Workshop on: Applying IEEE Standard 1547-2018

Tom Key and Aminul Huque, EPRI, Michael Ropp, NPPT and Jesse Leonard, Clemson University
Members of 1547 Working Group

PV Systems Symposium
Albuquerque, NM
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Some materials provided by NREL:
***Dave Narang**, 1547 Chairman*
***Andy Hoke**, 1547.1 Chairman*

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Getting Connected and Grid Integration with IEEE 1547-2018

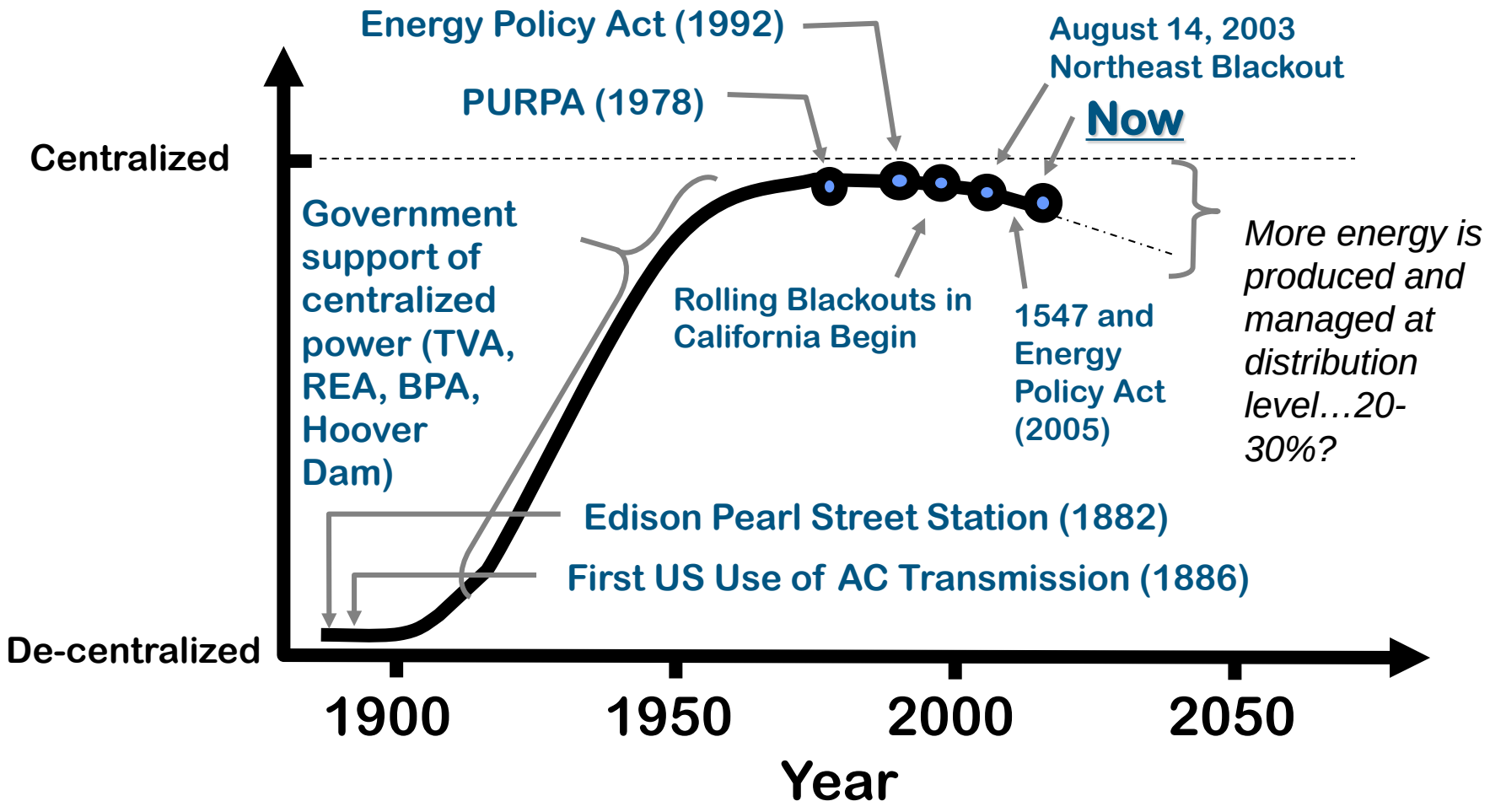
- **Introductions / Objectives - All**
- **Overview** – Tom Key
  - Discussion on Scope and Application
- **Smart Inverters, Support Requirements** – Aminul Huque (P and Q, voltage and frequency ride thru)
  - Discussion on Applications and Settings
- **Islanding and Protection** – Michael Ropp
- **Certification 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



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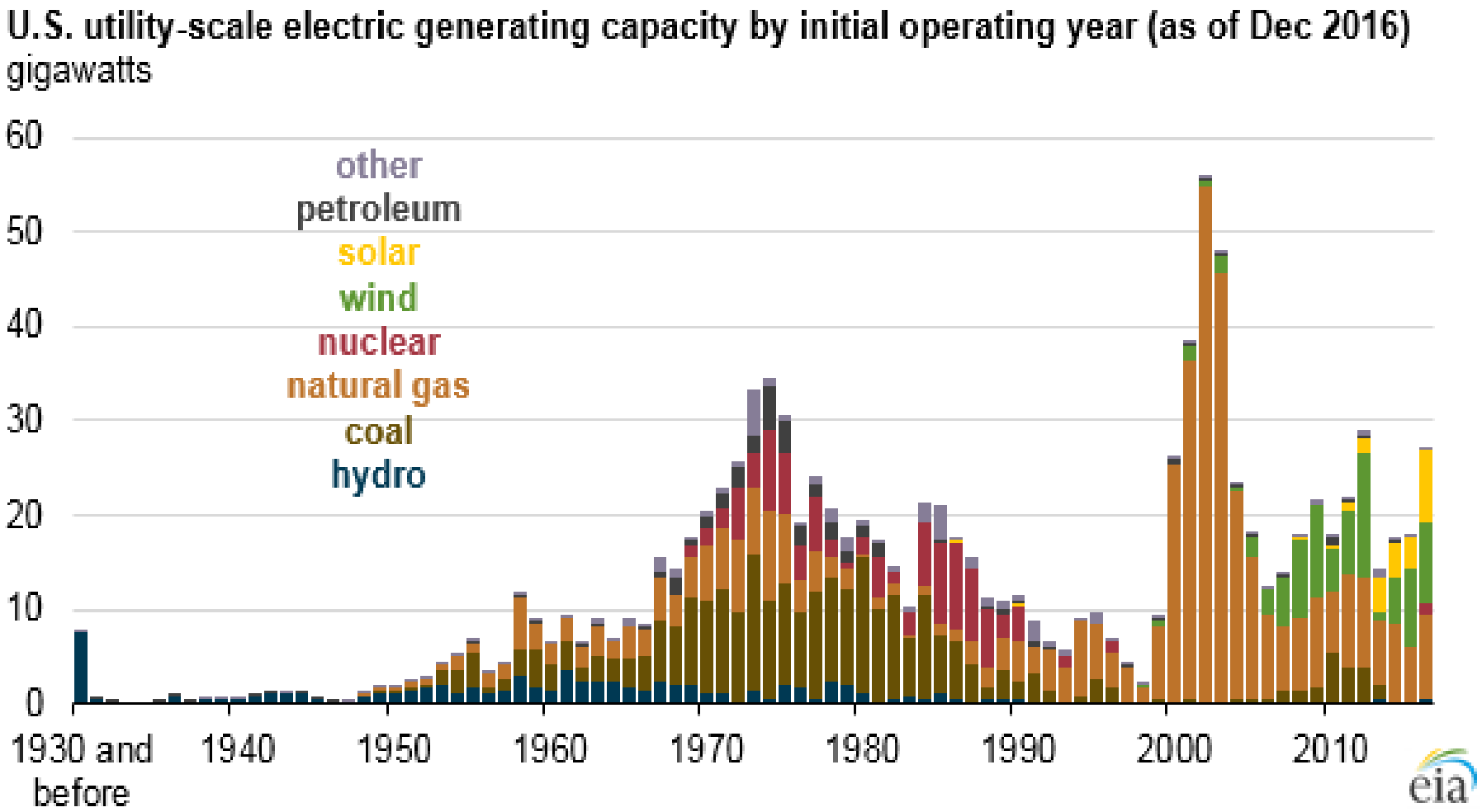
U.S. Generation Capacity Deployment (GW) up to now.



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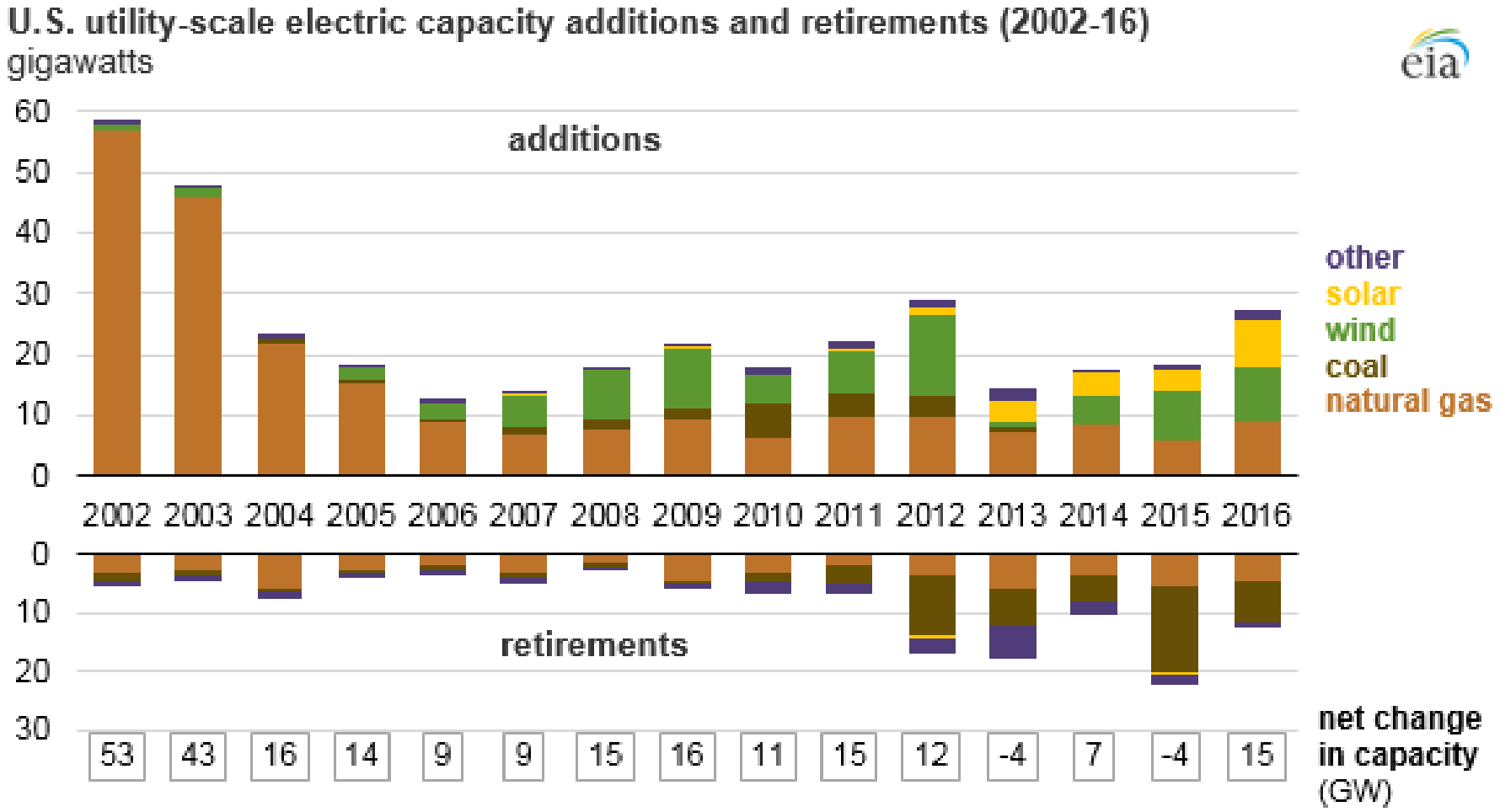
Changing Color of US Generation (GW) 2002-2016



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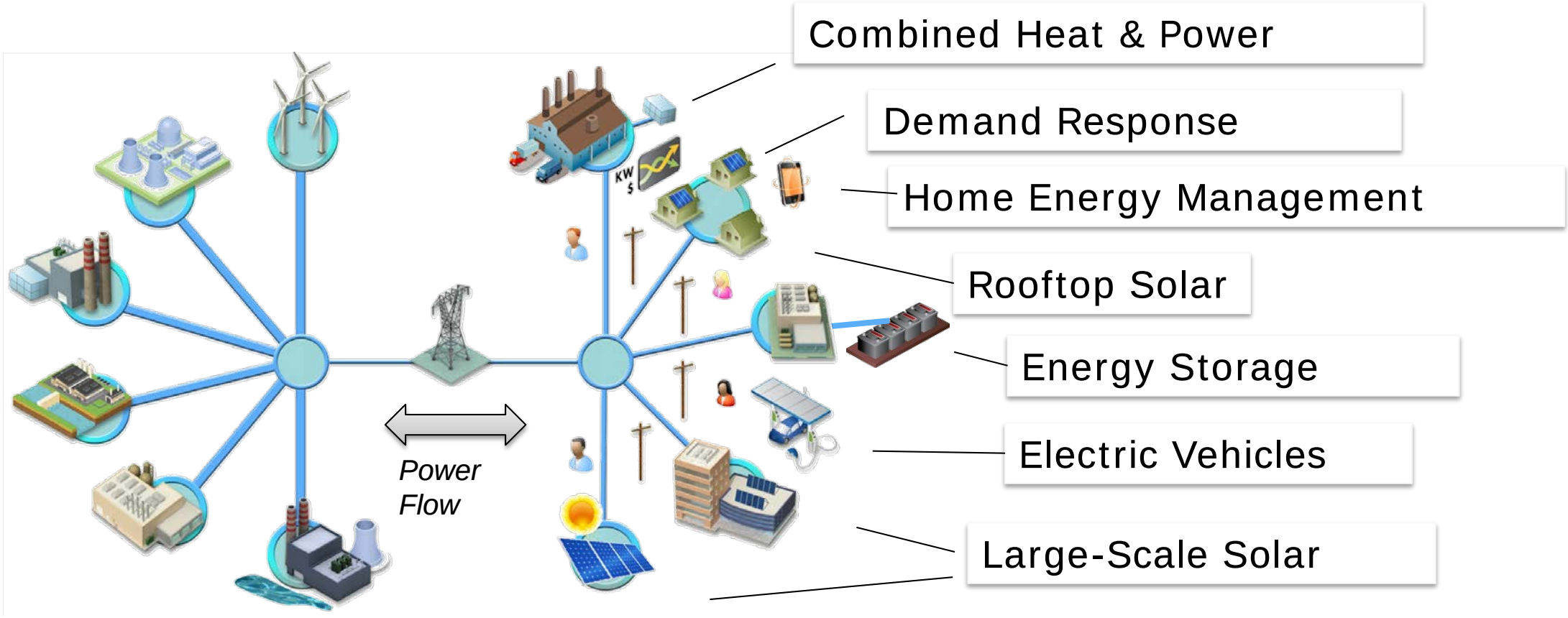
Distributed Energy Resources (DER) are Changing the Electric Grid



For more information on-line at: ***EPRI, The Integrated Grid***

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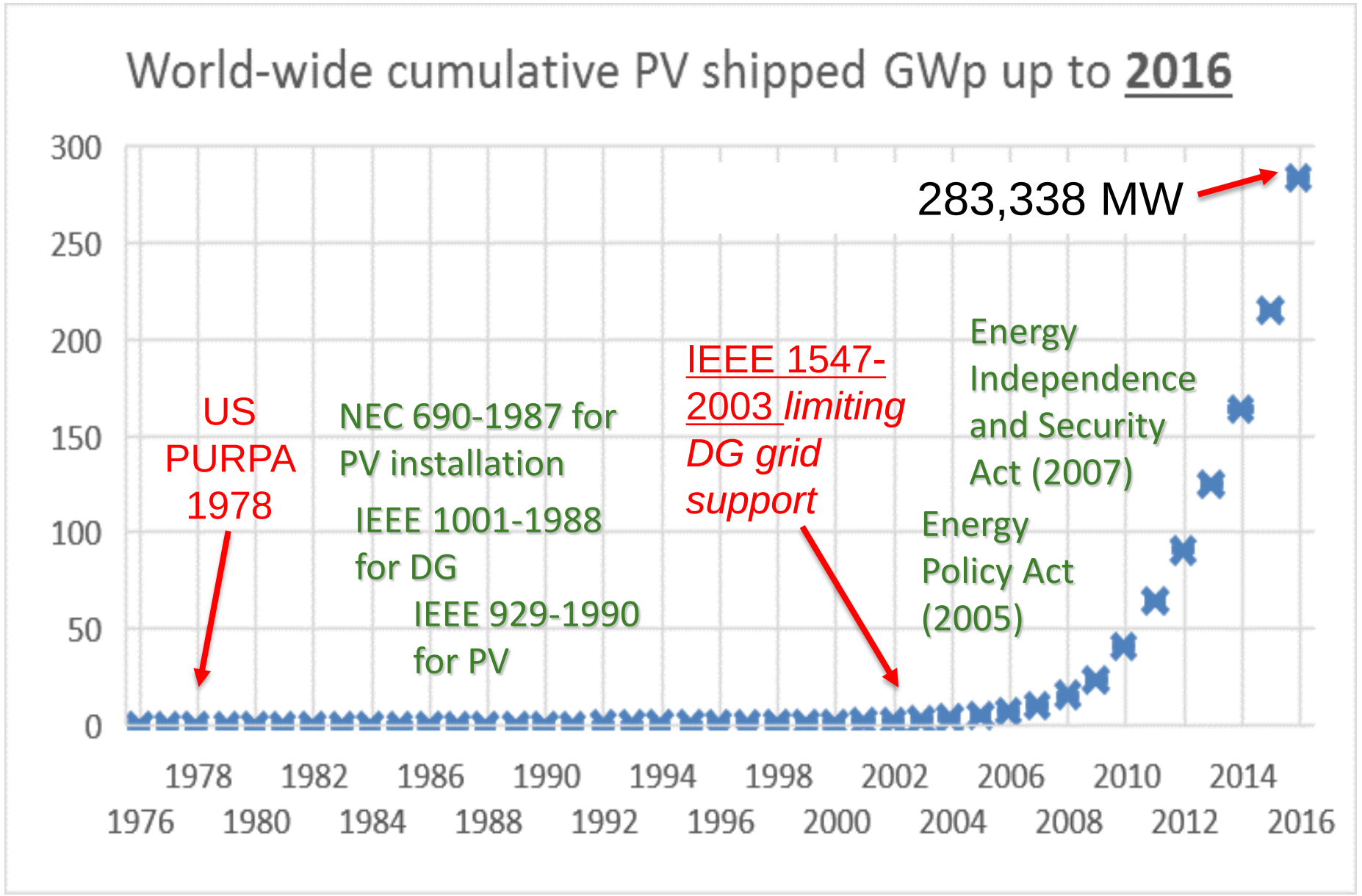

*Average sales price and shipments data source: P. Mints, SPV Market Research, www.spvmarketresearch.com

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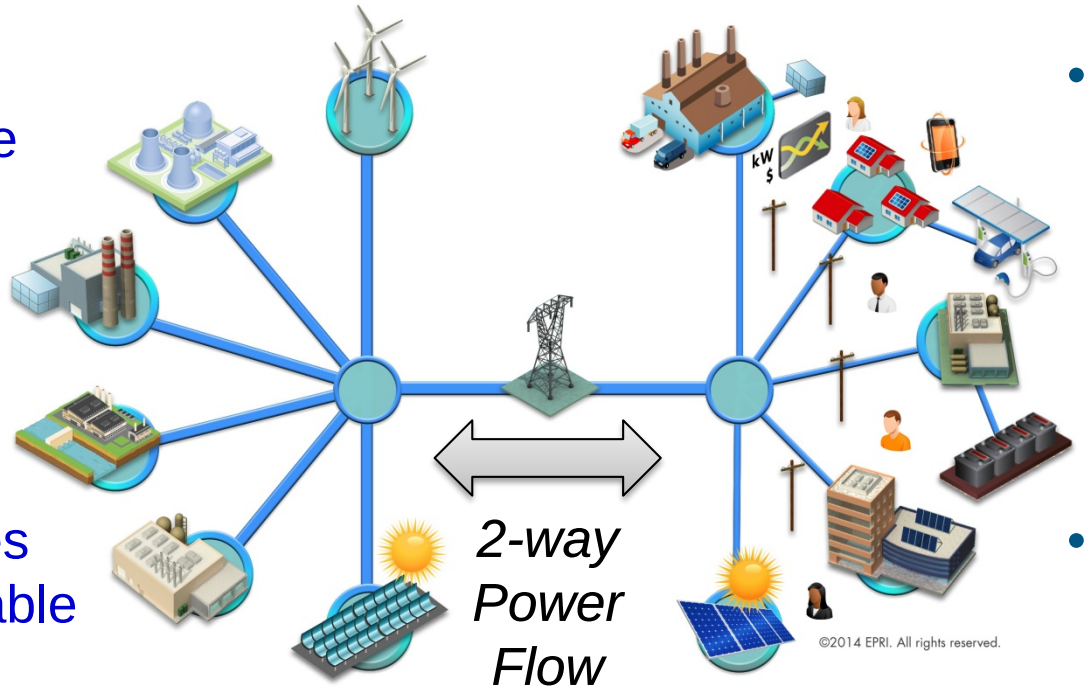
Operating the Grid – *Looking Forward*

More *Use of* Distributed Energy Resources (DER)

- Generation Becomes More Flexible
- T & D Becomes More Controllable and Resilient



- Consumers Become Energy Producers
- Loads Become More Interactive and Dynamic

A More *Dynamic* End-to-End Power System

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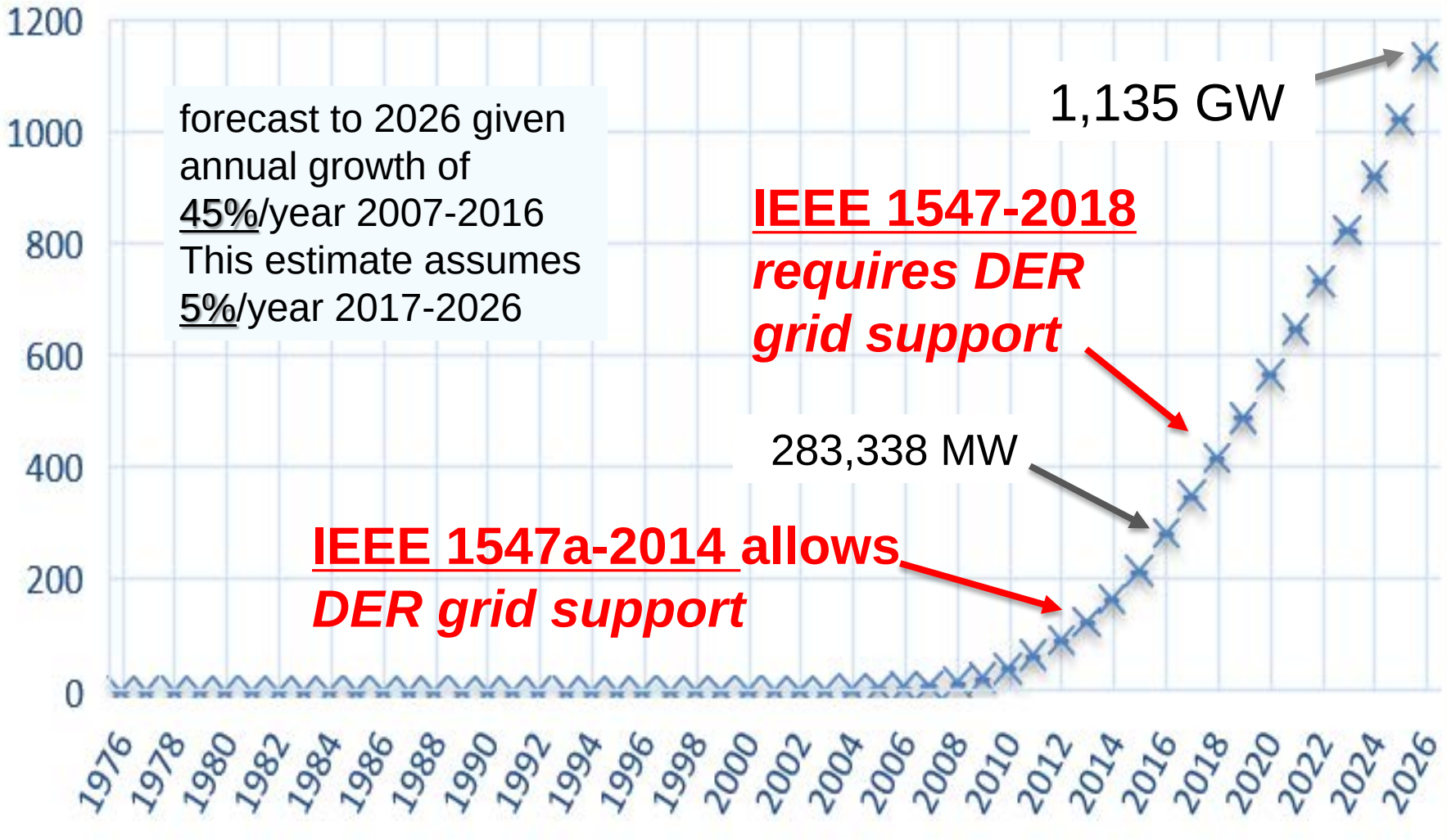
World-wide cumulative PV shipped GWp up to **2026**



Average sales price and shipments data source: P. Mints, SPV Market Research, www.spvmarketresearch.com

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Major Changes in 1547 Amendment

IEEE 1547 – 2003	IEEE 1547a - 2014
DR shall not actively regulate the voltage at the PCC	DR may actively participate to regulate the voltage by changes of real and reactive power
DR shall cease to energize if frequency >60.5Hz	DR shall be permitted to provide modulated power output as a function of frequency
Tighter abnormal V/F trip limits and clearance times	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.

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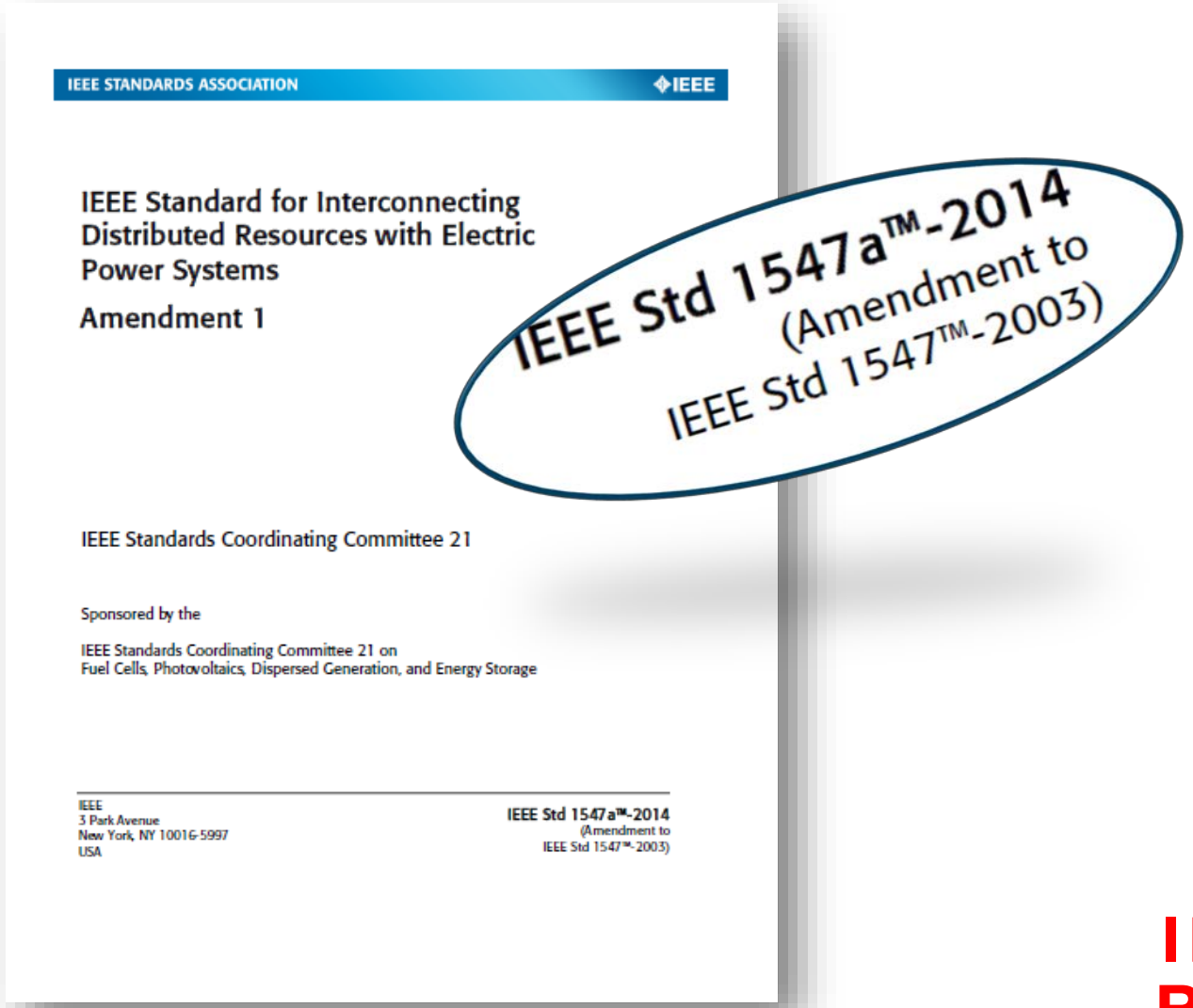
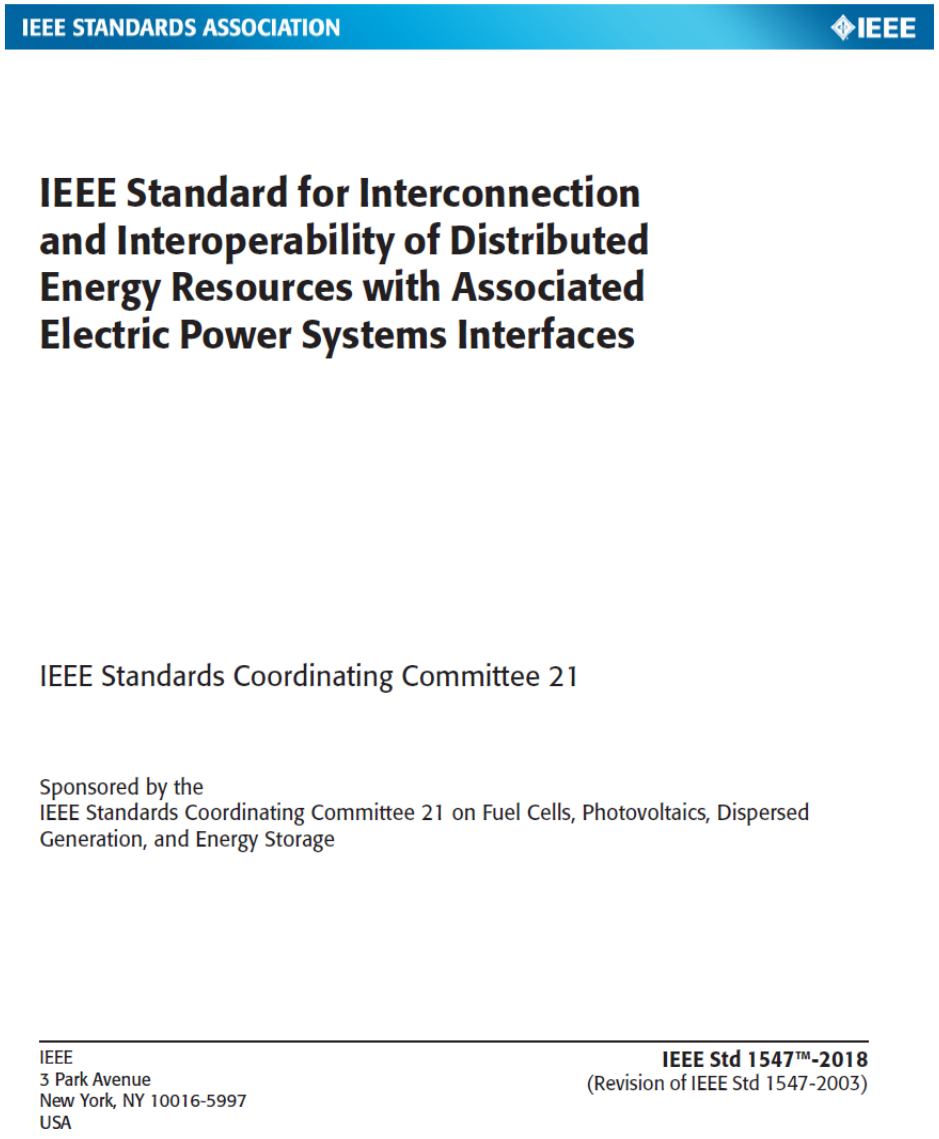
IEEE 1547aTM - 2014 allowed Grid Support Functions





IEEE 1547-2018 Requires Grid Support

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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)

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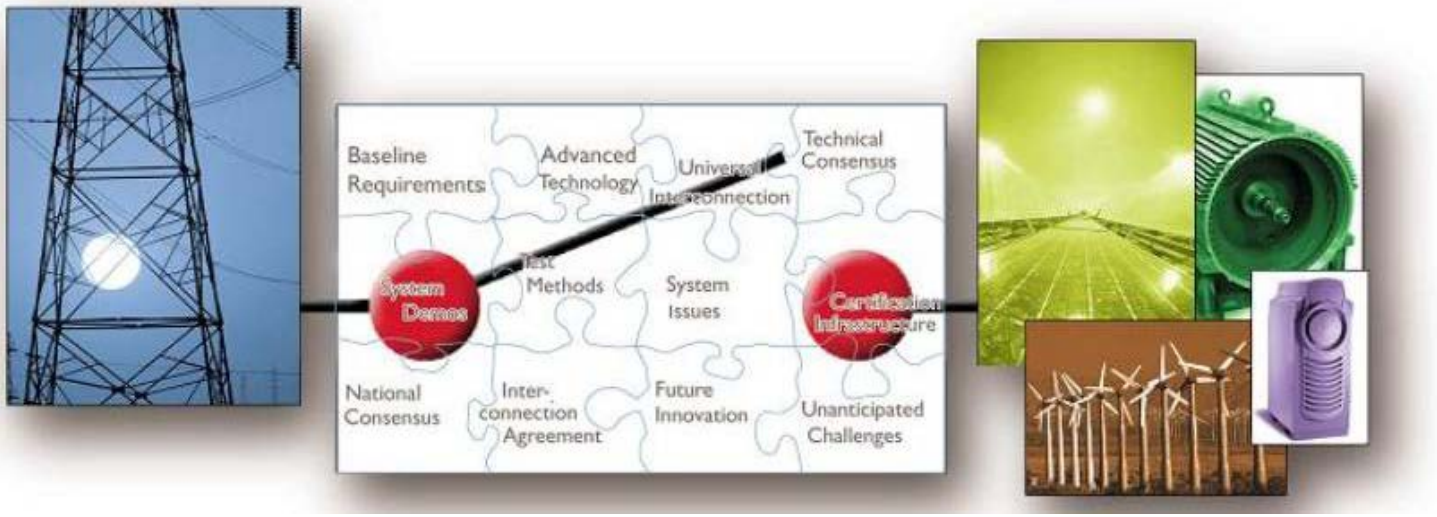
Connecting to and integrating with the grid

"**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.**



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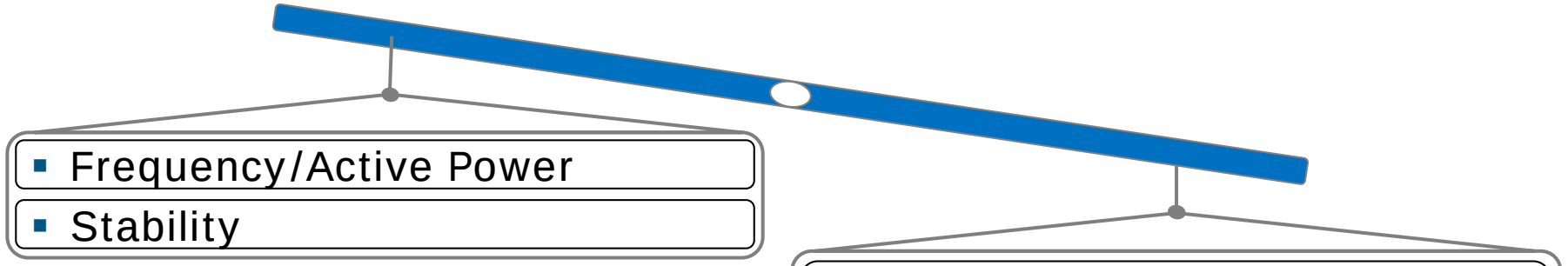
Balancing Distribution and Grid Operator Needs

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.***

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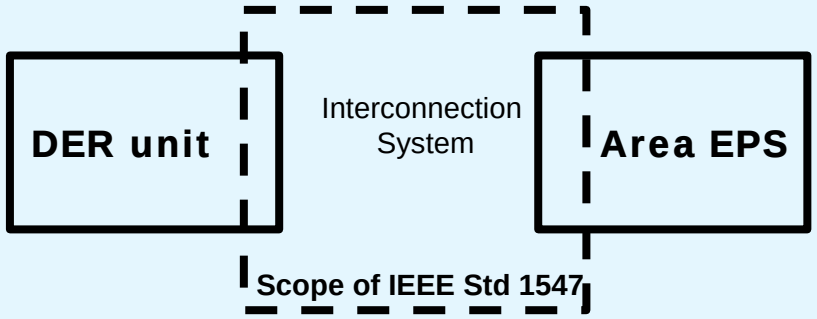
1.4 General remarks and limitations

- 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.

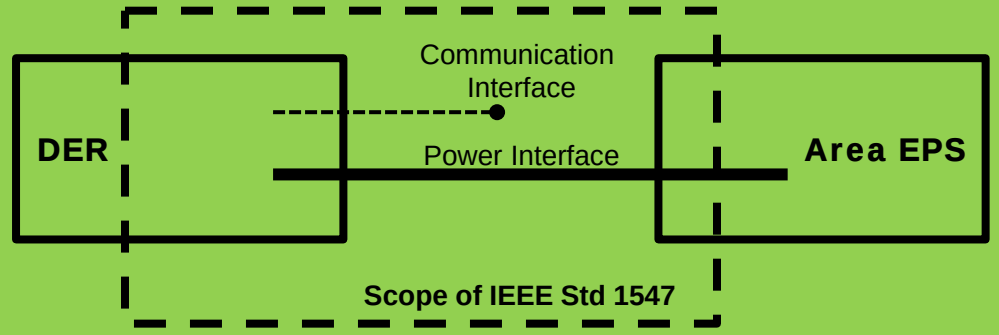
New Requirements

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.

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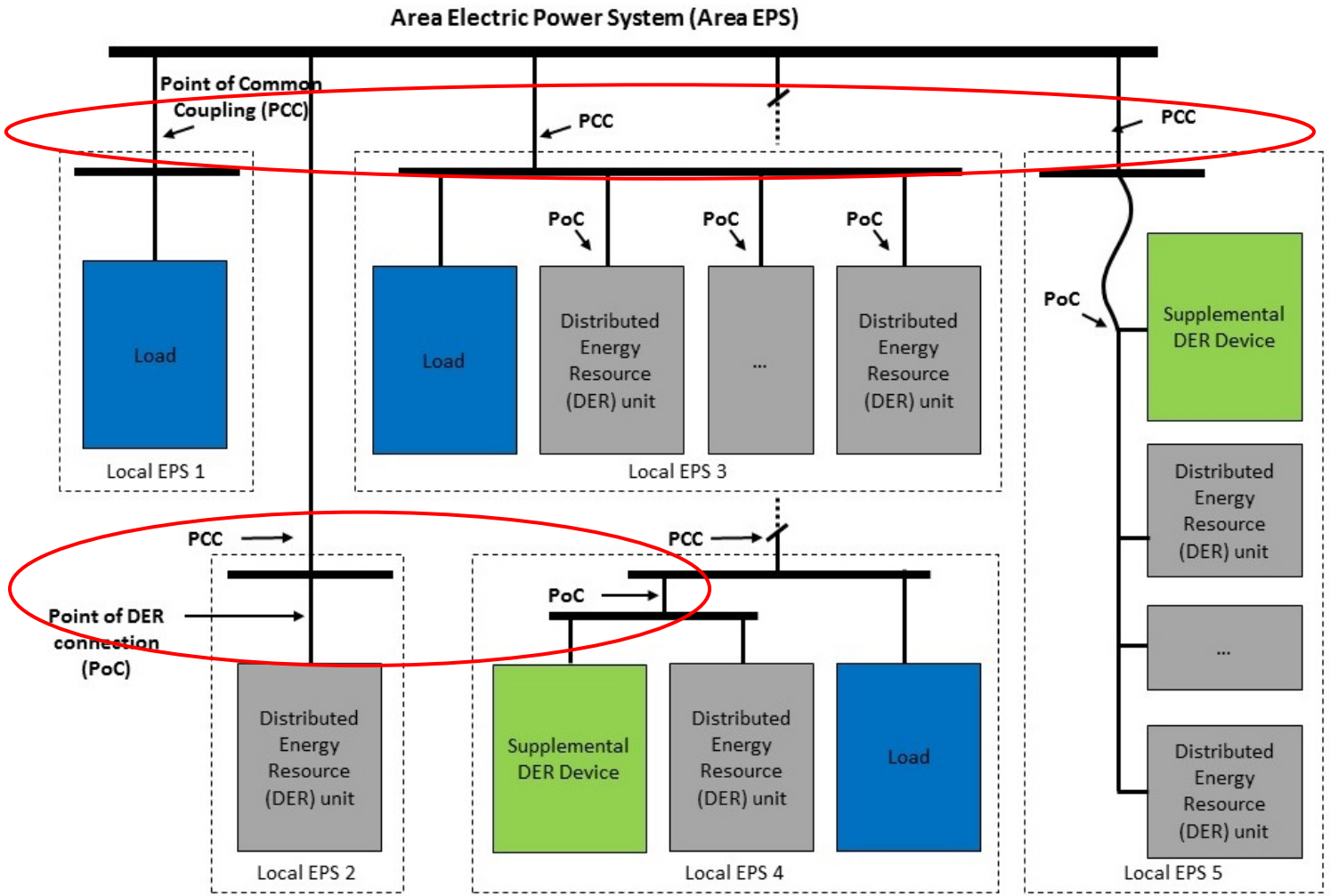
Reference Point of Applicability and Related Normative Definitions



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

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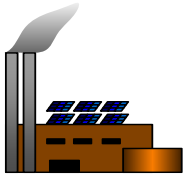
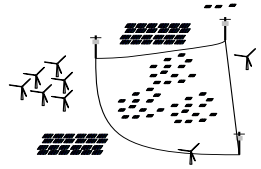
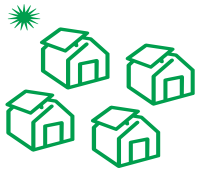
Decision Tree for Reference Point of Applicability

(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: dedicated generation facility

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

Yes: insignificant generation embedded in customer

No: significant generation embedded in customer

Clause 5.2 & Clause 7 met?

No

Yes

Discount influence of Local EPS load

Point of DER Connection, **PoC** (DER terminals)

Point of Common Coupling, **PCC**

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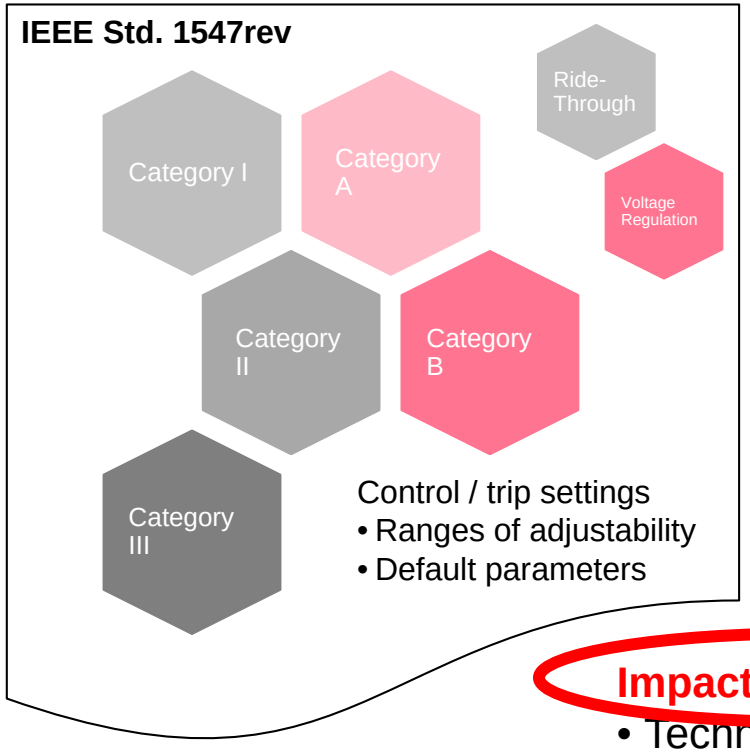
Sections 5 and 6 - Proposed New Requirements

Draft IEEE P1547 Performance Category Approach

DER Vendors

Market Analysis

- Costs
- Market segment
- Etc.



Authorities Governing Interconnection Requirements (AGIR)[1]

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.

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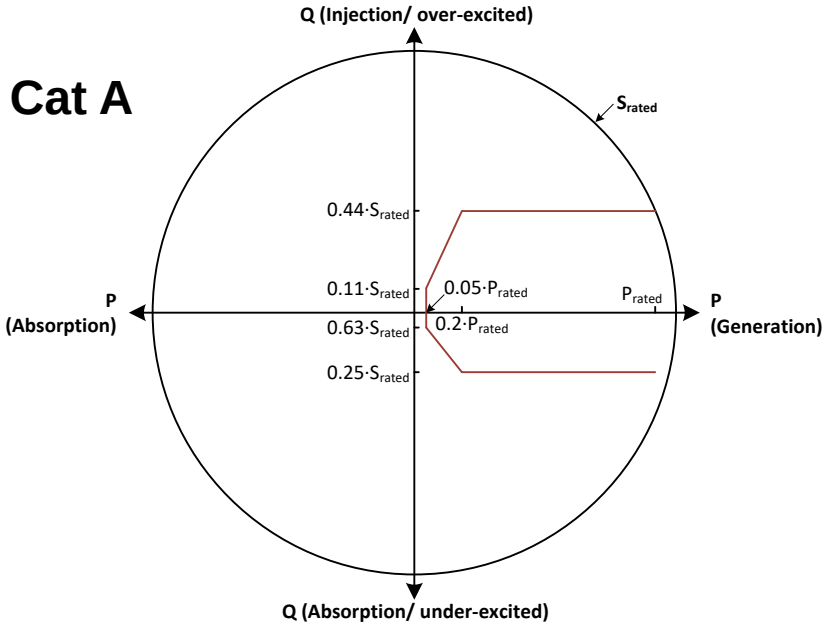
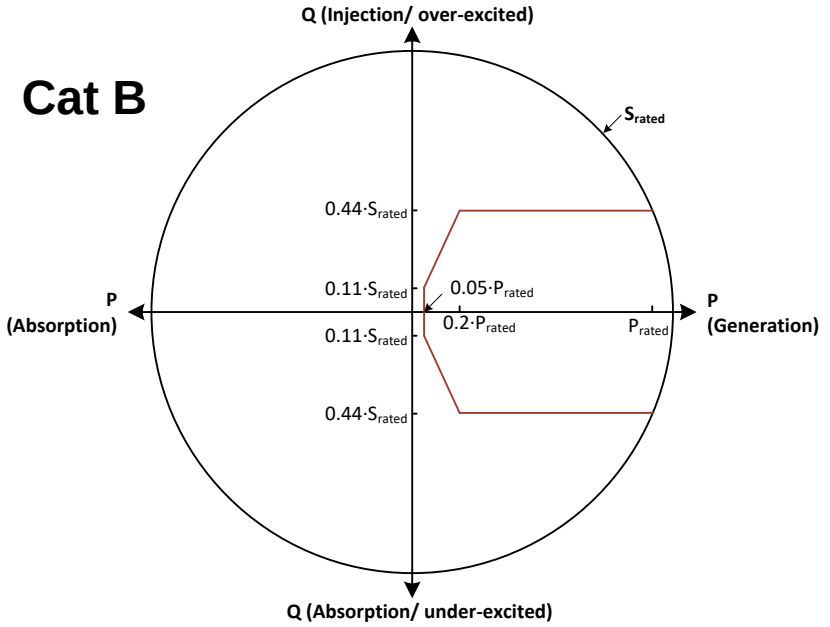
Required Reactive Power Capability of the DER





Minimum Reactive Power Injection and Absorption Capability

Category	Injection Capability as % of Nameplate Apparent Power (kVA) Rating	Absorption Capability as % of Nameplate Apparent Power (kVA) Rating
A (at DER rated voltage)	44	25
B (over the full extent of ANSI C84.1 range A)	44	44

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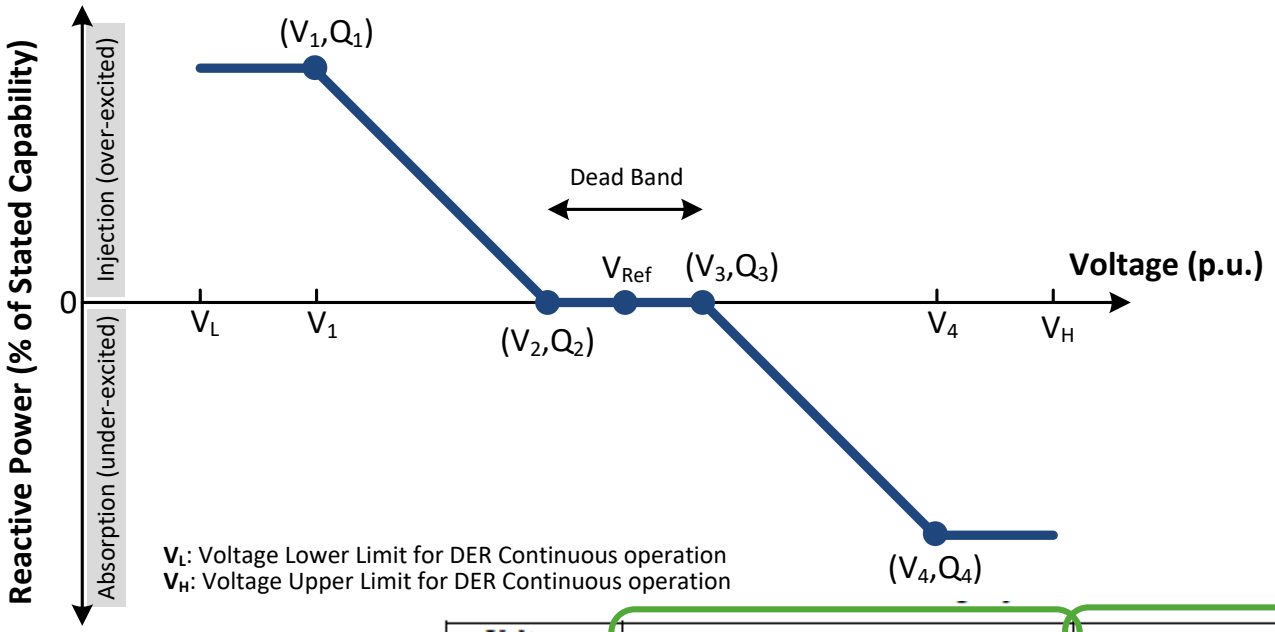
Voltage – Reactive Power (Volt-var) Mode



V_L: Voltage Lower Limit for DER Continuous operation
V_H: Voltage Upper Limit for DER Continuous operation

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

Voltage-reactive power parameters	Default settings		Ranges of allowable settings	
	Category A	Category B	Minimum	Maximum
V_{Ref}	V_N	V_N	0.95 V_N	1.05 V_N
V_2	V_N	$V_{Ref} - 0.02\ V_N$	Category A: V_{ref} Category B: $V_{Ref} - 0.03\ V_N$	V_{Ref} [c]
Q_2	0	0	100% of nameplate reactive power capability, absorption	100% of nameplate reactive power capability, injection
V_3	V_N	$V_{Ref} + 0.02\ V_N$	V_{Ref} [c]	Category A: V_{ref} Category B: $V_{Ref} + 0.03\ V_N$

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Section 6 - Basis of Abnormal Grid Performance - Ride-Through

Requirement	Category	Foundation	Justification
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_{nom} ➢ based on EPRI White Paper (May 2015)	• *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 ➢ based on EPRI White Paper (May 2015)	• All bulk system needs. • Low inertia grids.

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Section 7 Power Quality Requirements

PQ Section	1547 2003	1547 2017 PQ[1]
DC injection Limit	.5% current	No change
Synchronization	±5% ΔV at PCC	Table for Δf, ΔV, ΔΦ[2]
RVC	None	New ΔV MV-3%, LV-5%
Flicker	Shall not cause	New Pst < .35, Plt < .25
Harmonic Current	<5% TDD	<5% TRD, Relaxed Evens[3]
Harmonic Voltage	None	None
OV Temporary	No disturbing GFO	New to 138% $V_{l\text{-}g \text{ or } l\text{-}l}$[4]
OV "Cumulative Instantaneous"	None	New 2pu@1.5ms and 1.4pu@16ms

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

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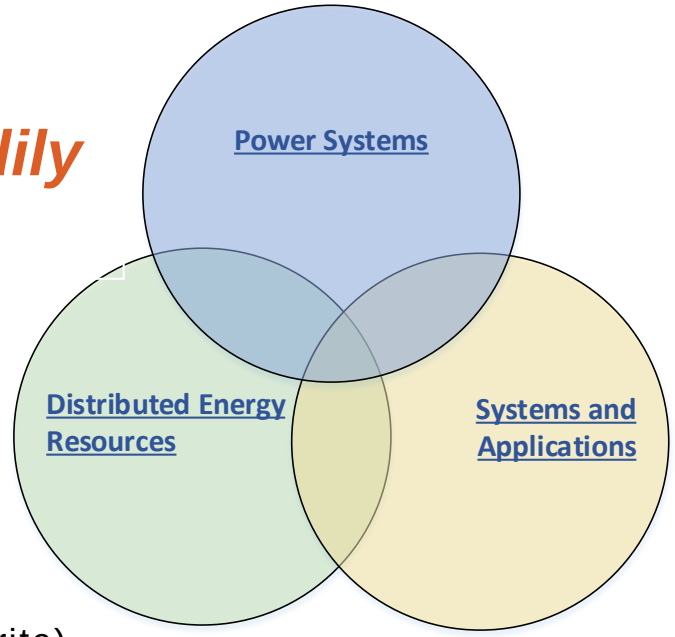
Interoperability Requirements Summary

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 (≤ 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)

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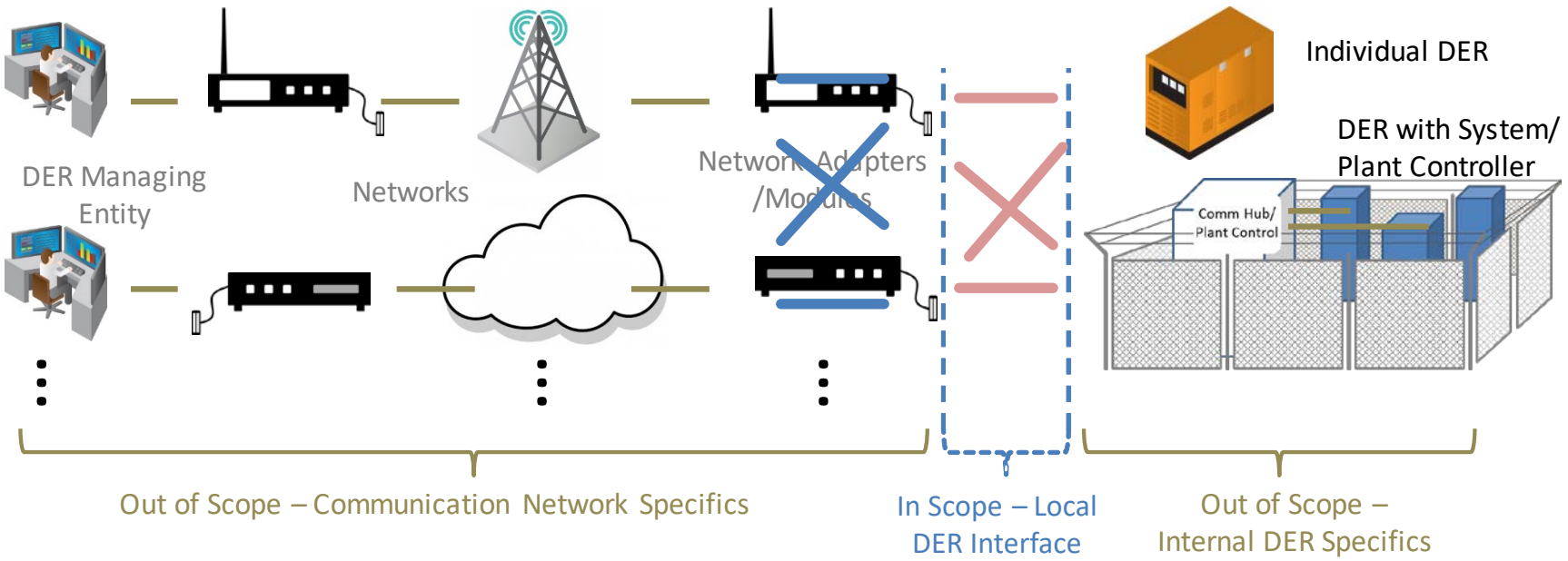
New Communications new Requirements



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

1547-approved standard protocols

Protocol	Transport	Physical Layer
IEEE 2030.5 (SEP2)	TCP/IP	Ethernet
IEEE 1815 (DNP3)	TCP/IP	Ethernet
SunSpec Modbus	TCP/IP	Ethernet
	N/A	RS-485

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IEEE 1547 Uses

IEEE 1547 is:

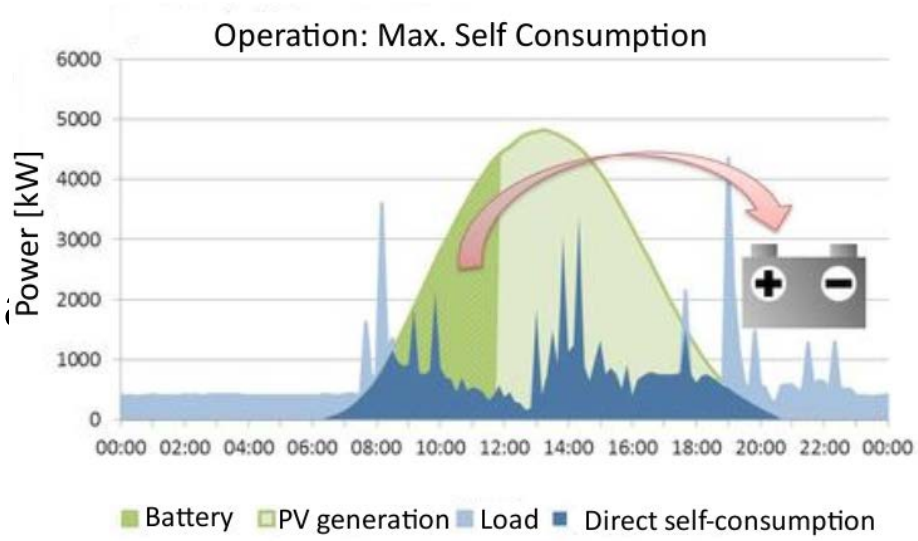
- A technical standard—functional requirements for the interconnection itself and interconnection testing
- A single (whole) document of mandatory, uniform, universal, requirements that apply at the point of common coupling (PCC) or point of DER connection (PoC)
- Technology neutral—i.e., it does not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

IEEE 1547 is not:

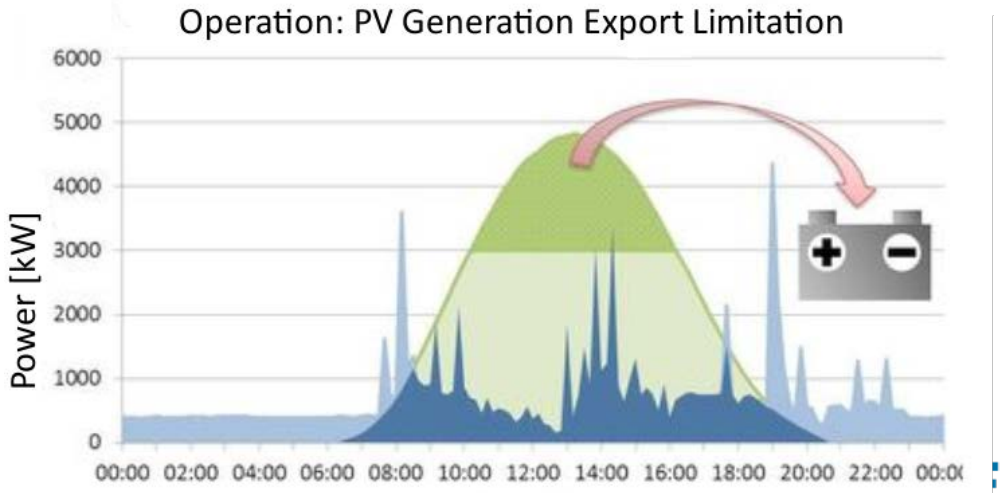
- A design handbook
- An application guide (see IEEE 1547.2)
- An interconnection agreement
- Prescriptive—i.e., it does not prescribe other important functions and requirements such as cyber-physical security, planning, designing, operating, or maintaining the area EPS with DER

Application of PV with Storage (Germany example)

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

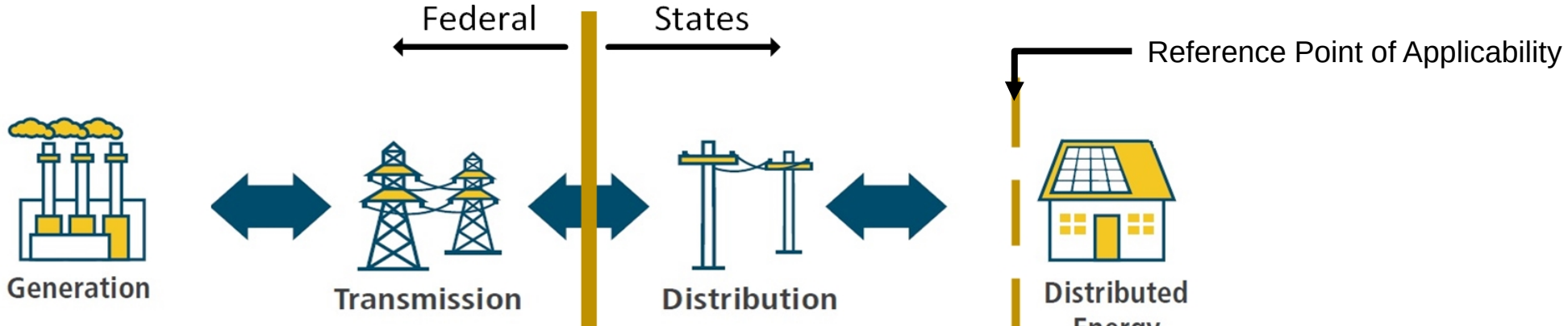


- PV-storage with ***export limit***:
  - federal incentive and advantage if peak pricing (over PV system lifetime)[1]



Source: [1] www.speichermonitoring.de

Important Terminology & Potential New Responsibilities



- Federal Energy Regulatory Commission (FERC)
- North American Electric Reliability Corporation (NERC)
- Regional Reliability Coordinator, i.e., NERC Reliability Coordinator (RTO/ISO)

- Area EPS Operator (distribution utility)
- Authority Governing Inter-connection Requirements (AGIR) (e.g., state regulator)

- Consumer / DER Developer
- DER Operator / Local EPS Operator
- 3rd party test & evaluation entities
- Authority Having Jurisdiction (AHJ) (e.g., local inspectors)

- FERC: Orders regarding Small Generating Facilities
  - — Order No. 827 (reactive power)
  - — Order No. 828 (ride-through) ➔ Transmission Providers to specify "Good Utility Practice" for SGIA
- NERC: Issues reliability guidelines for BPS-connected resources
- Regional Reliability Coordinator:
  - — May recommend technology-specific assignment of abnormal DER performance categories (ride-through)
  - — May recommend technology-specific "preferred" voltage and frequency trip settings

- Area EPS Operator:
  - — 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:
  - — 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
  - — Type testing (e.g., by NRTL)
  - — DER evaluation (e.g., by consultant)
  - — Certification, if required
- Authority Having Jurisdiction
  - — Inspects and approves the design and construction of Local EPS

IEEE 1547 / CA Rule 21 / UL 1741-SA

		Interconnection Standards			State/ PUC Rules	Listing/ Certification	
Function set	**Advanced Functions**	**IEEE 1547-2003**	**IEEE 1547a-2014**	**IEEE 1547 - 201?***	**CA Rule 21 - 2015**	**UL 1741(SA) 2016**	**IEEE 1547.1-201?***
Static	Adjustable Trip Settings		√	‡			Δ
Controlling	Power Curtailment			‡			Δ
	Ramp Rate Control				‡	Δ	
Freq. Support	L/H Frequency Ride-Through			‡	‡	Δ	Δ
	ROCOF Ride-Through			‡			Δ
	Frequency-Watt	X	√	‡		Δ	Δ
Voltage Support	L/H Voltage Ride-Through (L/H VRT)			‡	‡	Δ	Δ
	Dynamic Voltage Support during L/H VRT			√			
	Voltage Phase Angle Jump Ride-Through			‡			Δ
	Fixed Power Factor	√	√	‡	‡	Δ	Δ
	Fixed Reactive Power	√	√	‡			Δ
	Volt-Var	X	√	‡	‡	Δ	Δ
	Volt-Watt	X	√	‡		Δ	Δ
	Watt-Var	X		‡			Δ

** Final requirements not confirmed.*

Legend: X Prohibited, √ Allowed by Mutual Agreement, ‡ Capability Required, Δ Test and Verification Defined

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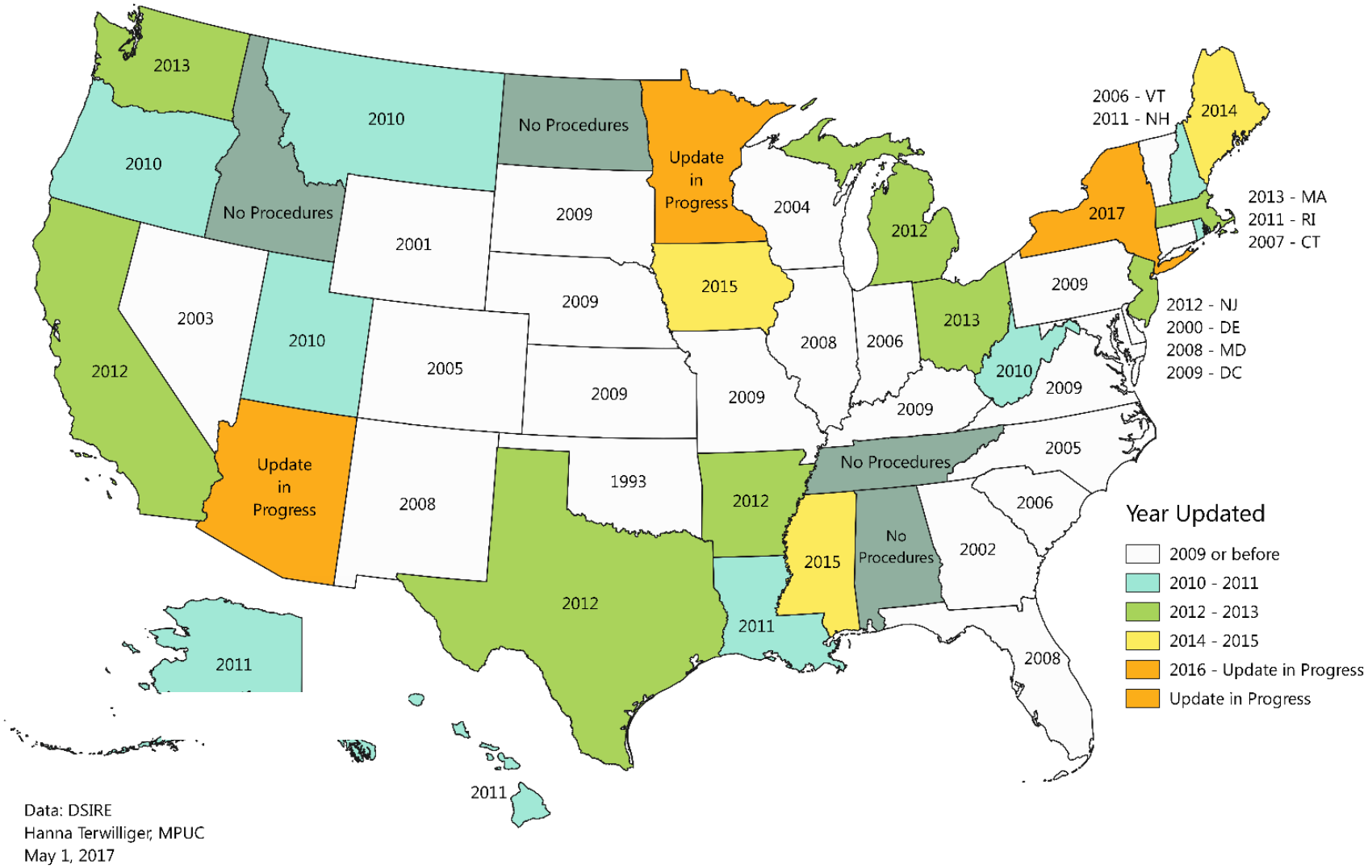
Recent Updates to State Interconnection Standards – in USA



Data: DSIRE
Hanna Terwilliger, MPUC
May 1, 2017

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Conclusions

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

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

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

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

For More Information

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

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

Contact Info:
Tom Key, tkey@epri.com

Thank You

New Requirements

Islanding

Islanding definitions in IEEE 1547-2018

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.

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Islanding definitions in IEEE 1547-2018

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

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Example of Island System

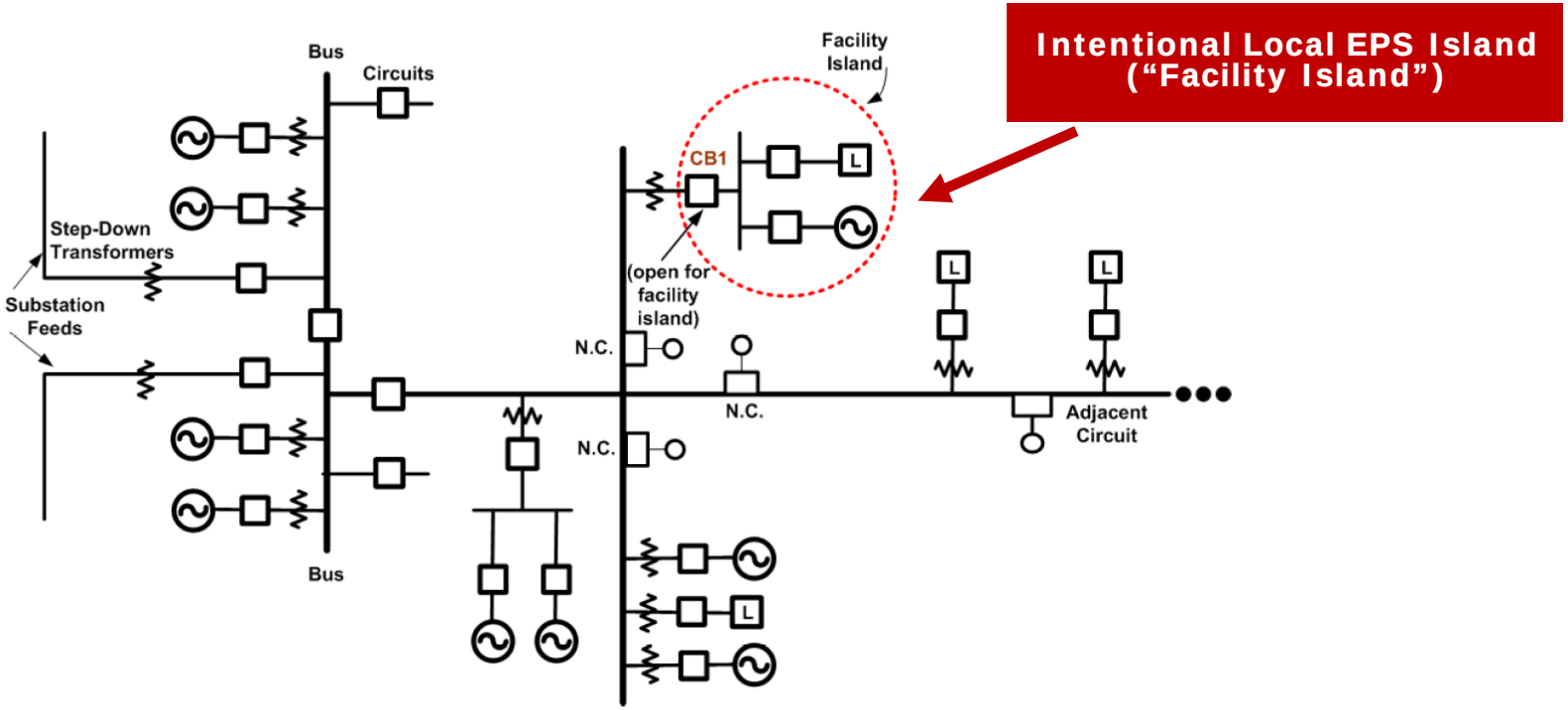

Figure 2—Local EPS island (facility island)

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)

Image source: IEEE Std 1547.4-2011

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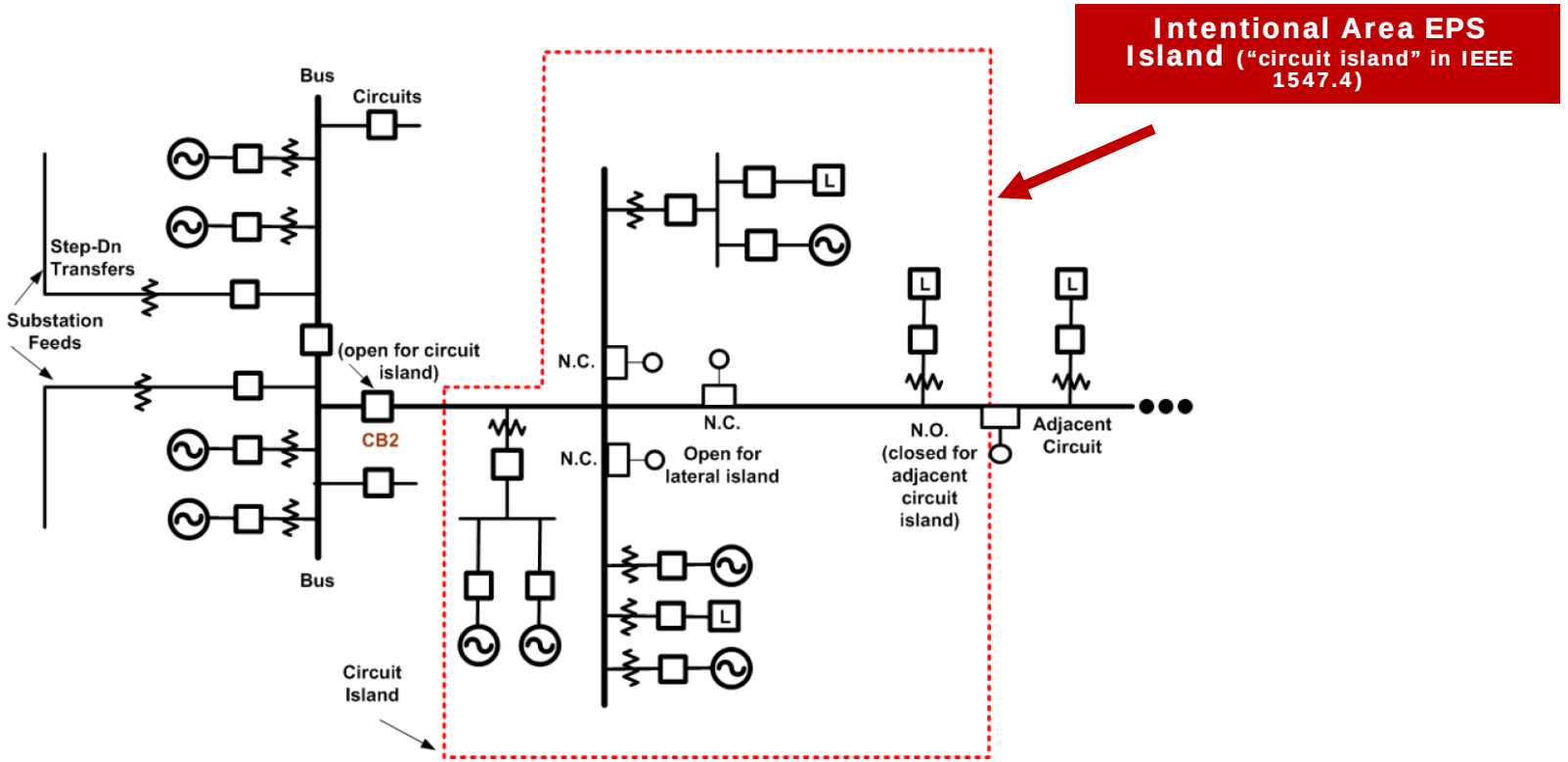
Example of Island System



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

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DER categories for intentional islands in IEEE 1547-2018

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).

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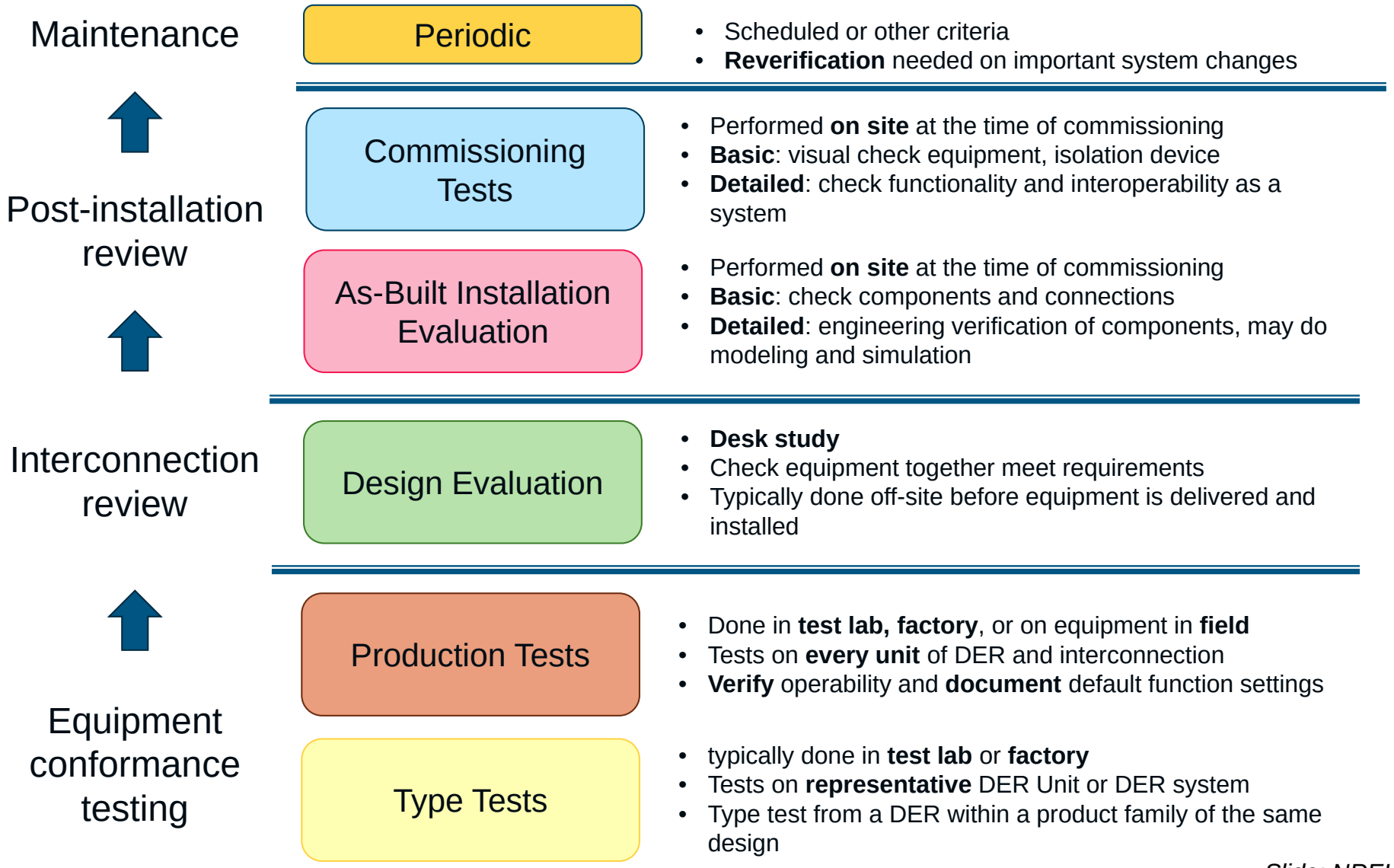
Revised Requirements

Test and Verification

High-Level Test and Verification Process

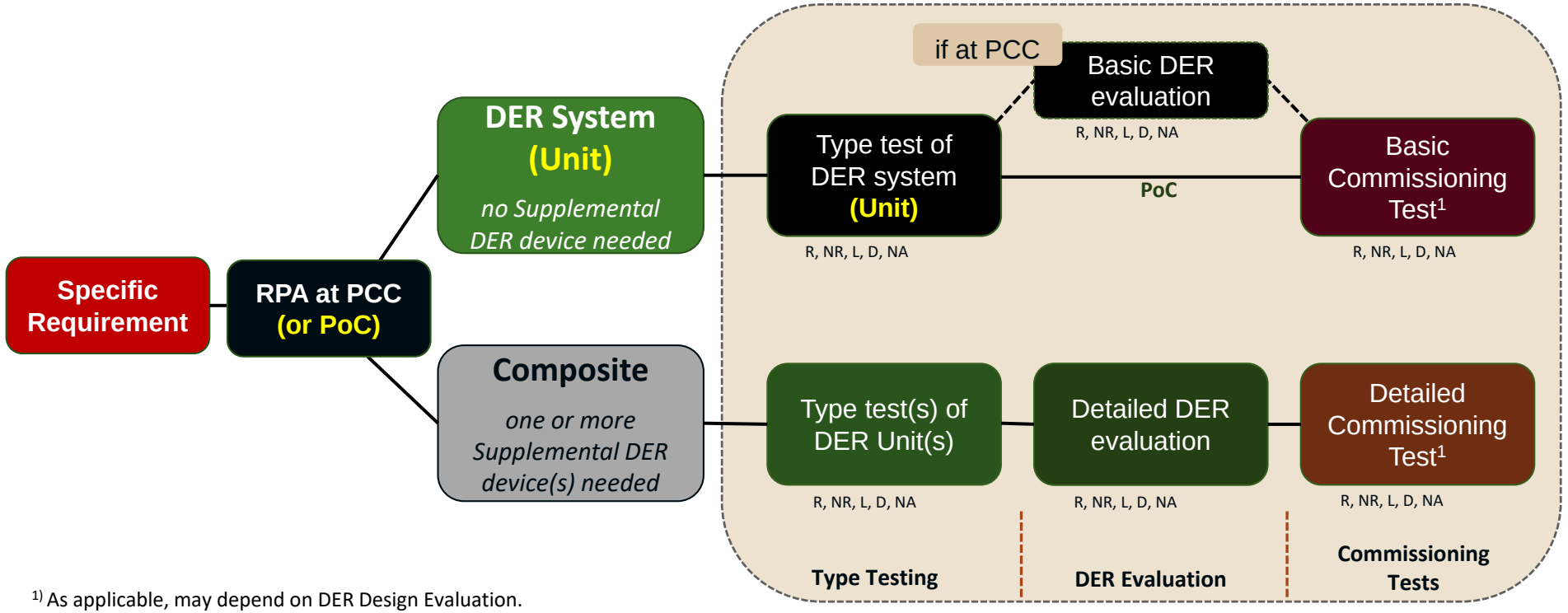


Slide: NREL

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

Slide: NREL

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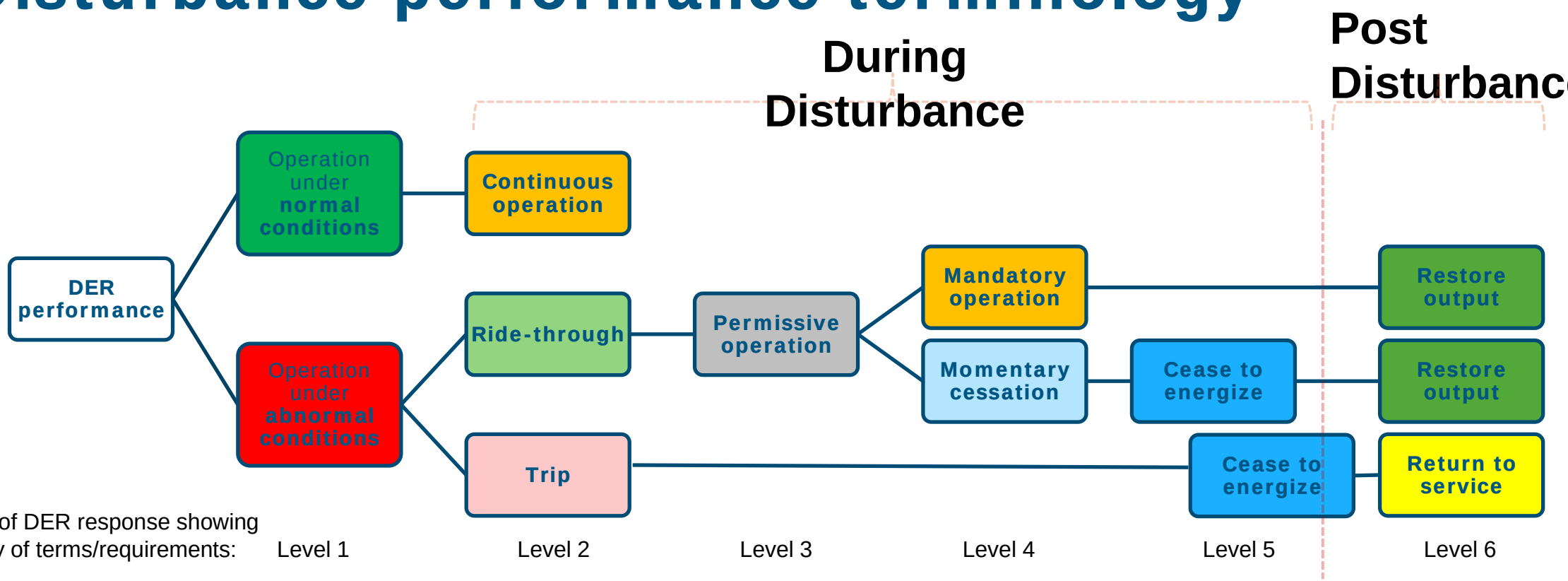
Disturbance performance terminology



"Levels" of DER response showing hierarchy of terms/requirements:

- **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

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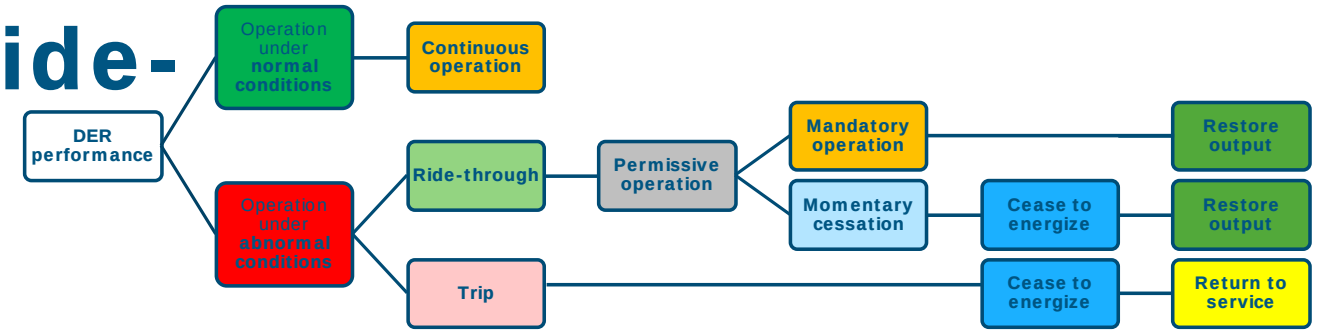
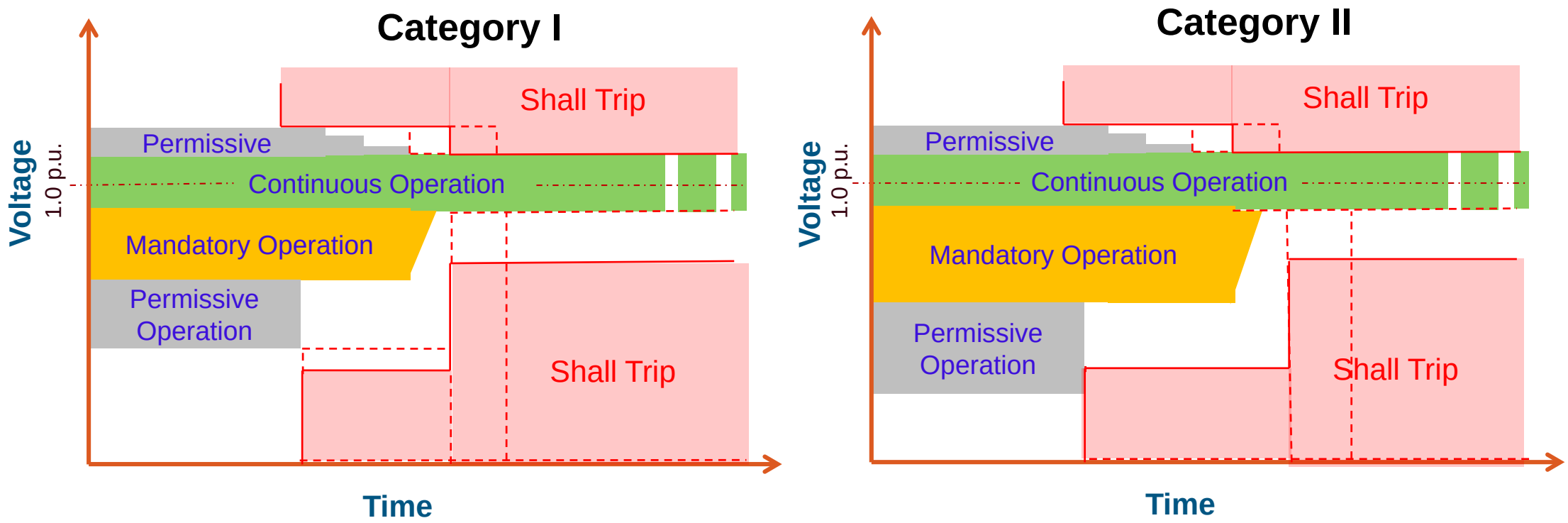
Structure of Voltage Ride-through – Cat. II





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

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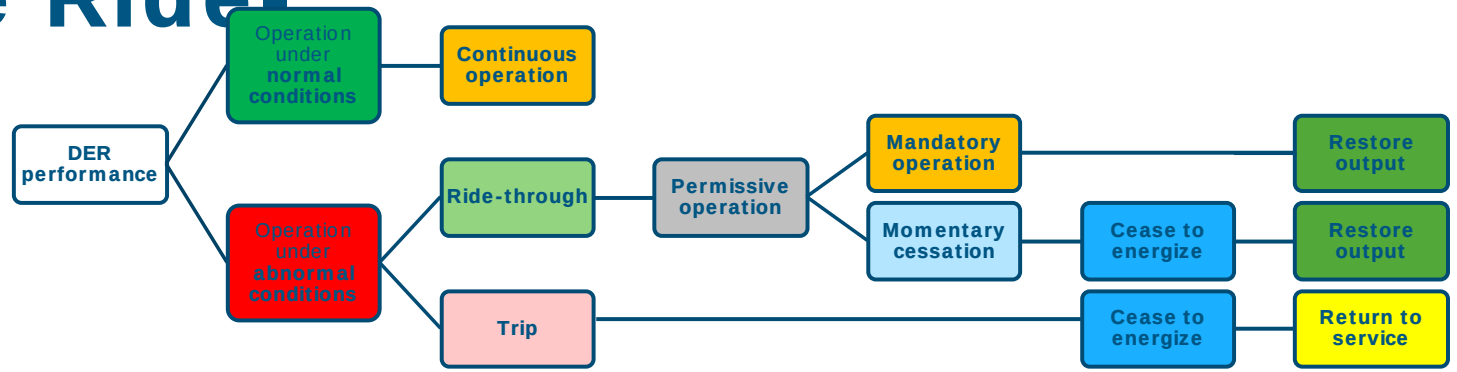
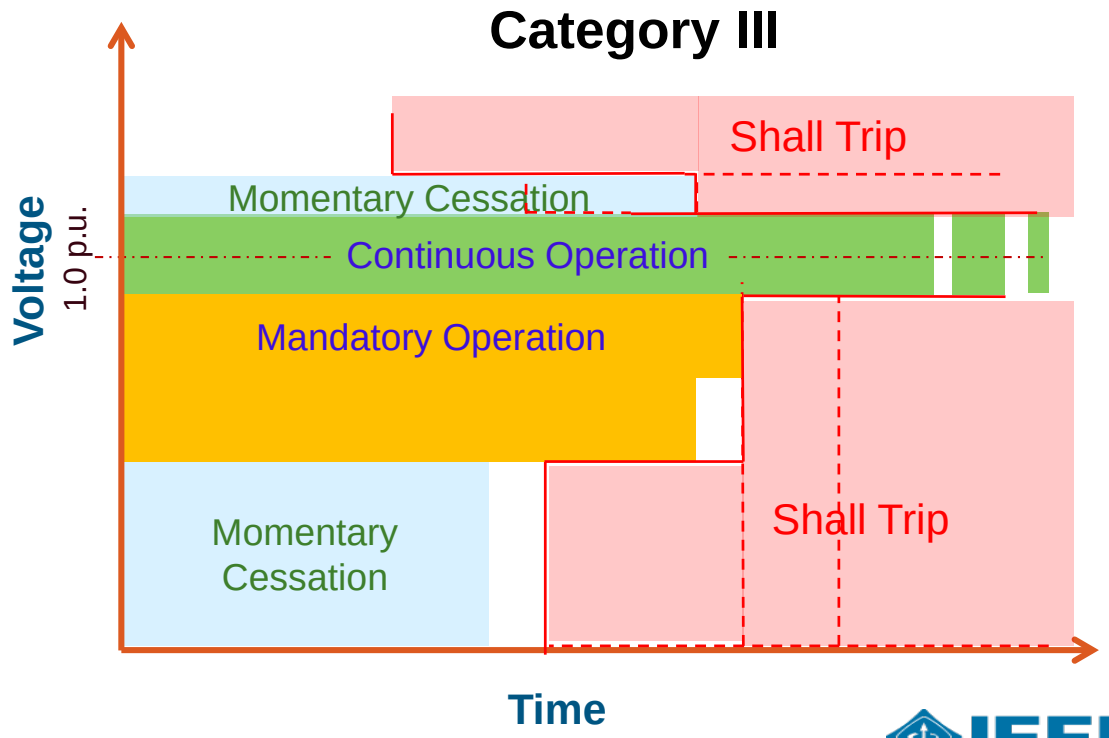
Structure of Voltage Ride-through – Cat. III



- 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



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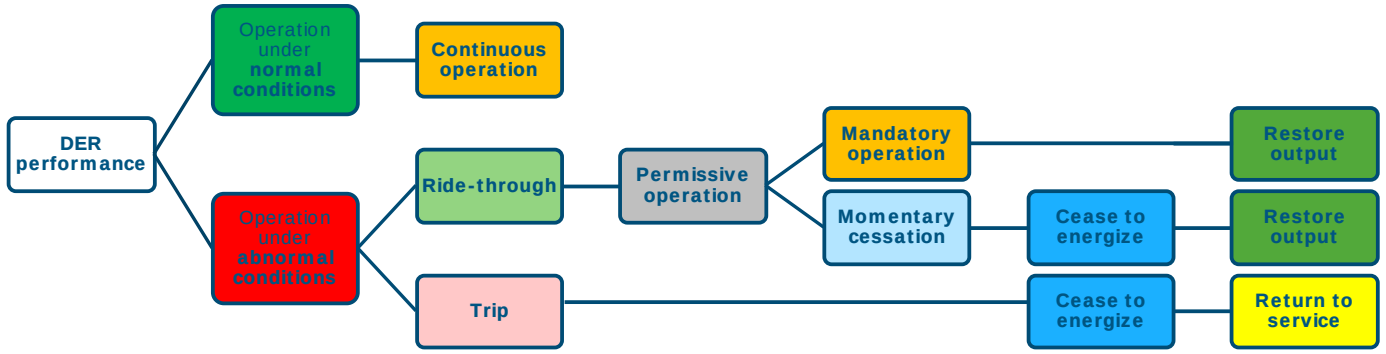
Frequency ride-through

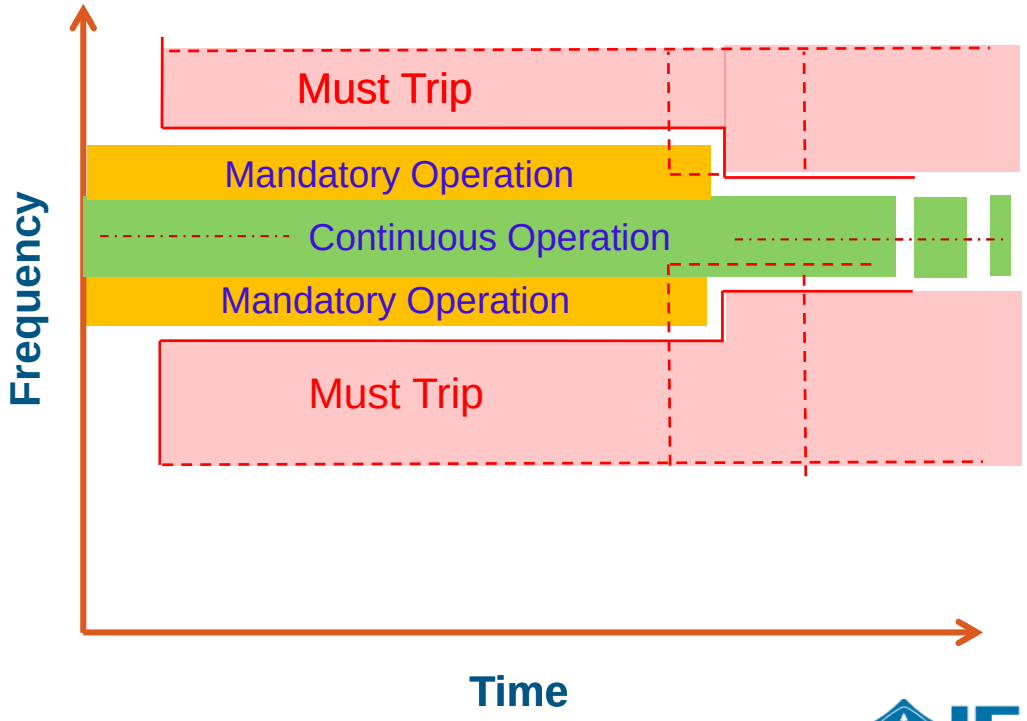


- Frequency is an interconnection-wide parameter
- Under-frequency tripping needs to be coordinated with UFLS
- IEEE P1547 allows wide range of must-trip settings to accommodate small, isolated grids
  - O/F: 61.8 – 66.0 Hz
  - U/F: 50.0 – 57.0 Hz

  } Short duration 0.16 – 1.0 s

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

  } Long duration 180 – 1000 s



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