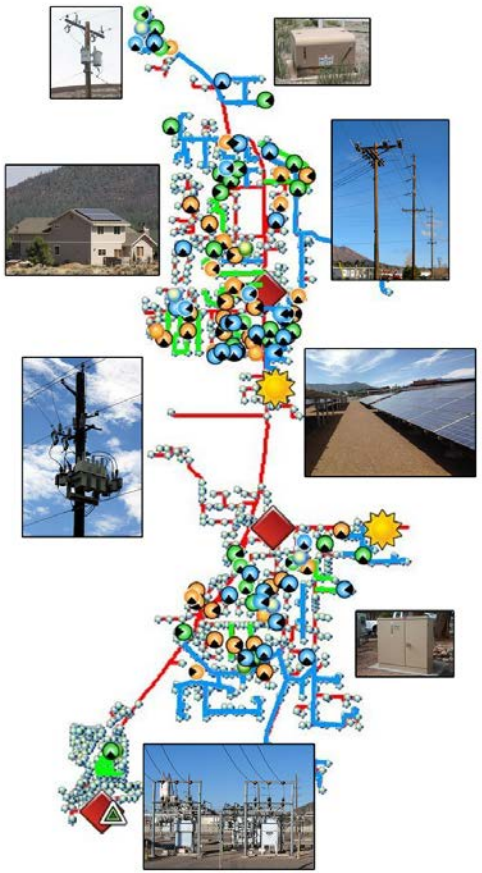
Increased Complexity in the Standard

Increased Complexity at Customer Facility



Note: Installation configurations and metering requirements vary across jurisdictions and utilities

Increased Complexity at Distribution Utilities



Photos by author

Distribution Operations/Situational Awareness

Feeder topology (GIS): Equipment specifications/ratings, DG size, location, adjacent feeder characteristics

Substation transformer loading (EMS): Measurements interior to feeder

Feeder load balancing

Equipment status/state/settings (mix—EMS, manual): Reclosers, capacitor banks, fuses, settings for dynamic voltage control devices, DG size, location, orientation, specifications

Solar irradiance: Historic, real-time forecast.

Power System Studies and Tools

Feeder historic peak load (manual process—annual): Feeder minimum daytime load

Steady-state studies: Load (power) flow, short-circuit/protection coordination, feeder PV hosting capacity, distributed generation point of interconnection "stiffness ratio"

Dynamic studies: Voltage stability (PSLF—transmission planning), interactions between smart grid devices

New scenarios: Optimal location and size of energy storage, control settings for smart inverters, feeder reconfiguration, microgrid applications, aggregation of distributed generation, forecast, transients, harmonics.

Increased Complexity at Regional Bulk Power Level

NERC Inverter-based Resource Performance Task Force (IRPTF)
https://www.nerc.com/comm/PC/Pages/Inverter-Based-Resource-Performance-Task-Force.aspx

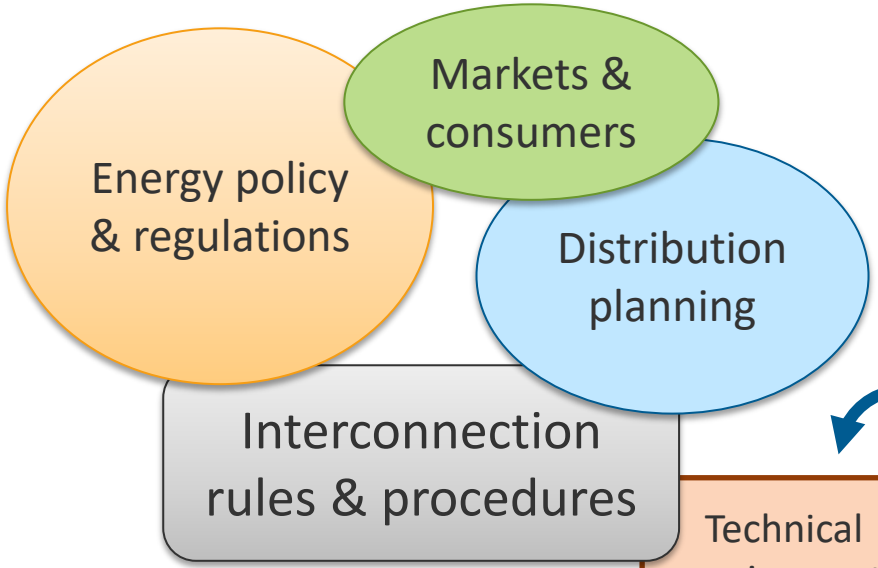
NERC System Planning Impacts from DER (SPIDER) Working Group
https://www.nerc.com/comm/PC/Pages/System-Planning-Impacts-from-Distributed-Energy-Resources-Subcommittee-(SPIDERWG).aspx

NERC Bulk Power System Reliability Perspectives on the Adoption of IEEE Std 1547-2018
https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Guideline_IEEE_1547-2018_BPS_Perspectives.pdf.

MISO´s IEEE 1547 – Distribution Interconnection Coordination
https://www.misoenergy.org/planning/generator-interconnection/ieee-1547/

PJM´s DER Ride-Through Task Force
https://pjm.com/committees-and-groups/closed-groups/derrttf.aspx

Increased Complexity at Local Regulatory Level



IEEE Std 1547 and related standards

IEEE Std 1547
Requirements
Interconnection system and test
2018

IEEE Std 1547.1
Test procedures
Conformance
2020

UL 1741
Certification
Equipment safety, performance
Expected Q3 2021

NFPA 70 (National Electric Code)
Equipment Installation Safety Code
Updated every 3 years

Technical requirements

Needs action for updates, additional education, and training

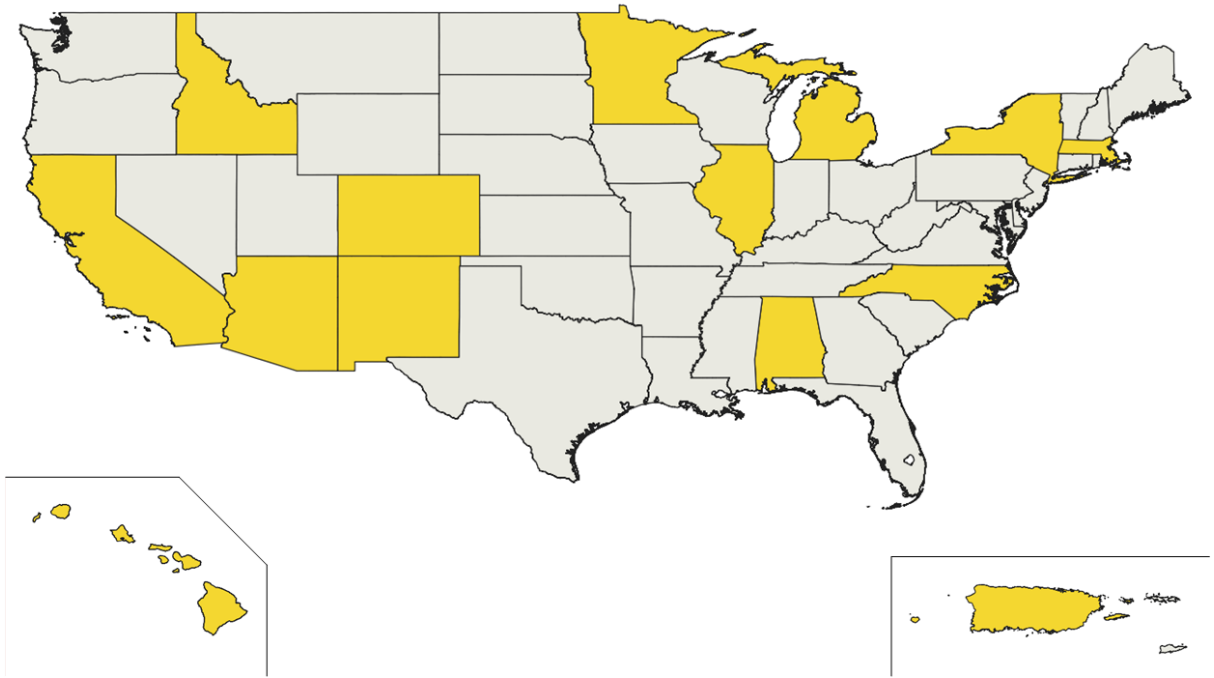
New compliant inverters expected Q4 2021/22

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.

State Activity on IEEE Std 1547-2018

The National Association of Regulatory Utility Commissioners (NARUC) resolution in February 2020 recommends state commissions act to adopt and implement the revised standard. https://pubs.naruc.org/pub/E86EF74B-155D-0A36-3138-B1A08D20E52B

This map highlights U.S. states that are actively investigating revisions or have already implemented revisions in updated interconnection rules.



Approaches to DER Interconnection Rule Update

1. **(Preplanning)** Determining the context, stakeholders, and major drivers

2. Developing the DER interconnection rule

3. Maintaining and revising

- **Internal motivations?** (e.g., reason for regulatory action, technical, market, policy)
- **Broader context?** (e.g., distribution system planning)
- **Stakeholders and roles?** (key decision makers)
- **Structure of the interconnection process?** (e.g., performance indicators, data collection, process map, and analysis)
- **Procedural timeline?**
- **Related/relevant procedures?**

- **Broad goals for technical requirements?** (e.g., safety, reliability, power quality, protection, affordability, markets, regulatory compliance)
- **IEEE Std 1547-specific?** (e.g., reactive power support, fault ride-through, interoperability, intentional islanding, energy storage)
- **Jurisdiction/utility-specific?** (e.g., metering, protection)
- **Other coordination required?** (e.g., bulk power sys.)

- **Triggers for updates?**
- **Scope of update?**
- **Maintainability of the rule?**

Examples of IEEE Std 1547-Related Educational Materials

- https://www.nrel.gov/grid/ieee-standard-1547/
- https://sagroups.ieee.org/scc21/standards/1547rev/

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

Examples of Activities in Process on Related Topics

DER cybersecurity: Acknowledged as critical but considered out of scope for 2018 version of 1547 due to scope of IEEE Std 1547, scope and complexity of cybersecurity requirements, system architecture flexibility, testability. Very active area of debate (e.g., https://sunspec.org/cybersecurity-work-group/, https://www.nist.gov/programs-projects/cybersecurity-smart-grid-systems, https://www.nist.gov/programs-projects/cybersecurity-smart-grid-systems)

Interactions with bulk power system: Very active across all areas (e.g., NERC and many others, https://www.nerc.com/comm/RSTC/Pages/IRPWG.aspx, https://www.nerc.com/comm/PC/Pages/System-Planning-Impacts-from-Distributed-Energy-Resources-Subcommittee-(SPIDERWG).aspx)

Unintentional islanding: Areas of detection, mitigation, evaluation/interconnection screens are all under review (e.g., CA Rule 21 WG 4, https://gridworks.org/initiatives/rule-21-working-group-4/)

Grid-forming inverters: Very active area focused on resilience (e.g., Grid-Forming Technologies Research Consortium https://www.energy.gov/articles/energy-department-announces-45-million-funding-solar-technologies)

DER aggregation: FERC 2222 opens door for aggregation from bottom up rather than top down (https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet ; https://pv-magazine-usa.com/2021/07/27/sunnova-and-solaredge-partner-to-provide-grid-support-services-in-new-england/)

Standards conformance: How to ensure standards are implemented properly? (e.g., https://standards.ieee.org/products-services/icap/programs/der/index.html)

Many other areas of active research and development.

Examples of Standards in Process on Related Topics

IEEE Std P2800 - IEEE Draft Standard for Interconnection and Interoperability of Inverter-Based Resources (IBR) Interconnecting with Associated Transmission Electric Power Systems
https://standards.ieee.org/project/2800.html

IEEE Std P1547.2 - Application Guide for IEEE Std 1547(TM), IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, https://standards.ieee.org/project/1547_2.html

IEEE Std P1547.3 - Guide for Cybersecurity of Distributed Energy Resources Interconnected with Electric Power Systems, https://standards.ieee.org/project/1547_3.html

IEEE Std P1547.9 - Guide to Using IEEE Standard 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems, https://standards.ieee.org/project/1547_9.html

IEEE Std P2030 - Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads

IEEE 2030.11-2021 - IEEE Guide for Distributed Energy Resources Management Systems (DERMS) Functional Specification, https://standards.ieee.org/standard/2030_11-2021.html (published in June 2021)

Preplanning for the Next Revision Is Underway

- DRAFT potential scope
- DRAFT general timeline
- Outreach to potential IEEE cosponsors (in addition to IEEE Standards Coordinating Committee 21)
- Outreach to stakeholders
- Development of DRAFT project authorization request (PAR)

?? New working group kickoff > 1 year from now??

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

Thank You

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NREL/PR-5D00-81028

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