DER Ride-Through Performance Categories and Trip Settings

Presentation at PJM Ride-Through Workshop, Philadelphia, PA, October 1-2, 2018

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"Navigating DER Interconnection Standards and Practices" Supplemental Project (SPN 3002012048)

Please visit the following link to participate in the quiz for this training module:

https://www.surveymonkey.com/r/epri-nav-partI-training02

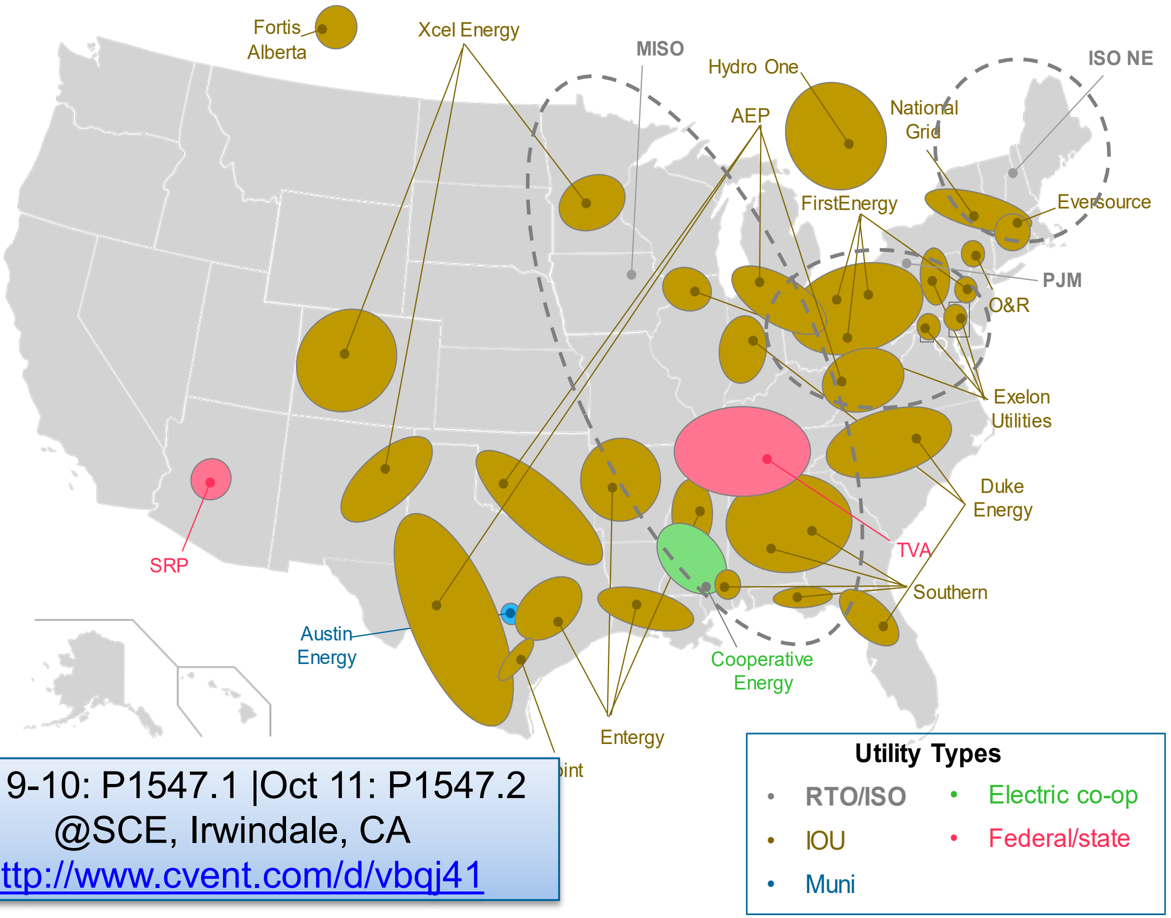
Navigating DER Interconnection Standards and Practices

EPRI Supplemental Project Background

- Need for development of a DER interconnection standards adoption roadmap
  - Getting ahead of DER deployment
- Need for education and knowledge transfer
  - Distribution and transmission owners/planners
  - State regulators, policy makers, others
- Collaborative learning opportunities in
  - EPRI project "Navigating DER Interconnection Standards & Practices" (near-term, EPRI members only)
  - IEEE P1547.2 (Application Guide for IEEE 1547) (mid-term, public stakeholders)

Oct 9-10: P1547.1 |Oct 11: P1547.2
@SCE, Irwindale, CA
http://www.cvent.com/d/vbqj41

Utilities interested in the application of IEEE Std 1547-2018 in the short- or near-term



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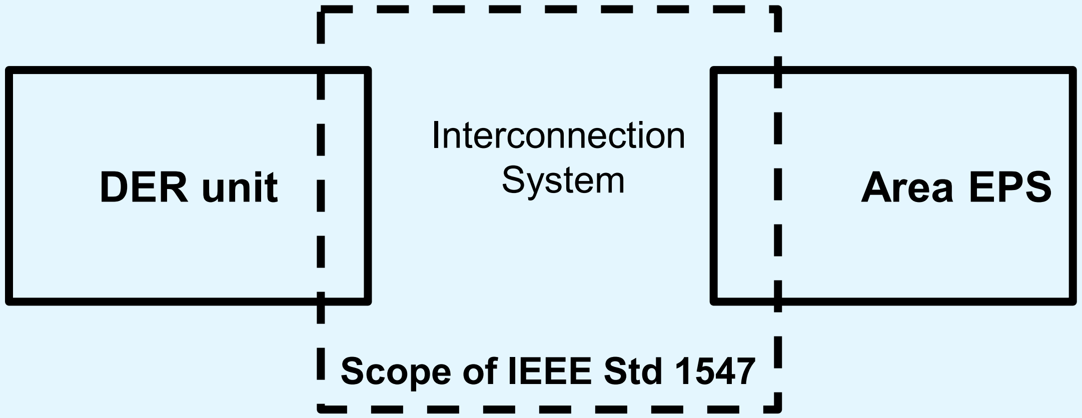
Disclaimer & Acknowledgements

- *This presentation and discussion here on IEEE Std 1547-2018 are EPRI's views and are not the formal position, explanation or position of the IEEE.*

- *We would like to thank our EPRI members for their continued support of our engagement in the revision and application of IEEE Std 1547. We also thank the IEEE Standard Coordination Committee 21 (SCC21) and IEEE P1547 Leadership for their contributions to this educational outreach.*

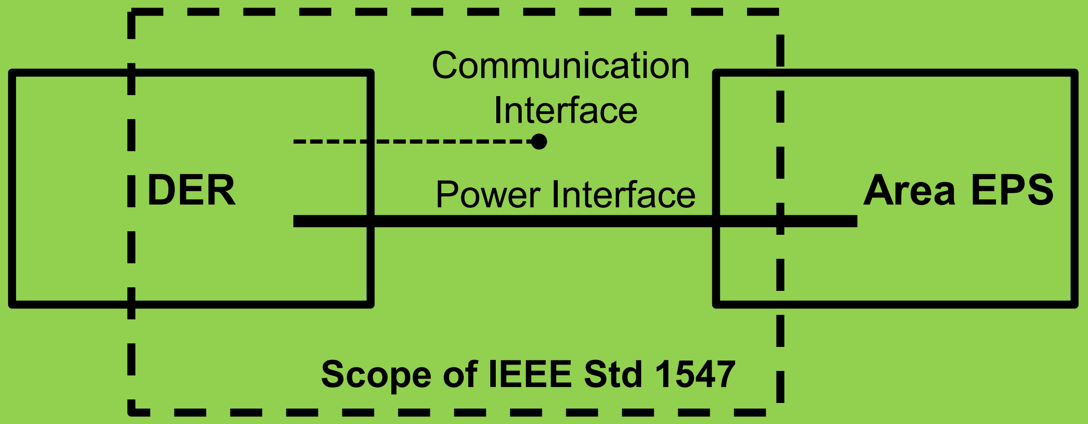
- *As an independent, nonprofit organization for public interest energy and environmental research, EPRI does not endorse any standards or gives any regulatory advice. Any statements in this presentation that could be construed otherwise are by mistake and not intended by the presenter.*

Important changes between 2003 and 2018



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.
- *Shall trip* and *shall not* regulate voltage



IEEE Std 1547-2018

- Focused on distribution and bulk system aspects.
- Specifications encompass the whole DER.
- Can be used for equipment listing as well as plant-level verification.
- Includes both electrical as well as interoperability/communications requirements.
- *Shall be capable of* ride-through and grid support

General remarks and limitations (per clause 1.4)

- Applicable to all DERs connected at typical primary or secondary distribution voltage levels
  - **Eliminated** the **10 MVA limit** from previous versions
  - But the Standard is **not applicable for transmission** or networked sub-transmission connected resources
- Specifies performance rather than the design of DERs
- Specifies capabilities and functions and not utilization of these
- Does not address planning, designing, operating, or maintaining the utility grid with DERs.
  - May be addressed in DER interconnection practices, incl. screening

General remarks and limitations (per clause 1.4)

"*The … ranges of allowable settings for voltage and frequency trip settings specified in this standard for DER are not intended to limit the capabilities and settings of* ***other equipment on the Area EPS****.*"

Standard recommends

- Area EPS protections conform to the voltage and frequency ride-through objectives of IEEE 1547 under normal circumstances
- Settings outside the allowable range only to be used occasionally and selectively to accommodate worker safety or to protect distribution infrastructure while in an abnormal configuration, such as:
  - Circuit reconfiguration
  - Temporary loss of direct transfer trip
- Coordinate special settings with regional reliability coordinator

IEEE 1547 Document Outline of Clauses – Focus of this Training

1. Overview
2. Normative references
3. Definitions and acronyms
4. General interconnection technical specifications and performance requirements
5. Reactive power capability and voltage/power control requirements (*Normal Conditions*)
6. Response to Area EPS abnormal conditions (*Abnormal Conditions*)
7. Power quality
8. Islanding – Unintentional islanding & intentional islanding
9. DER on distribution secondary grid/area/street (grid) networks and spot networks
10. Interoperability, information exchange, information models, and protocols
11. Tests and verification requirements

\+ Seven new informative annexes, including
- Annex B: Guidelines for DER performance category assignment
- Annex E: Basis for ride-through of consecutive voltage disturbances

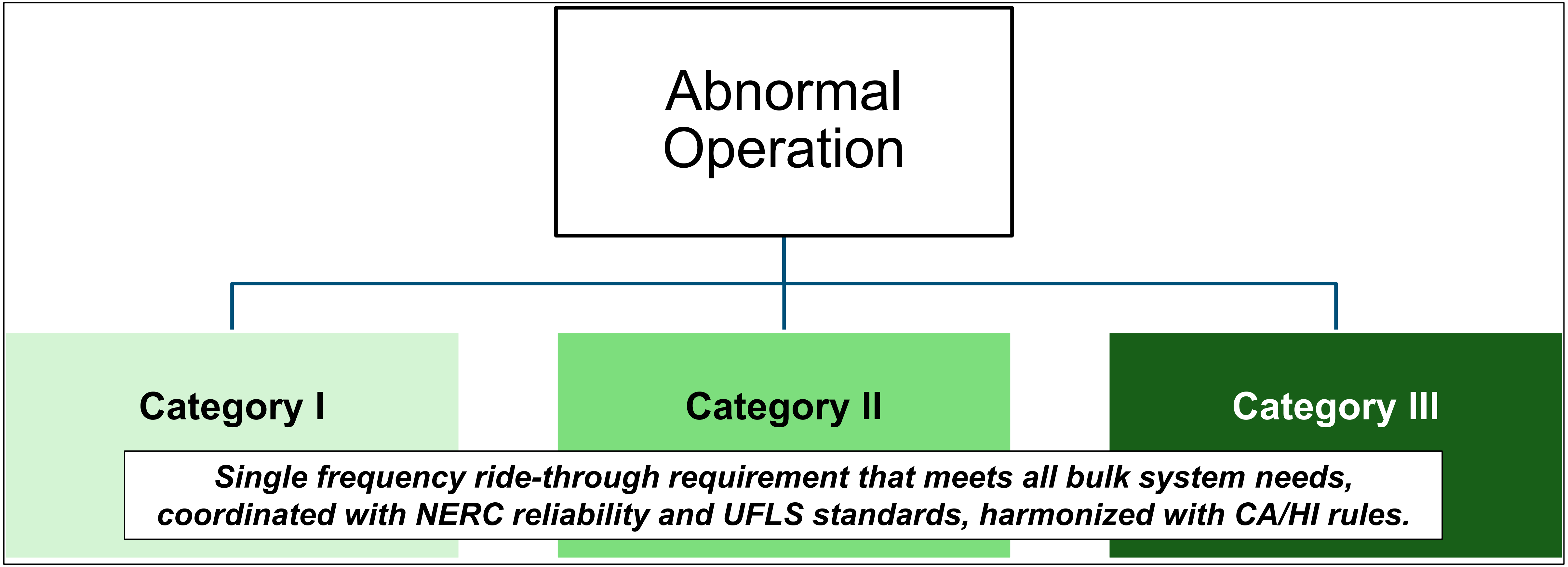
The latest version of IEEE 1547 is over 10X the length of previous versions.

Flexibilities provided by IEEE Std 1547-2018
and
the decisions that utilities and energy regulators need to make

Normal and Abnormal Performance Categories
and
Functional settings, ranges of allowable settings, and default values

Performance categories for Abnormal Operation

Frequency ride-through



Challenge (?): Coordination with unintentional islanding prevention

Performance categories for Abnormal Operation

Voltage ride-through

Decision criteria:

- Technology limitations
- Benefits & costs
- Expected regional DER penetration / bulk system modeling

Abnormal Operation

[1] fault-induced delayed voltage recovery, e.g., caused by single-phase air-conditioning systems.

Category I

Essential voltage ride-through capabilities

All state-of-art DER technologies can meet this

Category II

DER voltage ride-through for all bulk system needs

Consideration of FIDVR[1]

Category III

Bulk + distribution grid needs

Coordinated with CA/HI rules

Adjustable trip ranges limited

Perceived challenge: Coordination with utility reclosing practices

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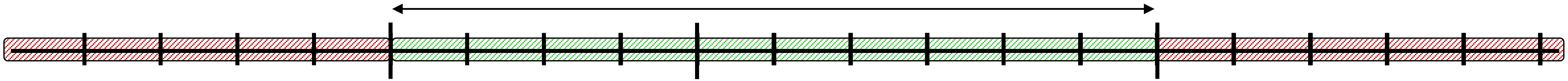
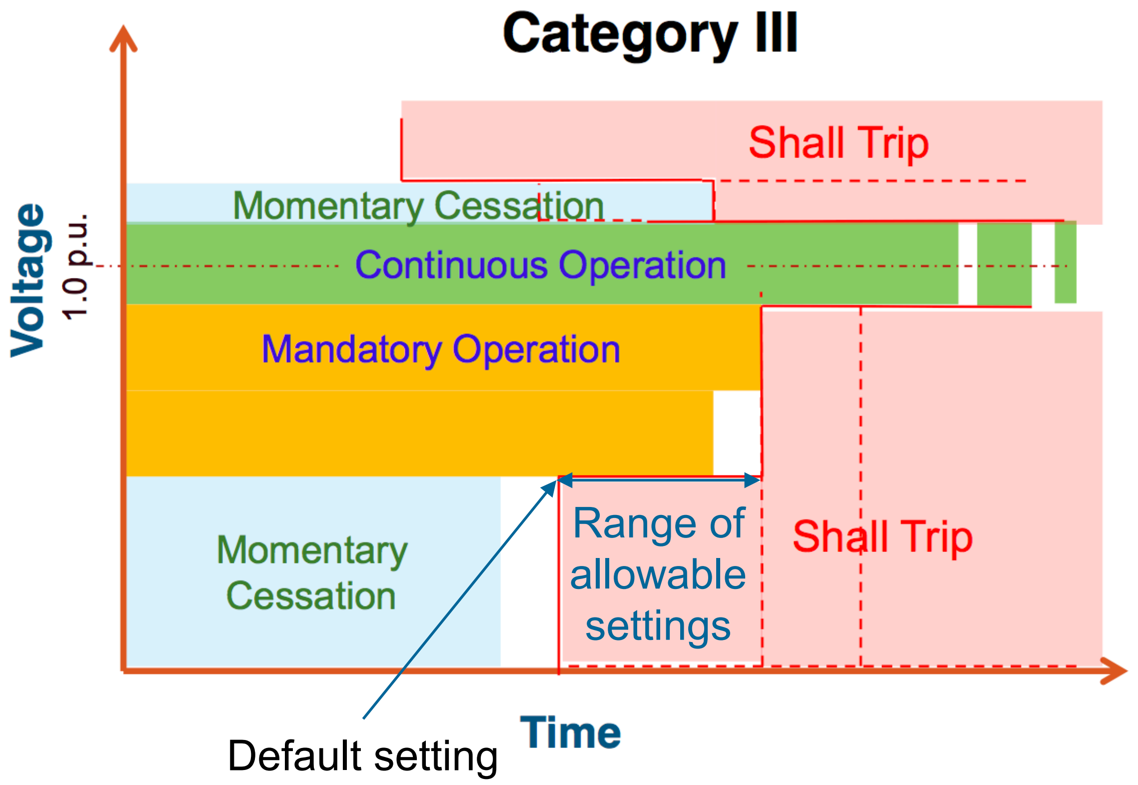
What are ranges of allowable settings?



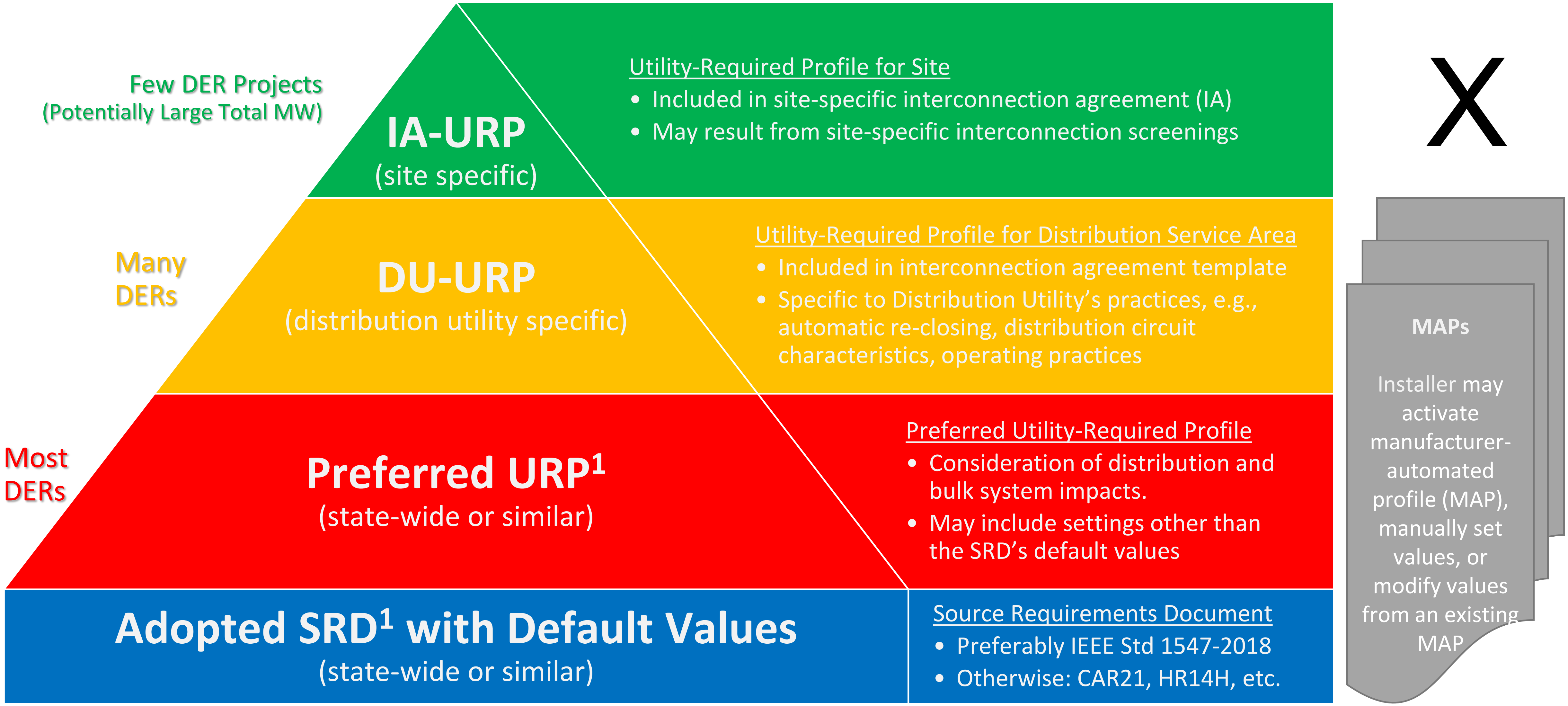
Voltage/Frequency Trip Settings



Meaning of Trip Ranges

- May determine the extent to which ride through capability is utilized.
- Depending on the function, sometimes a
  - Limiting requirement: the setting shall not be set to lower values.
  - Minimum requirement: the setting may be set above this value.
- Coordinated with bulk system reliability requirements.

Hierarchy of DER Interconnection Requirements & Settings

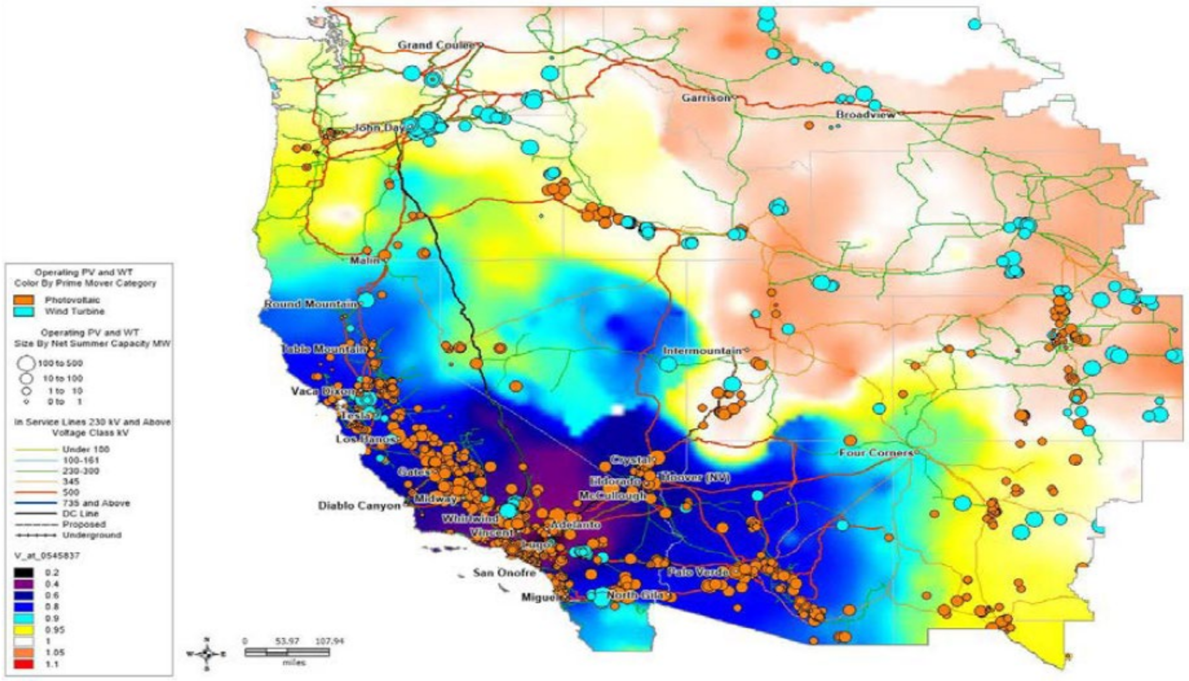


[1] Based on decision by Authority Governing Interconnection Requirements (AGIR), may be a public utilities commission or similar

IEEE Std 1547-2018 DER Ride-Through Performance Categories and Trip Settings

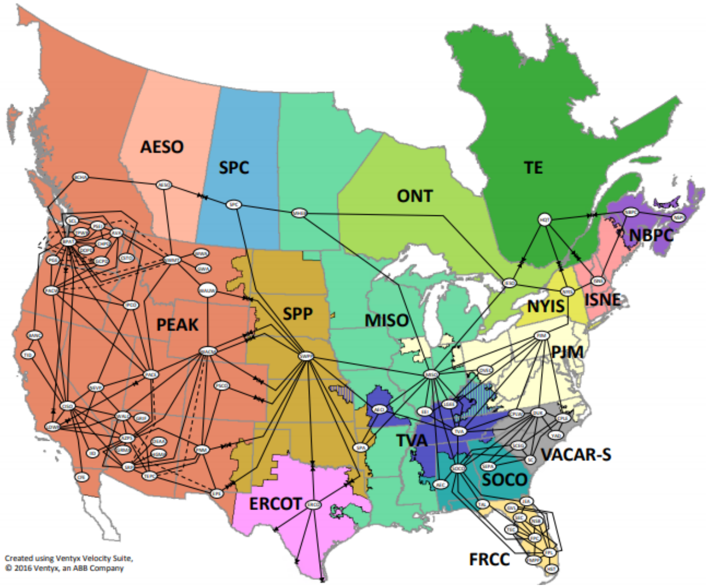
Driver for new ride-through requirements: Potential for widespread DER tripping

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



Source: NERC

- NERC Reliability Coordinators
  - Colored entities in the map to the right



Source: NERC

- 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 BPS event may be greatly aggravated

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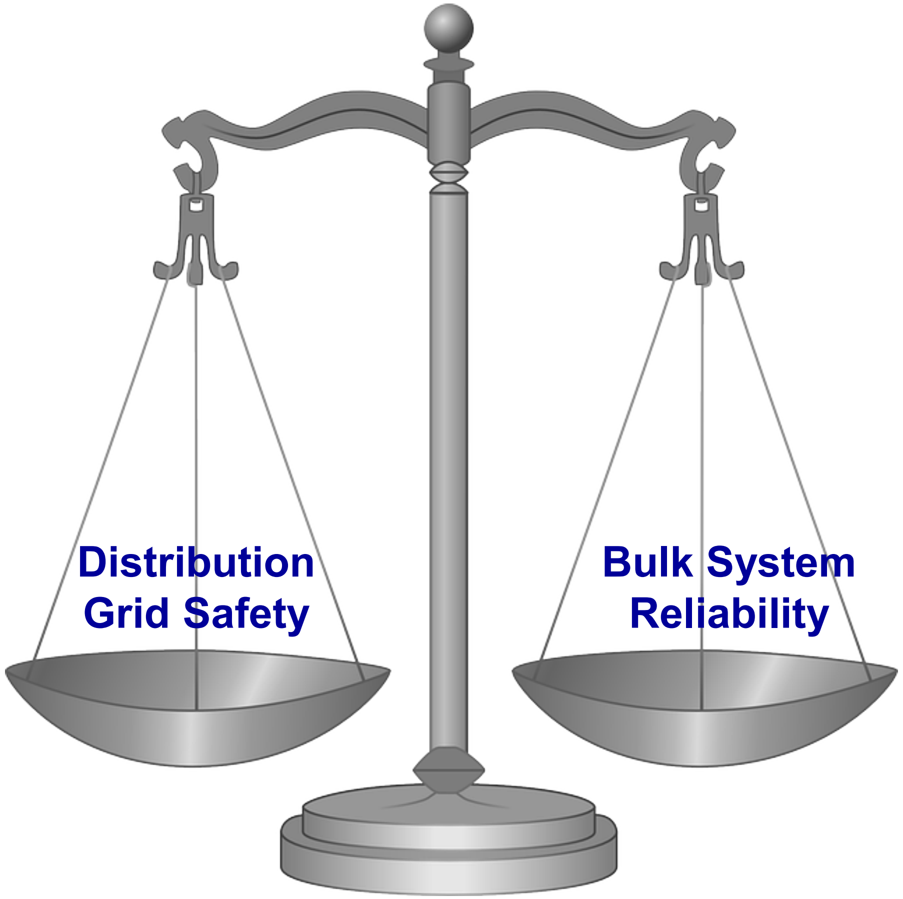
Opportunities provided by IEEE Std 1547-2018: Striking a new balance

- IEEE 1547-2018 mandates BOTH:
  - Tripping requirements, and
  - Ride-through requirements

- Ride-through is not a “setting”, it is a minimum *capability* of the DER

- Trip thresholds and clearing times are maximum operational *settings*
  - Determine the extent to which the ride-through capability is *utilized*
  - Shall be coordinate with the ***regional reliability coordinator***



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Differences between Trip of Interconnected and Islanded DER

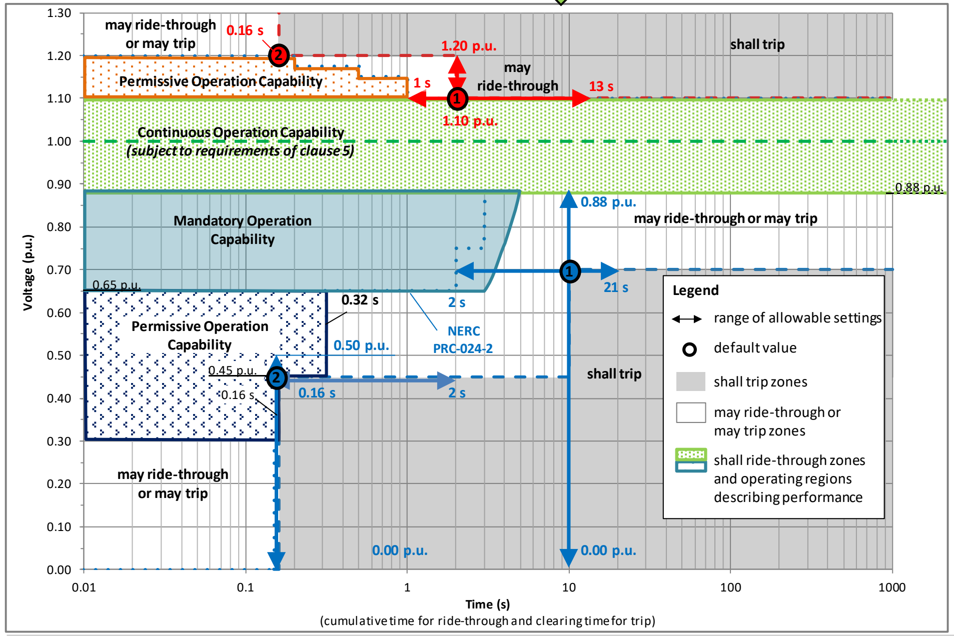
Trip Requirements

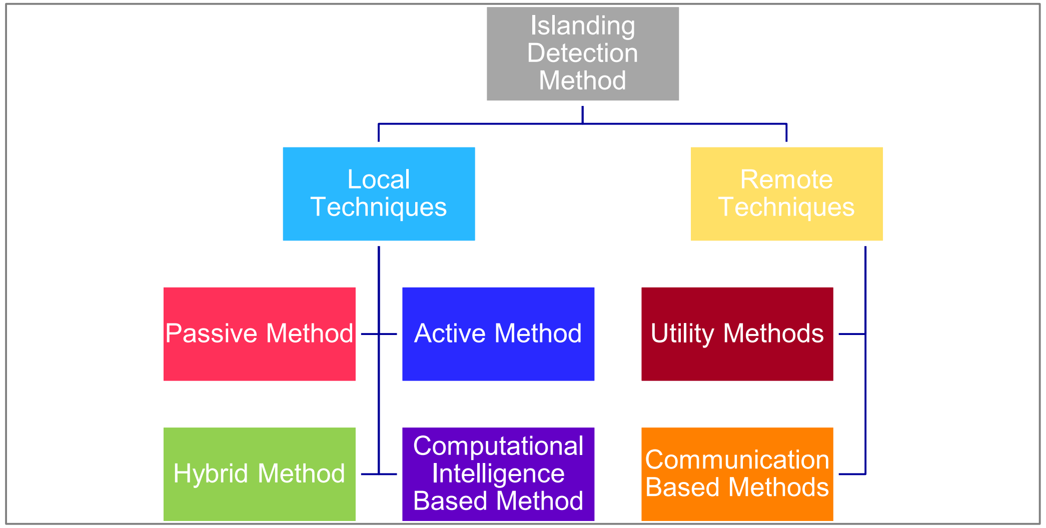
Non-islanded DER
interconnected to all of the Area EPS

Islanded DER
isolated from the upstream part of the Area EPS

Ride-Through (bulk system faults) & Trip

Anti-Islanding & Trip (2 sec.)





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General tripping and reclose coordination requirements

- DER must trip for any short-circuit faults on the circuit to which it is connected
  - Exception for faults not detectable by Area EPS protection
  - At Area EPS Operator discretion, sequential tripping can be employed
- DER must detect and cease to energize for open phase condition directly at the *reference point of applicability* within two seconds
- DER must implement means such that Area EPS circuit reclosing does not result in unacceptable stress or disturbance. Possible means include:
  - Low DER penetration = no islanding sustained for reclose delay
  - Feeder reclosing “hot-line blocking”
  - Transfer trip
  - Anti-islanding detection proven to be faster than reclose delay

Disturbance performance categories

- Not all DER technologies can meet the full extent of ride-through compatible with BPS requirements
  - Synchronous generators have stability issues with LVRT
  - Some “prime mover” or “energy source” systems can also have potential issues
  - Example: Fuel cell generator with extensive electrically-driven auxiliaries
- Solution: define “disturbance performance categories”
  - Authority Governing Interconnection Requirements (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
  - Non-technical criteria: DER use case, impacts on environment, emissions, and sustainability, etc.
    - Making non-technical judgements is outside purview of IEEE standards

Note: It is currently difficult/infeasible to retroactively change DER performance in most cases.

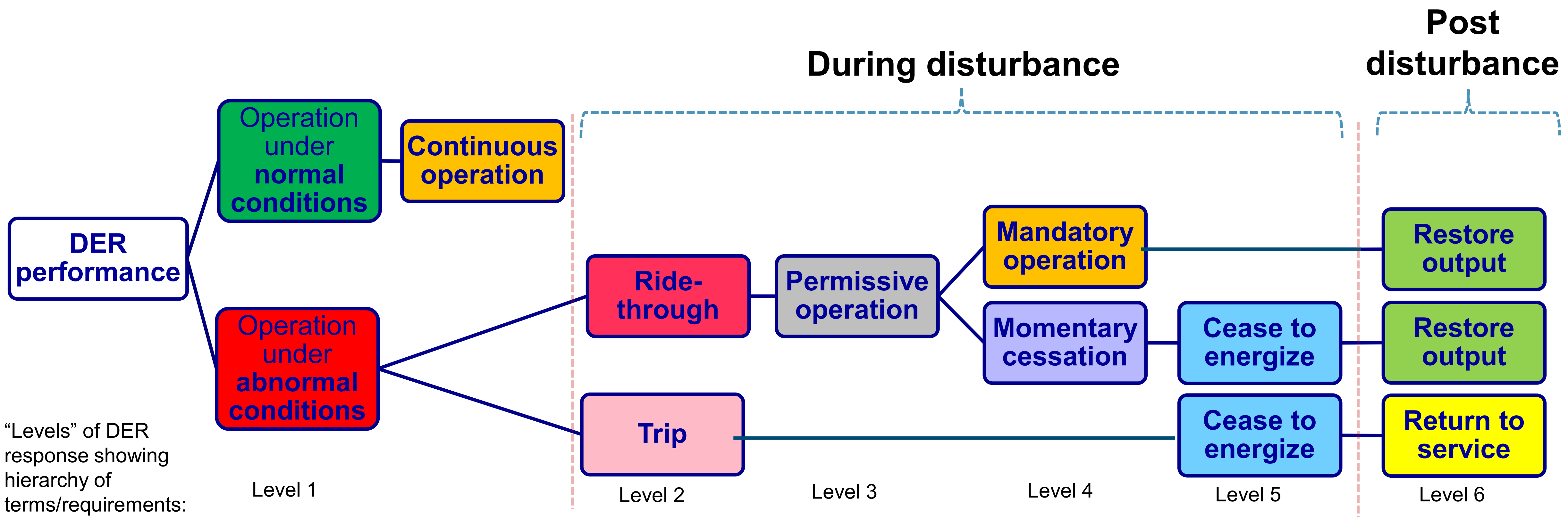
Think 30 years ahead when choosing performance category and settings!

Abnormal Performance Categories

Category	Objective	Foundation
I	Essential bulk system needs and reasonably achievable by all current state-of-art DER technologies	German grid code for synchronous generator DER
II	Full coordination with bulk power system needs	Based on NERC PRC-024, adjusted for distribution voltage differences (delayed voltage recovery)
III	Ride-through designed for distribution support as well as bulk system	Based on California Rule 21 and Hawaii Rule 14H

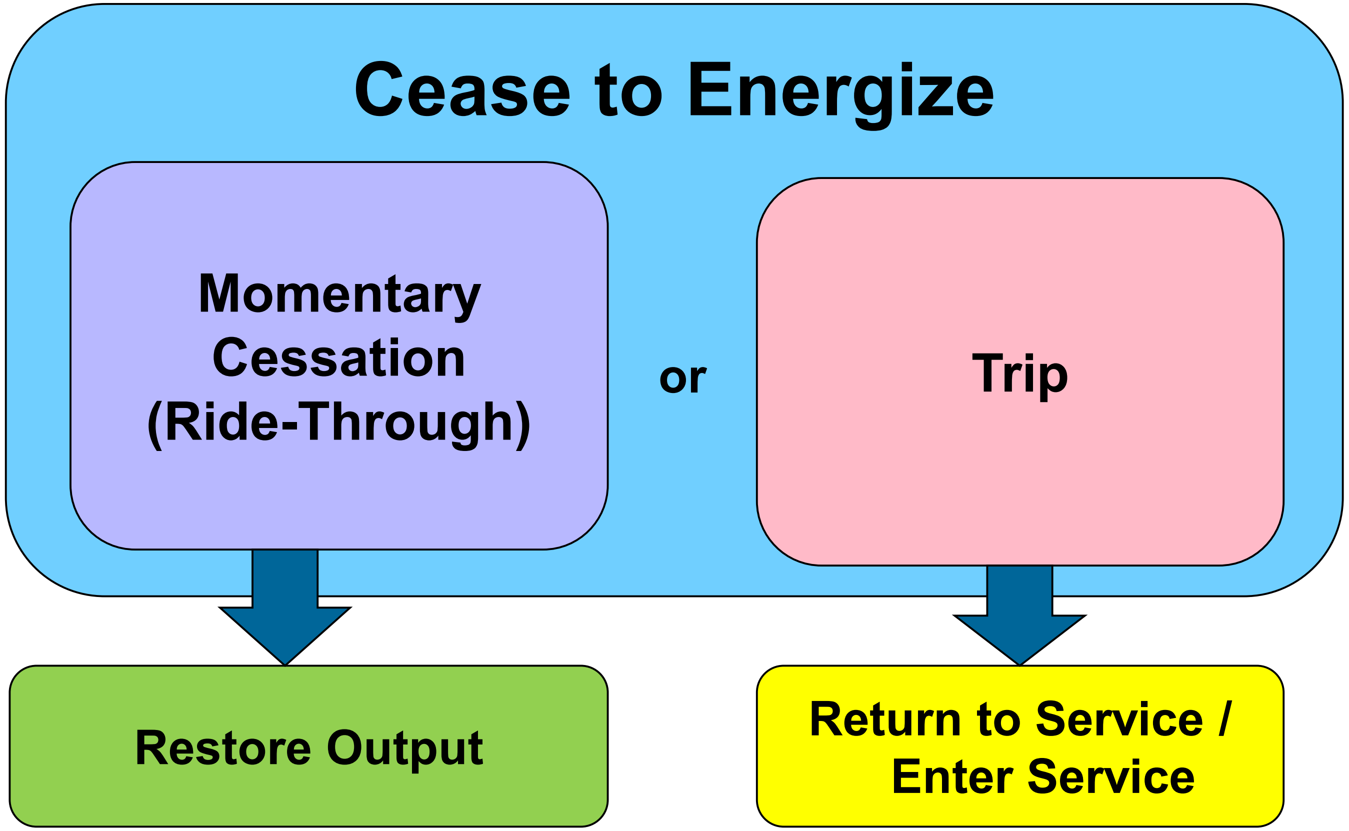
Category II and III are sufficient for bulk system reliability.

Disturbance performance terminology



- **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 the 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

Disturbance performance terminology

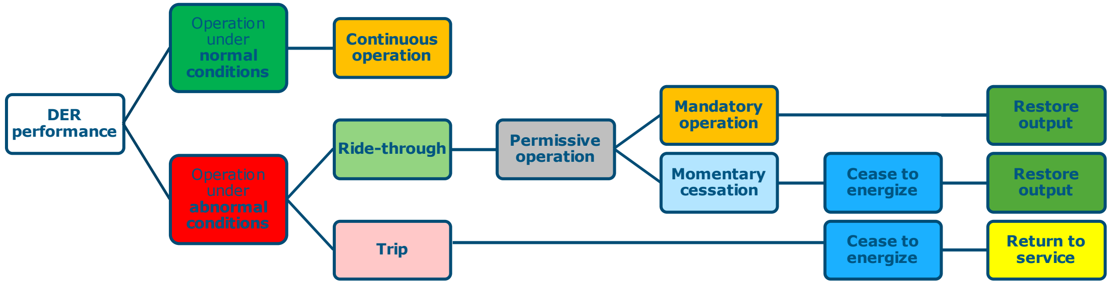


- Refers to Point of DER Connection (PoC) of individual DER unit(s)
- No active power delivery
- Limitations to reactive power exchange
- Does not necessarily mean physical disconnection
- Used either for *momentary cessation* or *trip*

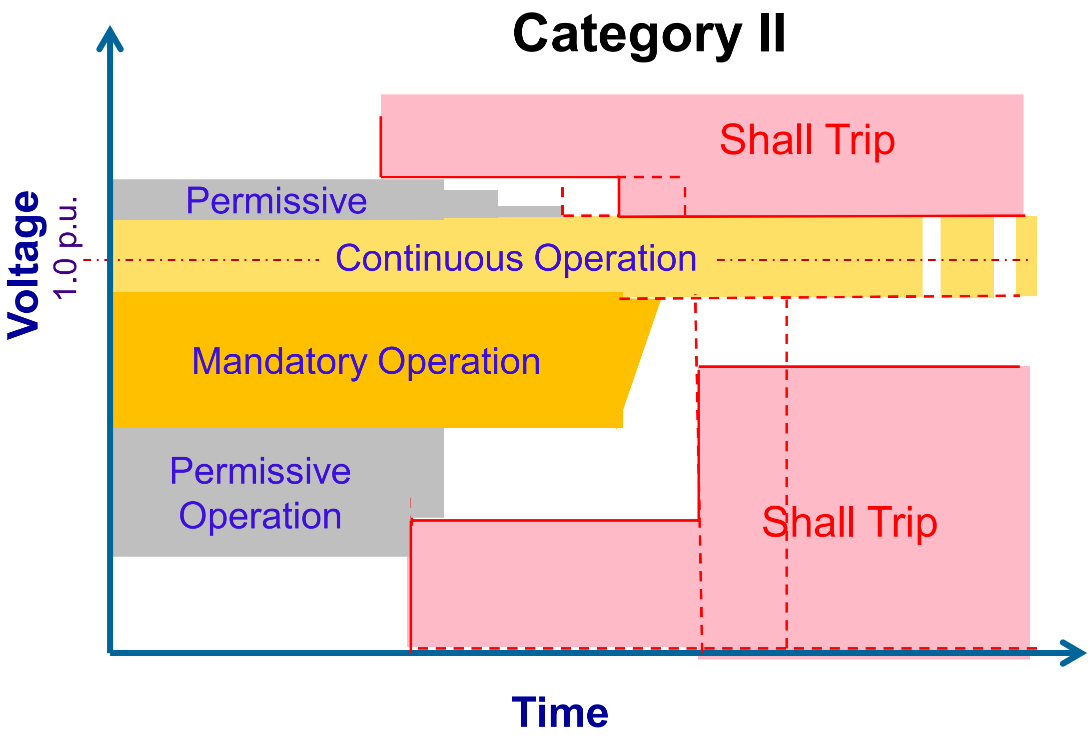
- 80% of pre-disturbance active current level within 0.4 seconds

- Permit service enabled
- Applicable voltage within ANSI C84.1 Range B
- Frequency within 59.5 Hz and 60.1 Hz
- Intentional delay of 5 minutes, ramped recovery

Structure of Voltage Ride-Through – Category II



- Two overvoltage and undervoltage trip levels.
- Ranges of allowable settings defined such that IEEE Std 1547a-2014 default settings <u>can</u> be accommodated.
- Permissive Operation Capability region <u>may</u> include requirements for *momentary cessation*, similar to Category III.
- <u>Achievable</u> by UL 1741 SA certified inverters



Dashed lines indicate permissible range of trip adjustment, solid lines indicate default settings.

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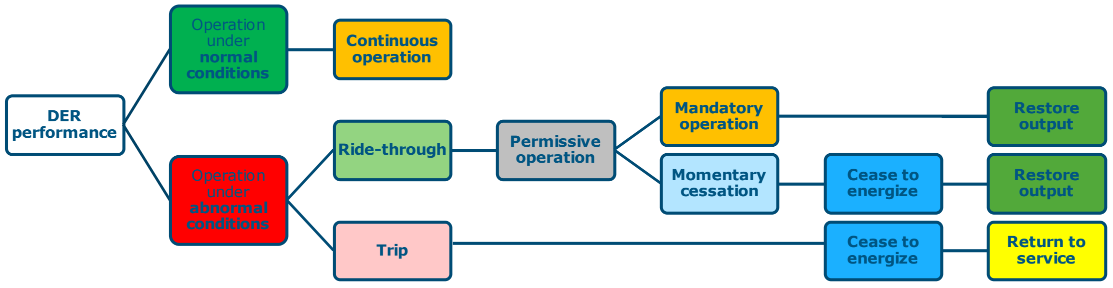
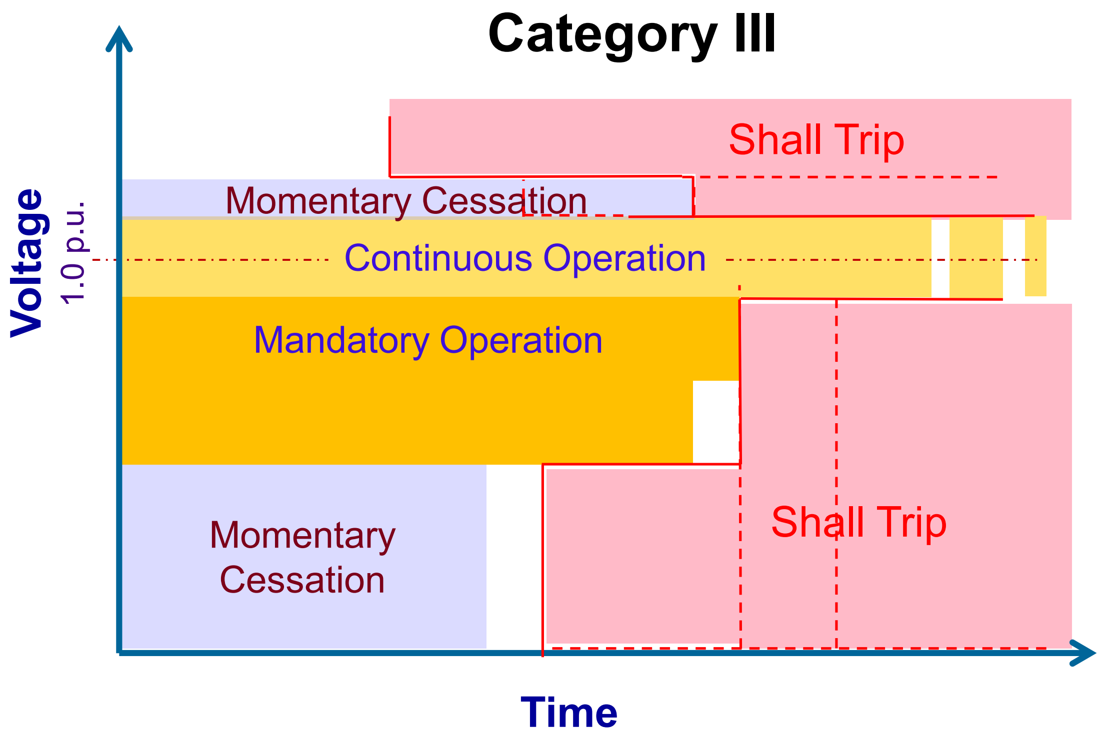
Structure of Voltage Ride-Through – Category III



- Ranges of allowable settings defined such that IEEE Std 1547a-2014 default settings cannot be accommodated.
- Category III mandatorily requires *momentary cessation*
  - If feeder is faulted and tripped at the substation, then DER in momentary cessation will not energize the islanded feeder
  - DER will eventually trip off if grid voltage does not return
- Requires a relatively long zero voltage ride-through requirement (in *momentary cessation* mode)
- Matches UL 1741 SA certified inverters



Dashed lines indicate permissible range of trip adjustment, solid lines indicate default settings.

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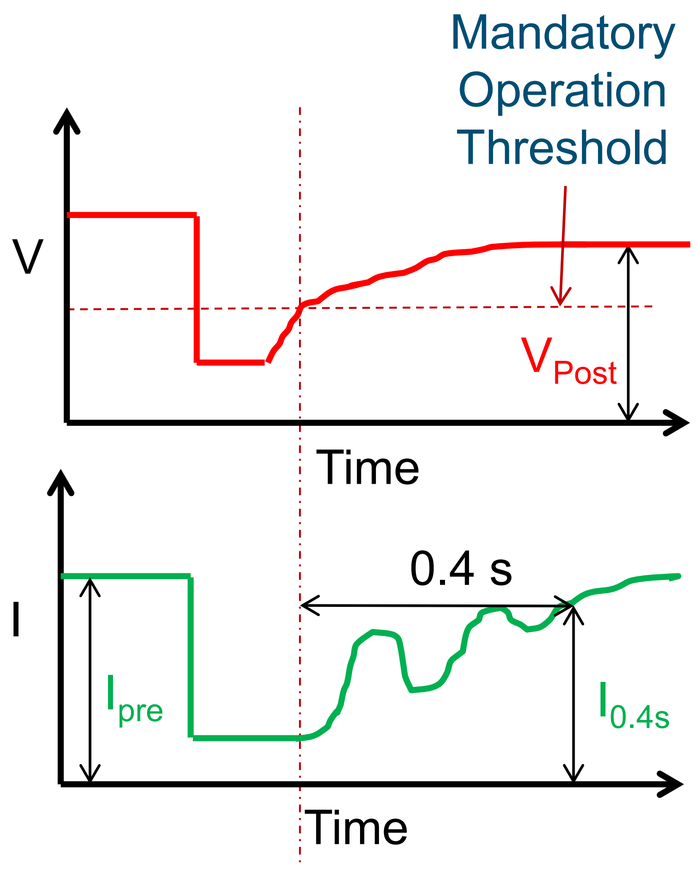
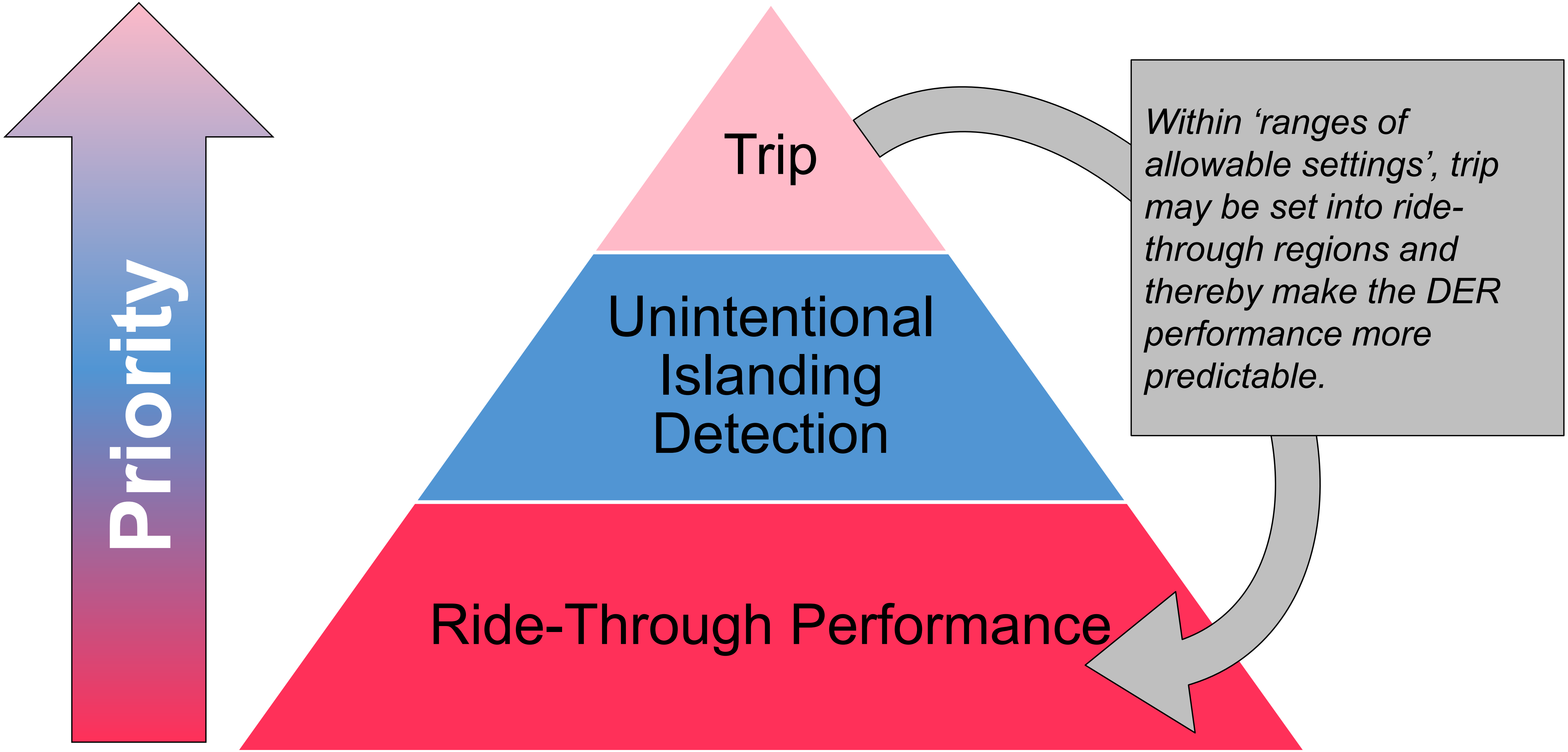
Restore Output after Ride-through Performance

- DER must *restore output* to 80% of pre-disturbance active current within 0.4 s
- Time begins when applicable voltage returns to mandatory operation or continuous operation ranges
- Oscillatory power output is acceptable if positively damped (accommodates rotor angle swings of synchronous generators and imperfect control of inverters)
- If DER provides dynamic reactive power support (not mandatory), dynamic support must continue for 5 seconds before returning to pre-disturbance reactive control mode.



$I_{0.4s} \geq 0.8 \times I_{pre}$

Prioritization of DER responses



Part I: Top 5 Concerns of Distribution Grid Planners, Operators, and Line Workers

1. "Cease to energize" with or without electrical separation?
2. Unintentional islanding risk with DERs that ride-through disturbances and regulate voltage and/or frequency.
3. DER coordination with Area EPS automatic reclosing.
4. DER coordination with Area EPS protection.
5. DER impact on line workers' safety during hot-line maintenance.

Specify **tests** in IEEE P1547.1

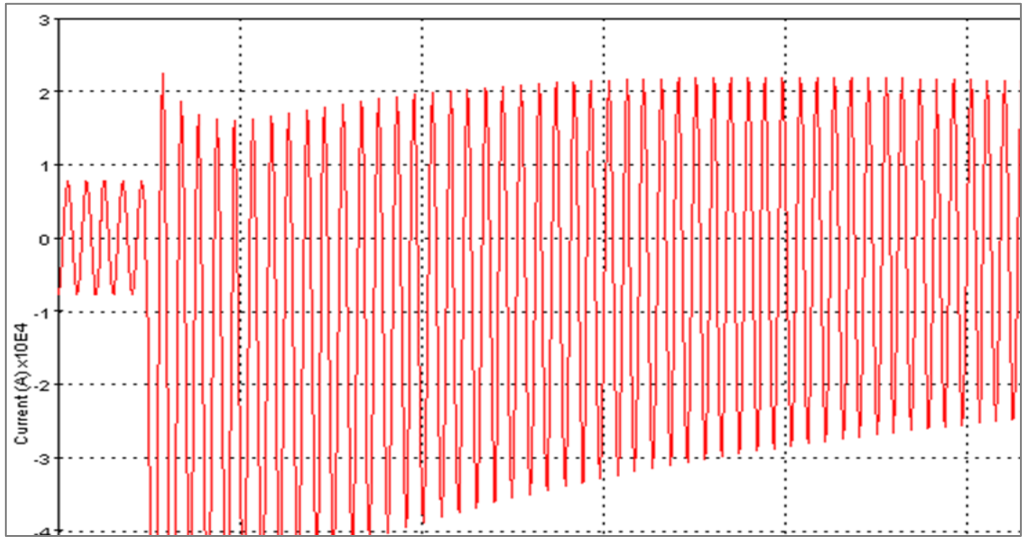
Address in DER interconnection practices via **screening**

This relates to Part II of the project

DER Fault Current Characteristics

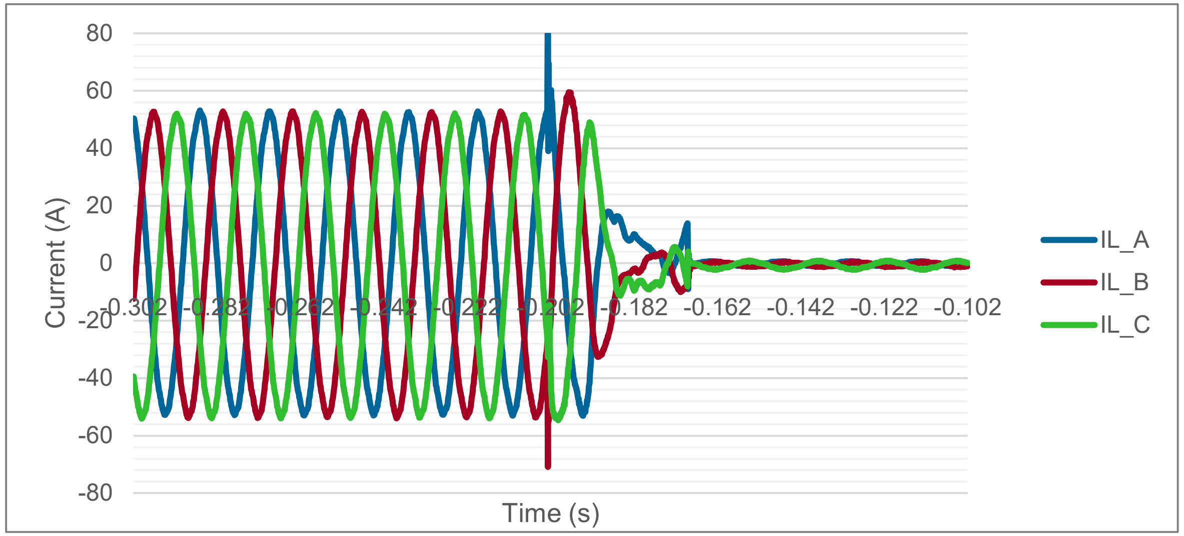
DER with Synchronous Generators

- Typically up to 4 – 6 p.u. positive and negative sequence current
- Generator fault current is always time-period due to tripping per IEEE 1547
- Current magnitude and angle depend on generator design, very little on controllers



DER with Inverters

- Typically less than 1.2 p.u. positive sequence current
- Inverter fault current is always time-period due to tripping per IEEE 1547
- Current magnitude and angle depend on inverter controllers and control mode.



1. "Cease to energize" with or without electrical separation?

- Distribution **protection** and **operation engineers** may be concerned about performance of DER during **cease to energize**, especially for inverter-based DER.
- However, IEEE P1547 explicitly states that DER shall not deliver **active power** and that DER shall limit **reactive power** exchange to **passive devices**.
- Hence, the new standard allows solid state means and does not require disconnection of the DER during cease to energize.

➢ Therefore, get engaged in IEEE P1547.1 to specify robust cease to energize **test** procedures .

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2. Unintentional islanding risk with DERs that ride-through disturbances and regulate voltage and/or frequency.

- Distribution **operations engineers** may be concerned about reduced effectiveness of **anti-islanding detection** when the new voltage and frequency regulation and ride-through requirements enter into effect.

- However, on an isolated circuit section with mostly resistive loads, voltage and frequency regulation of DERs tend to not effectively stabilize the island. Furthermore, IEEE P1547 still requires the 2s anti-islanding detection and clearing time – **without compromise**.

- Note that anti-islanding detection **may take longer than 2s** on a **limited number** of distribution circuits with certain combinations of load and DERs.

➢ Consider adding extra time margin, extending reclose delays longer (e.g., 5 seconds)

➢ Also, get engaged in IEEE P1547.1 to specify robust anti-islanding detection **test** procedures

3. DER coordination with Area EPS automatic reclosing.

- Distribution **protection engineers** may be concerned about **out-of-phase reclosing** onto a circuit remaining energized by DERs during low-voltage ride-through (LVRT) operation, especially on circuits with fast reclosing.

- However, IEEE P1547 explicitly requires **appropriate means** to ensure that automatic reclosing does not expose the grid to unacceptable stresses or disturbances.

- Even though out-of-phase reclosing may not be a big issue for inverter-based DER itself, it may cause high TrOV similar to capacitor restrike and severe magnetic inrush that can cause overcurrent protective devices to operate.

➢ Therefore, **screen for** DER and automatic reclosing coordination issues:
  - ➢ **Distribution utilities** may either need to extend automatic reclosing times or deploy measures to block hot reclosing, or
  - ➢ **DER owners** may need to deploy means like direct transfer trip or very fast islanding detection.

4. DER coordination with Area EPS protection.

- Distribution **protection engineers** may be concerned about adverse impacts of DERs during low-voltage ride-through (LVRT) on **distribution protection schemes**.

- However, IEEE P1547 requires a DER to trip for faults on the circuit to which the DER is connected, keeps the under voltage trip value UV2 close to the 1547a-2014 default value and requires “Momentary Cessation” for LVRT below 50% of nominal voltage for Category III (very high penetration) DERs.

- All that said, high-impedance faults, for which the retained voltage remains high, may still be of concern.
  - Retained voltage for detectable faults can only be in the UV1 zone under limited very-high penetration situations with very long UV1 times and/or very sensitive TOC settings

➢ Therefore, **screen for** issues where DER **short-circuit current** for high-impedance faults **may exceed a defined threshold**

Reclosing Coordination and High Impedance Faults

- Minimally detectable fault impedance $R_F = 1/I_{PkUp}$
- Inverter can only support an island voltage equal to its output current times this fault impedance
- Inverter current maximum = $K_{oc} \times I_{DER}$ where K_{oc} is the overcurrent limit of the inverter controls and I_{DER} is in p.u. of the feeder peak load current
- The amount of DER penetration, relative to feeder peak load, required to maintain an island voltage V_{isl} is $I_{PkUp} \times V_{isl}/K_{oc}$
- For typical values, penetration to reach UV1 range is $0.75 \times 0.5/1.2 = 31.3\%$
- ***However, this assumes that even with a fault present, there is sufficient real and reactive load balance to sustain the island***

5. DER impact on line workers' safety during hot-line maintenance

- Distribution **line workers** may be concerned about **increased arc flash energy** during hot-line maintenance, due to DERs feeding a current during low-voltage ride-through (LVRT).
- However, in addition to the previously mentioned requirements, IEEE P1547 allows the utility to require and operate an isolation device or send a shut off the DER via SCADA prior to the maintenance.
- Note that **arc flash** hazard is not uniquely related to fault ride-through of DERs. For **arc flash**, high-impedance faults during hot-line maintenance may still a concern, unless DERs are preventively tripped by the **distribution operators**.
- Arc flash **risk** can be substantially **increased** by unnecessary application of ground sources or ground sources with too low impedance

➢ Therefore, **screen for** conditions where arc energy may exceed a defined threshold for high-impedance faults and the current contribution from inverter-based DERs may be in the same order of magnitude as the grid contribution, or where added ground sources significantly delay ground fault clearing time. For synchronous generator-based DERs, overcurrent protection or direct transfer trip can minimize DER fault contribution.

Interconnection screening may need to address DER integration issues such as *protection coordination*, *reclosing coordination* and *risk of islanding*.

Majority of cases of IEEE 1547-2018-compliant applications

- Voltage and frequency regulation
- Frequency and voltage ride-through
- 2s anti-islanding detection/clearing time
- Trip for faults on the circuit where DER connected
- UV2 close to the 1547a-2014 default value
- "Momentary Cessation" for LVRT < 0.5 p.u.

Preliminary Screens, Fast Track

Common cases with DER in distribution areas that use **fast reclosing**

Some cases where DER may **disrupt Area EPS protection coordination** for **high-impedance faults**

Rare cases with reduced effectiveness of **anti-islanding detection**

Supplemental Screen for issues, also consider extending anti-islanding detection/clearing time from 2s to up to 5s

Supplemental Screen for issues, then apply means:

- DER overcurrent protection or
- DER voltage-supervised overcurrent protection

Supplemental Screen for issues, then apply **appropriate means, e.g.:**

- extend automatic reclosing times,
- block hot reclosing,
- direct transfer trip,
- very fast islanding detection

Navigating DER Interconnection Standards and Practices

Part I: Application of IEEE Std 1547-2018

Objective: Support Staff Development to Apply New IEEE Standards

Training Modules & Collaborative Webcasts → **Member-specific value proposition** → **Multi-member workshop** | **Part III Member-specific training workshop** (*Optional*)

Training Modules & Collaborative Webcasts

- Requirements (1547)
  - Performance category assignment
  - Grid-specific tuning of DER settings
  - Communication protocols
- Verifications
  - Interim solution UL1741(SA) vs. mid-term solution IEEE 1547.1
  - Type tests vs. composite DER
  - DER evaluations vs. utility screening methods
  - Commissioning testing

Member-specific value proposition

- Evaluate member needs and address specific challenges
- Standardize forms and procedures for DER settings
- Support in specification of utility-required profile (URP)
- Support in developing interconnection standard adoption roadmap
- Direct line (phone + email) to EPRI staff involved in P1547
- IEEE 1547 recommendations

Multi-member workshop

- Share experiences and learnings of participants
- Identify leading interconnection practices

  (workshop includes both the participants in Part I and II)

Part III Member-specific training workshop — *Optional*

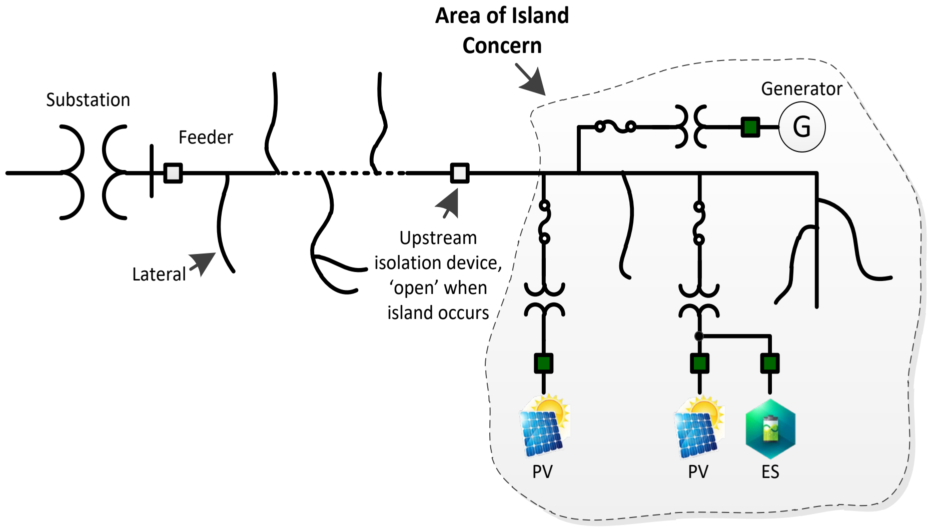
- Tailored in-person workshop covers:
  - Application of 1547 in utility-specific context
  - Support and input to inform regulatory proceedings

Transmission Planners + **Distribution Planners**

Evaluation of Inverter On-Board Detection Methods to Prevent Unintended Islanding

Objectives and Scope

- To improve analytical tools and methods for evaluating risk of unintentional islanding and in DER interconnection screening
- To consider inverter on-board detection capabilities as well as feeder and load characteristics.
- Take a deep dive into inverter on-board islanding detection methods, to characterize responses, develop generic non-proprietary models
- Adapt these for feeder analysis tools and supporting DER protection requirements in light of new IEEE 1547.



Value

- Improve interconnection screening, analysis and decisions on additional protection requirements
- Define critical parameters, conditions, and risk indicators for unintended islanding
- Identify effective detection methods and requirements in light of increased smart inverter deployment
- Update of Sandia Screening for islanding risk studies

Details and Contact

Timing: January 2018 to December 2019

Technical Contacts:

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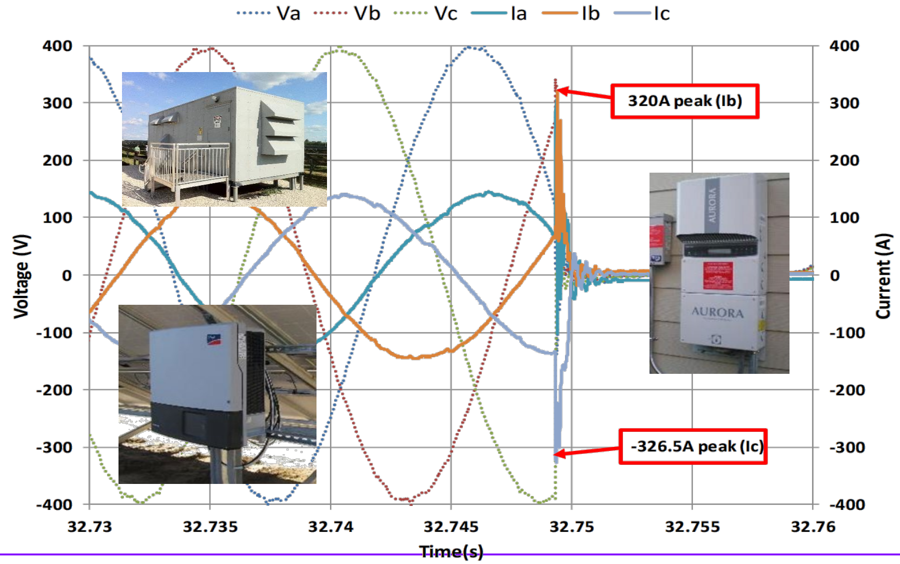
Inverter Fault Response Characterization for Protection and Planning

Objectives and Scope

- Understand dynamic behavior of wide range of inverter based DER types and scales
- Develop, improve, and verify models based on measured data
- Develop standard set of tests and reporting template for model validation to be used by inverter manufacturers

Value

- Validation of existing models for protection and planning studies and basis for development of new models
- Enhanced knowledge of commercial inverters' dynamic behavior:
  - Short-circuit current magnitude and duration
  - Active/reactive current during fault ride through and TOV
  - Response to abnormal grid conditions (sag, swell, loss of phase, phase jump)
  - Grid synchronization during fault ride through
  - Islanding detection
  - Reconnection time and behavior after fault



Schedule and Cost

- Project beginning Q4 2018; Duration: 24 months
- For pricing information, contact the below; Qualifies for TC and SDF

Technical Contacts

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SPN Number: *TBD*

Improve Methods to Incorporate DER into Protection Design, Planning Process, and Tools

Conclusions

- DER ride-through and trip requirements in IEEE 1547-2018 balance distribution safety with bulk system reliability needs.
- The standard provides default trip settings but allows for customization within ranges of allowable settings.
- Trip settings need to be coordinated with the Regional Reliability Coordinator.
- Distribution protection schemes may need to be adjusted to new DER ride-through requirements.

Together…Shaping the Future of Electricity

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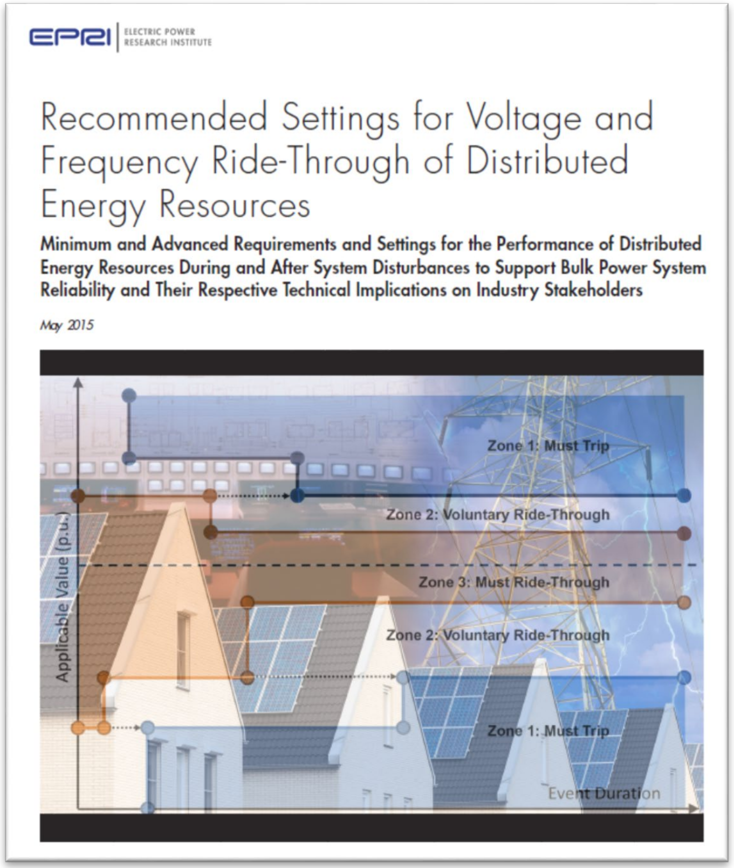
Backup Slides

Driver for new ride-through requirements: Limitations on the Loss of Source

- Planning criteria for stability analysis require limitations on the amount of sources that may be lost for a contingency
- Historically, the concern has been large generators being disconnected or going unstable and tripping
- Tripping of DER for a transmission fault would potentially aggravate the disturbance
- If total source loss exceeds the amount allowed by the planning criteria, a system upgrade would be required



EPRI White Paper from 2015: LINK

Excursion: NERC TPL-001-4

NERC Standard TPL-001-4 “Transmission Planning Performance Requirements”

- The purpose of the standard is to “Establish Transmission system planning performance requirements …to develop a Bulk Electric System (BES) that will operate reliably over … a wide range of probable Contingencies”

- TPL-001-4 is a *deterministic* planning criteria

- TPL-001-4 specifies a list of contingencies that must be tested and for which the System must remain reliable

Excursion: NERC TPL-001-4, *continued*

- In addition to NERC criteria, Regional Reliability entities have planning criteria that sometimes require even more severe contingencies to be tested

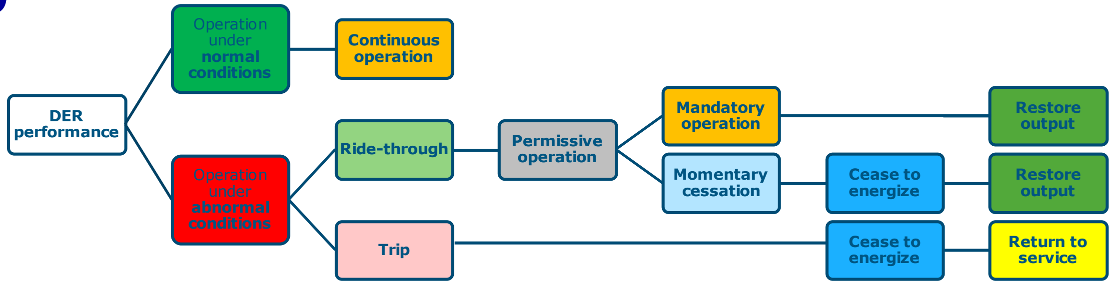
- As an example NERC criteria requires that the transmission system remain secure for a permanent three-phase fault with normal fault clearing
  - Normal clearing of a three-phase fault on the 345 kV system is approximately 0.1 seconds
  - Normal clearing of a three-phase fault on a the 115 kV system can range from 0.1 seconds to over 0.5 seconds depending on the protective relay scheme

Excursion: NERC TPL-001-4, *continued*

- NERC criteria also require analysis of a three-phase fault with delayed clearing
  - Delayed clearing of a three-phase fault on the 345 kV system is approximately 0.1-0.2 seconds
  - Delayed clearing of a three-phase fault on a 115 kV system can range from 0.3 seconds to over a second depending on the protective relay scheme

- For unbalanced faults, stability program results show positive sequence voltage, individual phase voltages much lower
  - DER respond to least-phase undervoltage, max-phase overvoltage

Frequency trip and ride-through



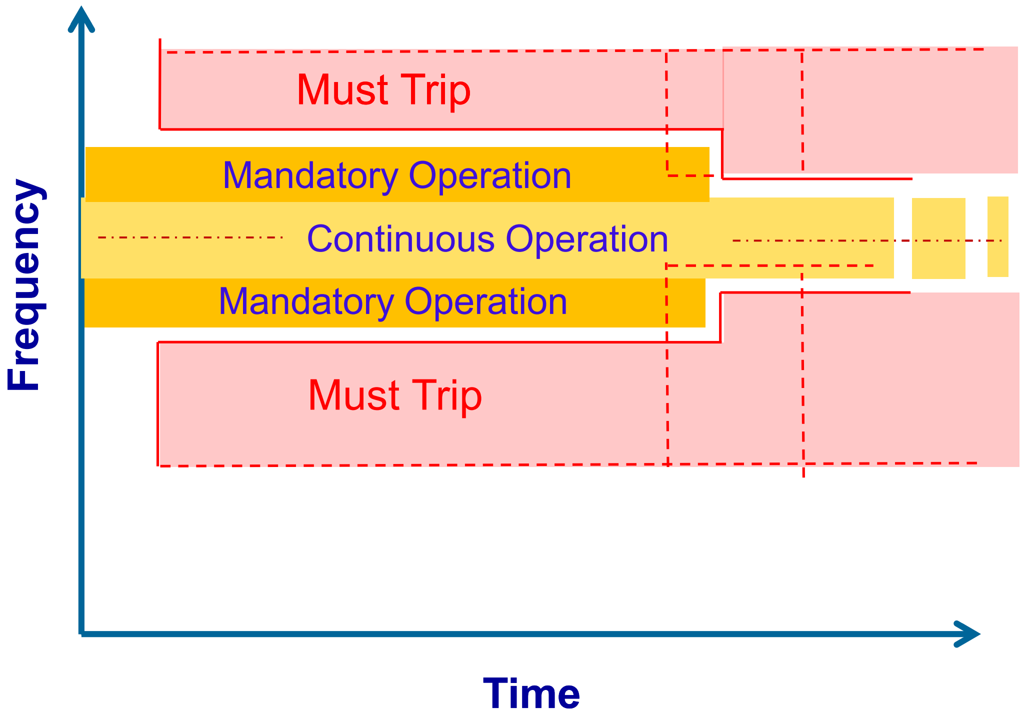
- Frequency is an interconnection-wide parameter

- Underfrequency tripping needs to be coordinated with UFLS, trip no sources before loads are tripped

- IEEE 1547-2018 allows wide range of must-trip settings to accommodate small, isolated grids
  - OF: 61.8 – 66.0 Hz
  - UF: 50.0 – 57.0 Hz

  } Short duration 0.16 – 1.0 s
  - OF: 61.0 – 66.0 Hz
  - UF: 50.0 – 59.0 Hz

  } Long duration 180 – 1000 s



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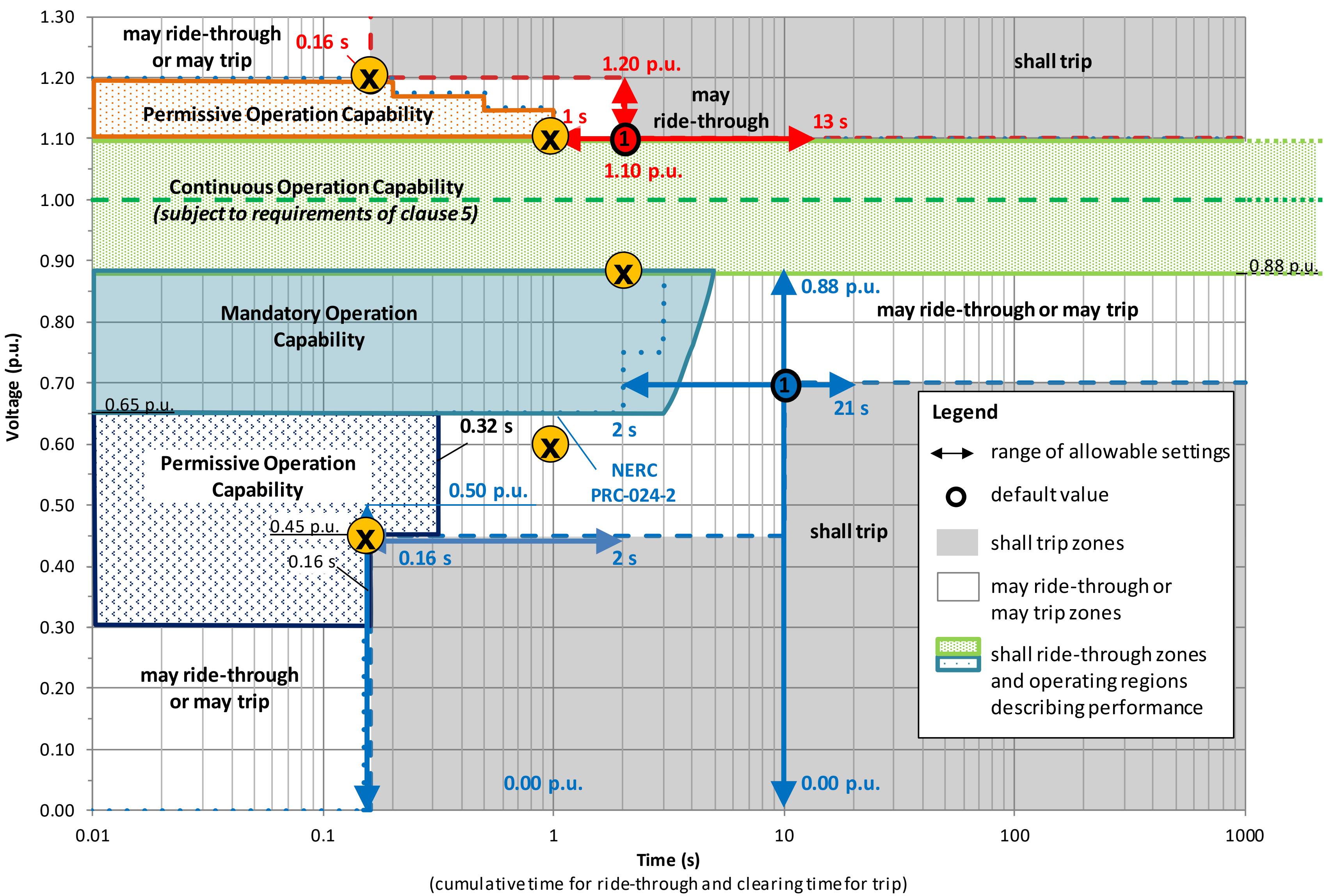
Actual Abnormal Voltage Requirements for Category II



- Two overvoltage and undervoltage trip levels.
- Ranges of allowable settings (↔) defined such that IEEE Std 1547a-2014 default settings (x) can be accommodated.
- Permissive Operation Capability region may include requirements for Momentary Cessation, similar to Category III. !

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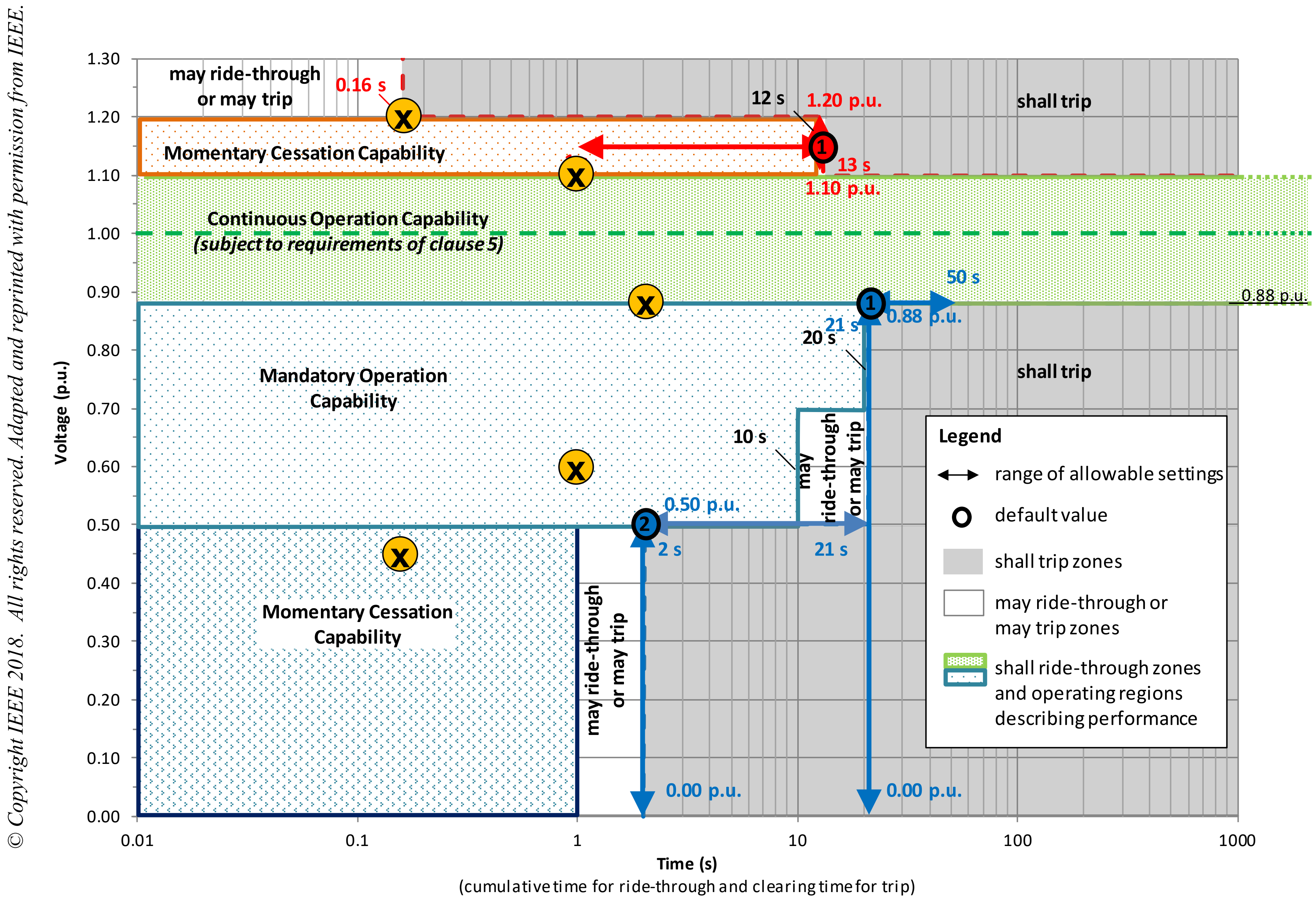
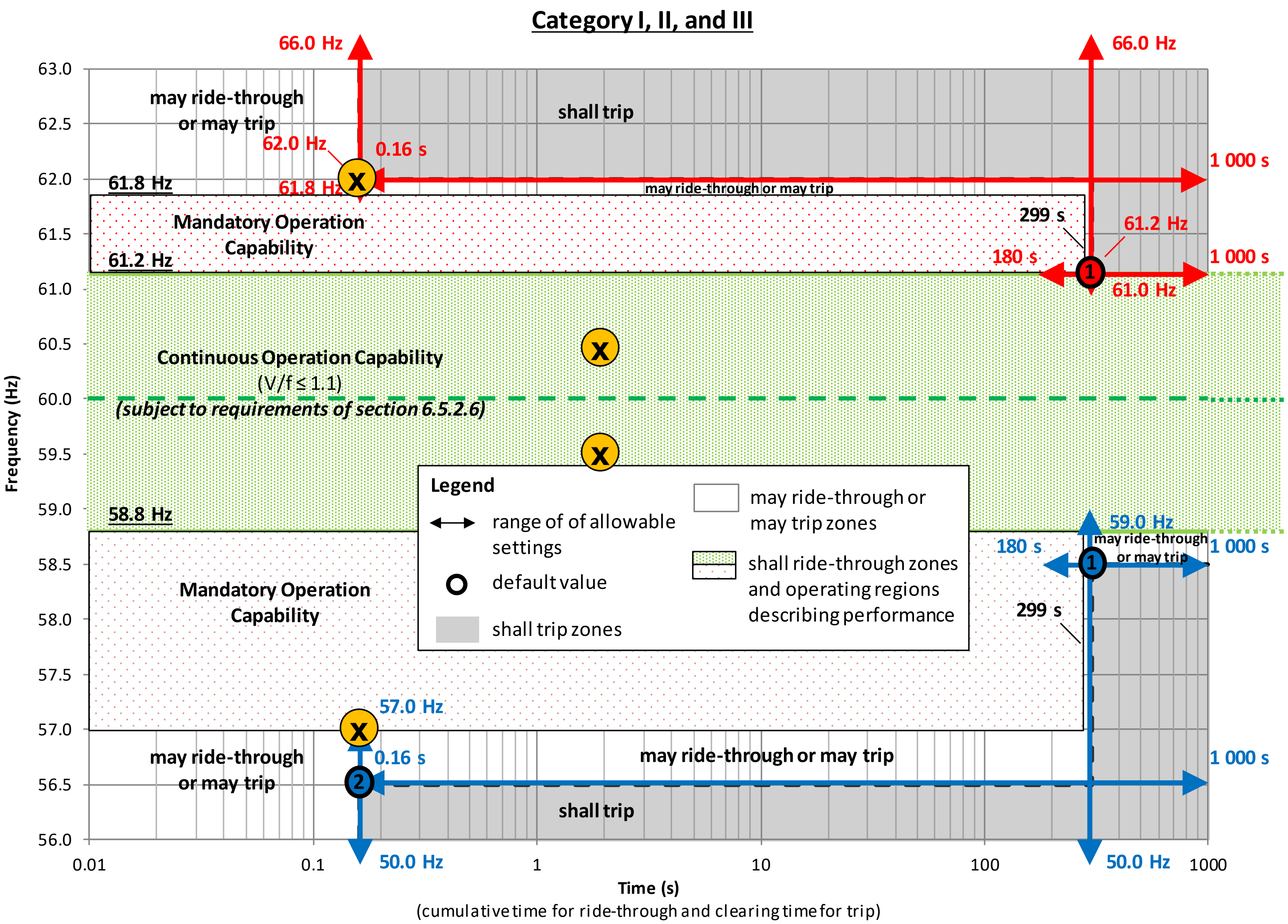
Actual Abnormal Voltage Requirements for Category III



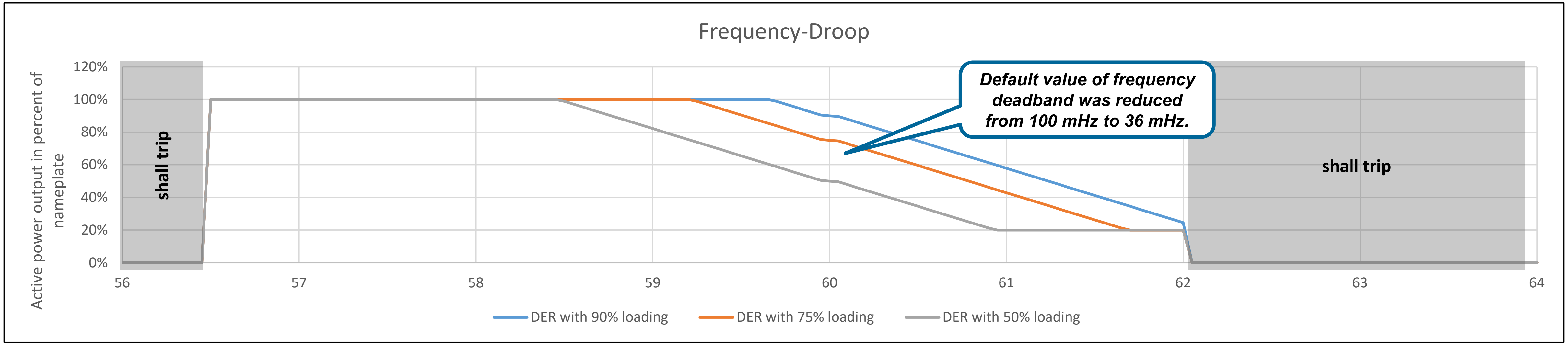
- Two overvoltage and undervoltage trip levels.
- Ranges of allowable settings (↔) defined such that some IEEE Std 1547a-2014 default settings (x) can NOT be accommodated.

Actual Abnormal Frequency Requirements



- Two over- and underfrequency trip levels.
- Ranges of allowable settings (↔) defined such that some IEEE Std 1547a-2014 default settings (x) can NOT be accommodated.

Frequency Support



- ***This function is per IEEE Std 1547-2018 not to be disabled, adjust dead bands and droop if necessary***
  - Only a functional capability requirement – Utilization remains outside the scope of IEEE 1547-2018
  - Overfrequency: all DERs required to provide droop response
  - Underfrequency: No requirement to maintain operational headroom

Parameter	Default settings [a]			Ranges of allowable settings[b]		
	Category I	Category II	Category III	Category I	Category II	Category III
db_{OF}, db_{UF} (Hz)	0.036	0.036	0.036	0.017 [c] – 1.0	0.017[c] – 1.0	0.017[c] – 1.0
k_{OF}, k_{UF}	0.05	0.05	0.05	0.03 – 0.05	0.03 – 0.05	0.02 – 0.05
$T_{response}$ (small-signal) (s)	5	5	5	1 – 10	1 – 10	0.2 – 10

Other conditions DERs must ride through

- If frequency remains in the continuous operation or ride-through frequency range, DER shall not trip for **rate-of-change-of-frequency (ROCOF)** < criterion:
  - Category I: ROCOF ≤ 0.5 Hz/s
  - Category II: ROCOF ≤ 2.0 Hz/s
  - Category III: ROCOF ≤ 3.0 Hz/s

- IEEE 1547-2018 voltage **phase-jump** ride-through requirements:
  - Up to 20° positive-sequence voltage phase angle step
  - Up to 60° individual phase voltage phase angle step

- **Voltage unbalance** ride-through:
  - Negative sequence voltage (V_2) ≤ 5% for duration ≤ 60 s.
  - Negative sequence voltage (V_2) ≤ 3% for duration ≤ 300 s.