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Grid Transformation and Implications of 1547-2018

Vermont System Planning Committee

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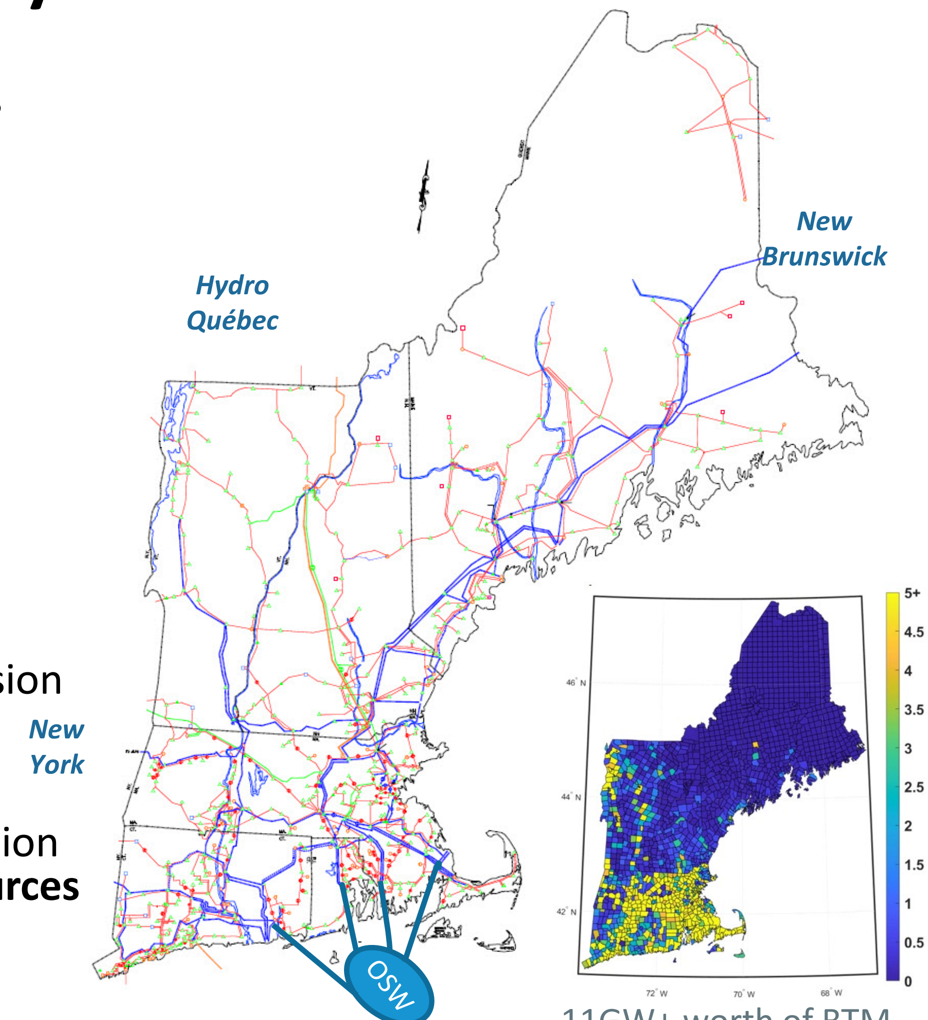
SENIOR ENGINEER-TRANSMISSION SERVICE STUDIES

Presentation Outline

- About the New England electric grid
- About IEEE 1547, its importance,
  and its implementation in New England
- Details regarding proposed changes to the standard
- Questions

New England's Transmission Grid Is the Interstate Highway System for Electricity

- **9,000 miles** of high-voltage transmission lines (primarily 115 kV and 345 kV)
- **13 transmission interconnections** to neighboring power systems in New York and Eastern Canada:
  - New York (8 AC ties, 1 DC tie)
  - Hydro Québec (2 DC ties)
  - New Brunswick (2 AC ties)
- **14%** of region's energy needs met by imports in 2022
- **$11.9 billion** invested to strengthen transmission system reliability since 2002; **$1.3 billion** planned
- Developers have proposed multiple transmission projects to access **non-carbon-emitting resources** inside and outside the region

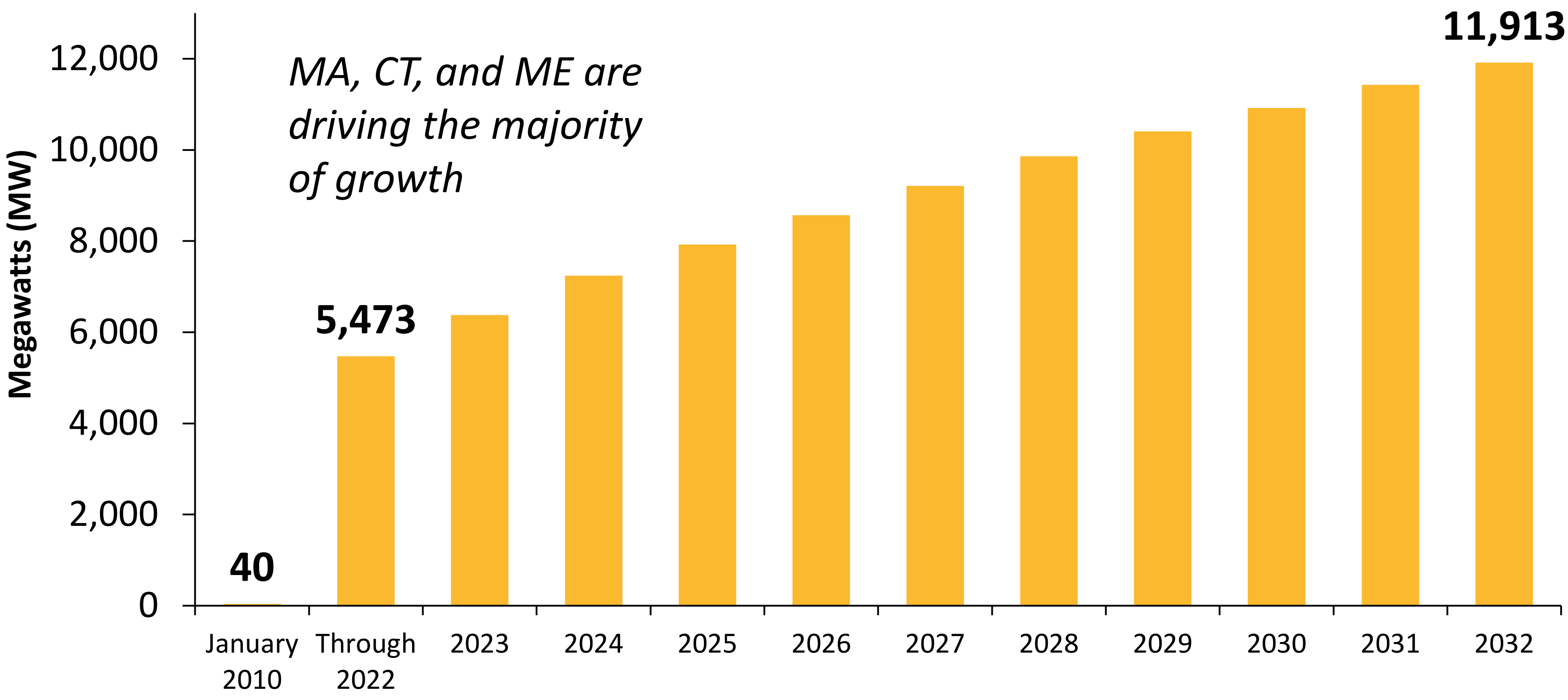


13GW+ worth of OSW in queue

11GW+ worth of BTM PV forecasted by 2031

ISO New England Forecasts Strong Growth in Solar Photovoltaic (PV) Resources

Cumulative Growth in Solar PV through 2032 (MW)



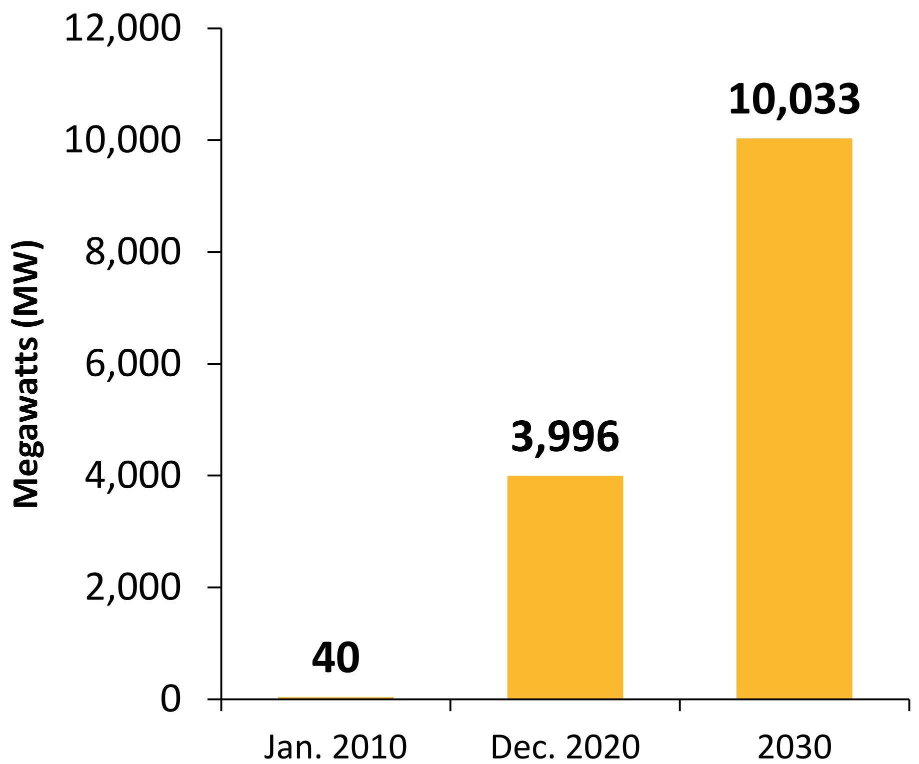
Note: The bar chart reflects the ISO's projections for nameplate capacity from PV resources participating in the region's wholesale electricity markets, as well as those connected "behind the meter." The forecast does not include forward-looking PV projects > 5 MW in nameplate capacity. Source: ISO New England 2023-2032 Forecast Report of Capacity, Energy, Loads, and Transmission (2023 CELT Report) (May 2023); MW values are AC nameplate. State specific details are available in the final report.

ISO New England Forecasts Strong Growth in Solar Photovoltaic (PV) Resources

December 2020 Solar PV Installed Capacity (MW_{ac})

State	Installed Capacity (MW_{ac})	No. of Installations
Connecticut	682.3	53,758
Massachusetts	2,502.3	114,487
Maine	68.8	5,597
New Hampshire	125.3	10,757
Rhode Island	223.8	9,688
Vermont	393.5	15,344
New England	**3,995.9**	**209,631**

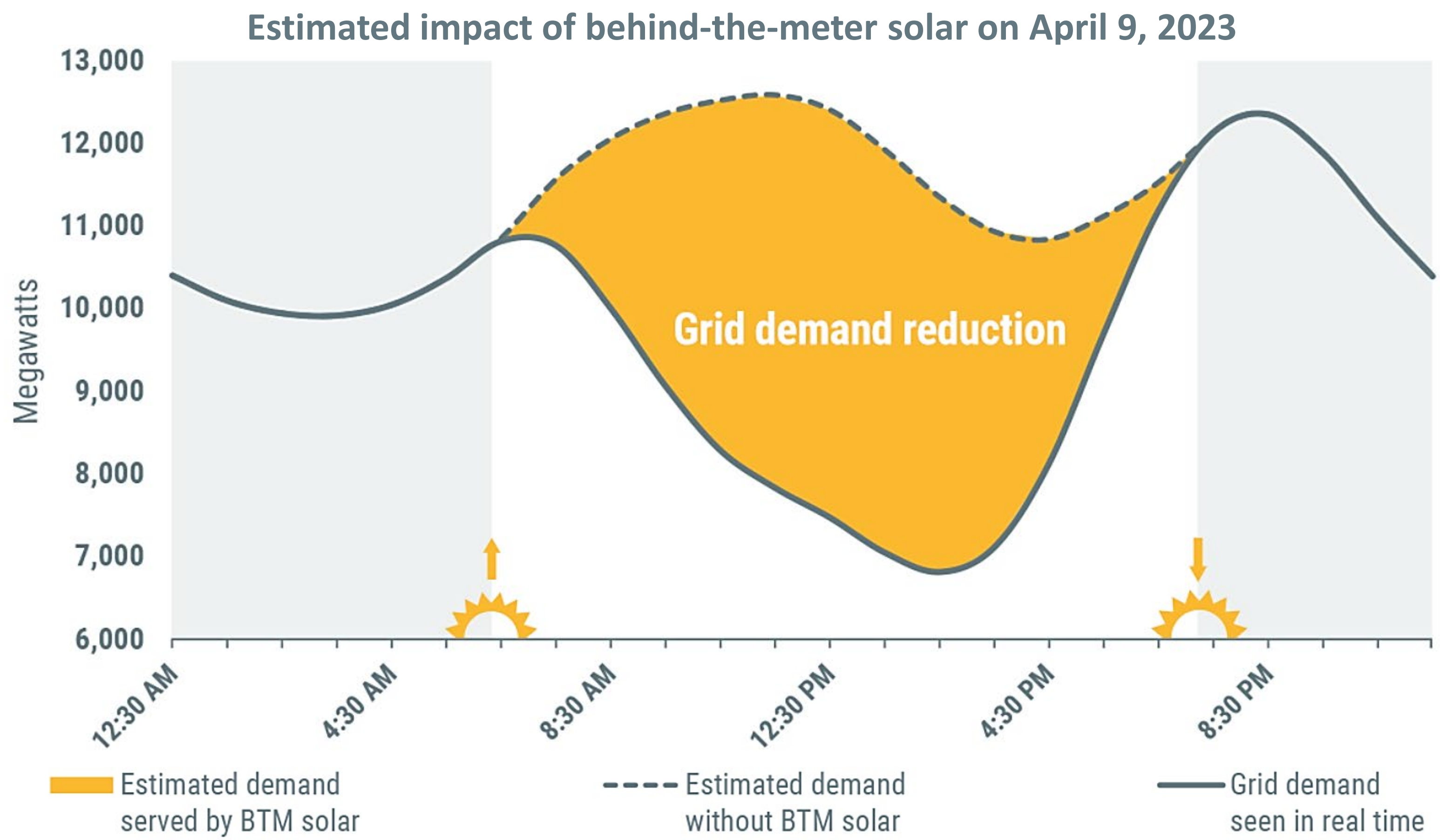
Cumulative Growth in Solar PV through 2030 (MW_{ac})



Note: The bar chart reflects the ISO's projections for nameplate capacity from PV resources participating in the region's wholesale electricity markets, as well as those connected "behind the meter." The forecast does not include forward-looking PV projects > 5 MW in nameplate capacity.
Source: Final 2021 PV Forecast (April 2021); and December 2020 Distributed Generation Survey Results; MW values are AC nameplate.

Nighttime Electricity Load on the Region's Electric Grid is Exceeding Daytime Consumption On Sunny Days

Continued development of solar deployment drives down afternoon load, especially in spring when demand is lower

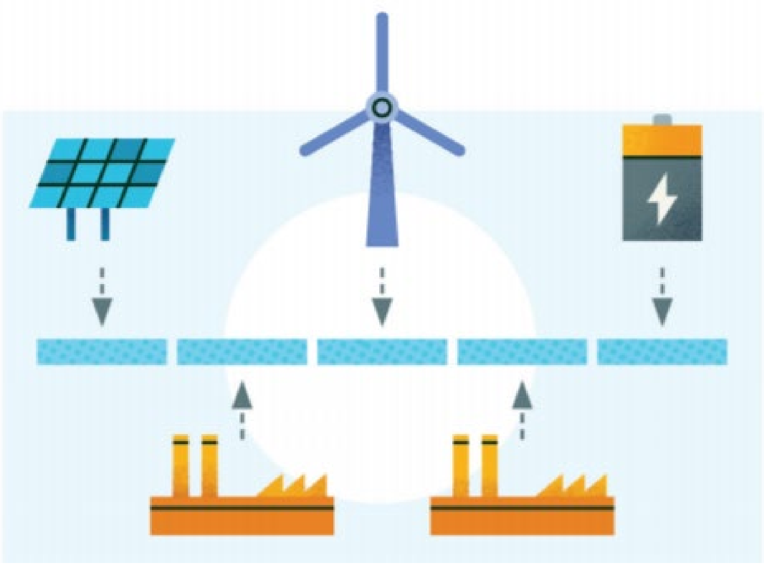


Source: ISO Newswire Article from April 11, 2023, [New England again sets record for low demand on regional power system - ISO Newswire]

New England Will Need Flexible Resources to Balance the Variability of Renewables

ISO is working to adapt both its operations and markets so the grid stays reliable and prices competitive as our energy mix transitions

Due to state policies driving change, **variable, renewable resources** will eventually become the new "baseload" resource and produce most of the electrical energy



Balancing resources will be necessary to "fill in" the energy gaps, which may last from seconds to weeks, and occur when renewable resources are not available or are not producing at full capacity

IEEE 1547-2018

What Is IEEE 1547?

- **The Institute of Electrical and Electronics Engineers (IEEE)** first created the standard in **2003**
- The Energy Policy Act of 2005 requires electric utilities to provide interconnection services based on IEEE 1547
- **IEEE 1547:**
  - **Governs** how certain resources connect to the electric grid, including:
    - **Technical specifications for, and testing of,** the interconnection and interoperability between utility electric power systems (EPSs) and distributed energy resources (DERs)
  - **Provides requirements** for:
    - **Performance, operation, testing, safety considerations, and maintenance** of the interconnection, including **cybersecurity standards** for information exchange and protocol
    - Responses **to abnormal conditions**, power quality, islanding, and test specifications

IEEE 1547-2018 AND BES/BPS RELIABILITY

IEEE 1547 is Essential for the Reliable Integration of DERs

- As the distribution system has **evolved**, so too has the transmission system

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

- Standards set by the North American Electric Reliability Corporation (NERC) and the Northeast Power Coordinating Council (NPCC) **require** the ISO to plan for **the contingency loss of resources**

- Historically, the concern has been large generators being disconnected or going unstable and tripping
  - This has changed with the proliferation of solar PV and other inverter-based/power electronics-based resources

NPCC, Inc.

Illustrative Example of the Need for IEEE 1547

- If the bulk system suffers a contingency, such as a loss of a large generator or transmission line, **and** a significant amount of DERs tripped off line because of it, the system would face a possible **second contingency from the loss of the DERs**
- This, in turn, would create **a surge in demand**, which would create further reliability problems
- If total source loss exceeds the amount allowed by the planning criteria, **a system upgrade would be required**

- **Key Takeaway**: Inverter settings can help address reliability issues and **obviate the need for transmission upgrades**

IEEE 1547-2018 IN NEW ENGLAND

Adoption of IEEE 1547 in New England

- Beginning in 2012, the ISO began providing support to stakeholders who were looking to adopt what was, at the time, a new iteration of the IEEE 1547 standard, IEEE 1547-2014a
- Beginning Jan 1, 2019 the ISO New England Source Requirement Document was in place for all states
  - Interim approach to IEEE 1547-2018
- Since that time, DERs have continued to proliferate and IEEE has updated its standard, IEEE 1547, again
- Eversource and National Grid have begun to adopt the latest version of IEEE 1547-2018 as amended by 1547a-2020
  - These utilities operate in Massachusetts, Connecticut, New Hampshire, and Rhode Island
  - **More than 60% of solar PV in New England is/will be installed in Massachusetts**
  - Additional details are available in the Appendix

Next Steps re: Adoption of IEEE 1547 in New England

- ISO New England will continue to provide technical support to stakeholders **throughout the region**
- The MA-Technical Standards Review Group (TSR has issued an update to the Source Requirement Document (SRD) **in July 2022,** which:
  - Had an effective date of **January 1st, 2023**

- **This new settings document will replace the current ISO-SRD**
- Eversource, Unitil, and National Grid have begun to adopt the latest version of IEEE 1547-2018 as amended by 1547a-2020
  - Because these utilities operate in **Massachusetts, Connecticut, New Hampshire, and Rhode Island,** their adoption **will apply to 80% of all solar PV in New England**

ENTER SERVICE SETTINGS

Enter Service Settings

- Clause 4.10 includes several settings associated with the criteria for entering service which includes return to service after tripping
  - Minimum voltage
  - Maximum voltage
  - Minimum frequency
  - Maximum frequency
  - Delay time
  - Ramp Rate
- From Transmission perspective:
  - Are default settings acceptable in each category?
  - If DER will ride-through for most transmission faults, is enter service mostly a distribution issue?
  - Is black start a concern?

Enter Service Settings

- 1547-2018 Clause 4.10.3.c establishes the ramp rate for entering service
- DER shall increase output of active power, or exchange of active power for energy-storage-DER, during *enter service* as specified. Active power shall increase linearly, or in a stepwise linear ramp, with an average rate-of-change not exceeding the DER nameplate active power rating divided by the enter service period. The duration of the *enter service* period shall be adjustable over a range of 1 s to 1000 s with a default time of 300 s. The maximum active power increase of any single step during the *enter service* period shall be less than or equal to 20% of the DER nameplate active power rating. Where a stepwise ramp is used, the rate of change over the period between any two consecutive steps shall not exceed the average rate-of-change over the full *enter service* period. This requirement is a maximum ramp rate requirement and the DER may increase output slower than specified.
- *Exception 1: For Local EPS that have an aggregate DER rating of less than 500 kVA, individual DER units may increase output of active power with no limitation of the rate-of-change, following an additional randomized time delay with a default maximum time random interval of 300 s, and with an adjustable range for the maximum time random interval of 1 s to 1000 s.*
- *Exception 2: Increase of output of active power by Local EPS having an aggregate DER rating of equal to or greater than 500 kVA and increasing output with active power steps greater than 20% of nameplate active power rating shall require approval of the Area EPS operator* ***in coordination with the regional reliability coordinator***

Enter Service Settings

- 1547-2018 Clause 4.10.3.b states DER shall be capable of delaying *enter service* by an intentional adjustable minimum delay.
- The default minimum delay is 300 s
- The adjustable range of the minimum intentional delay shall be 0 s to 600 s
- Can be dependent on size

New England			
Size Class	Site Count	ACKW	% ACKW
<10kW	127,095	727,423.56	24.6%
10kW-<20kW	23,877	274,996.02	9.3%
20kW-<100kW	3,334	148,065.92	5.0%
100kW-500kW	1,893	456,415.09	15.4%
>500kW-<1000kW	277	214,550.77	7.2%
1000kW-<5000kW	493	970,315.75	32.8%
>=5000kW	15	168,156.10	5.7%
Total	156,984	2,959,923.21	100%

*As of 12/31/2018

IEEE 1547 CATEGORIES FOR RESPONSE TO ABNORMAL CONDITIONS

IEEE 1547 Categories

- IEEE 1547 is technology neutral and thus does not establish performance requirements for specific DER technologies
- Instead it defines three categories related to the response of DER to abnormal conditions (Voltage and Frequency) that have different performance requirements
- IEEE 1547 suggests that "Authorities Governing Interconnection Requirements" define the performance requirement (the category) for each type of DER and provides guidance on how to do this in Annex B
- A significant factor in determining performance requirements is the level of penetration of the DER technology
- DER technology that has a high level of penetration will have the largest impact on reliability and should have the highest performance requirements

IEEE 1547 Category I

- Category I is based on minimal bulk electric system reliability needs and is reasonably attainable by all DER technologies that are in common usage today
- The disturbance ride-through requirements for Category I are derived from the German standard for medium voltage synchronous generators and is one of the most widely applied standards in Europe
- Many synchronous generator manufacturers are currently designing products to meet the requirements of this standard

IEEE 1547 Category II

- Category II is meant to cover all BES reliability needs and is coordinated with existing reliability standards to avoid widespread DER tripping for disturbances for which the bulk system generators are expected to remain connected
- It is based on NERC Standard PRC-024 (generator frequency and voltage protective relay settings), with additional allowance for the fact that voltage levels in distribution systems may have delayed recovery after disturbances due to load effects, and is harmonized with NERC Standard PRC-006 (under frequency load shedding standard) with regard to frequency ride-through requirements

IEEE 1547 Category III

- Category III provides the highest disturbance ride-through capabilities, intended to address integration issues such as power quality and system overloads caused by DER tripping in local Area EPS having very high levels of DER penetration
- This category also provides increased bulk power system security by further reducing the potential loss of DER during bulk system events
- These requirements are based on the California Rule 21 Smart Inverter requirements
- Note amendment 1547-2020a established more ride through capability for Cat III

Example Assignment of IEEE 1547-2018 Categories

DER Type	Example of Applications	Example Category
Engine	land fill gas	Category I
Synchronous generators	small hydro	Category I
Synchronous generators	combined heat and power	Category I
Synchronous generators	self-generation	Category I
Inverters sourced by solar PV		Category III
Inverters sourced by fuel cells		Category II
Inverters sourced by energy storage	Batteries either stand alone or associated with solar PV	Category II
Wind Turbines		Category II

*Example, not to be used as reference

FREQUENCY DROOP SETTINGS

Frequency Droop Settings

- IEEE 1547-2018 addresses frequency droop in Clause 6.5.2.7
- Frequency droop operation is mandatory for Categories I, II and III for high frequencies
- Frequency droop operation is mandatory for Categories II and III and optional for Category I for low frequencies
- 1547-2018 includes three settings associated with frequency droop
  - Dead band (*db*of,*db*uf)
  - The per-unit frequency change corresponding to 1 per-unit power output change (*k*of,*k*uf)
  - Open-loop response time, $T_{\text{response(small signal)}}$
    - Small-signal defined as a frequency deviation resulting in a power change of less than 5% of Rated Active Power
- Are the default settings for these variables satisfactory?

Frequency Droop Settings

Table 23—Formula for frequency-droop (frequency-power) operation for low-frequency conditions and high-frequency conditions for DER for all performance categories

Operation for low-frequency conditions	Operation for high-frequency conditions
$p = \min\limits_{f<60-db_{UF}} \left\{ p_{pre} + \frac{(60-db_{UF})-f}{60 \cdot k_{UF}}; p_{avl} \right\}$	$p = \max\limits_{f>60+db_{OF}} \left\{ p_{pre} - \frac{f-(60+db_{OF})}{60 \cdot k_{OF}}; p_{min} \right\}$

Table 24—Parameters of frequency-droop (frequency-power) operation for DER of abnormal operating performance Category I, Category II, and Category III

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

[a]Adjustments shall be permitted in coordination with the Area EPS operator.

[b]For the single-sided deadband values (db_{OF}, db_{UF}) ranges, both the lower value and the upper value is a minimum requirement (wider settings shall be allowed). For the frequency droop values (k_{OF}, k_{UF}) ranges, the lower value is a limiting requirement (the setting shall not be set to lower values) and the upper value is a minimum requirement (the setting may be set to greater values). For the open-loop response time, $T_{response\ (small\text{-}signal)}$, the upper value is a limiting requirement (the setting shall not be set to greater values) and the lower value is a minimum requirement (the setting may be set to lower values). Any settings different from the default settings in Table 24 shall be approved by the *regional reliability coordinator* with due consideration of system dynamic oscillatory behavior.

[c]A deadband of less than 0.017 Hz shall be permitted.

OTHER CONSIDERATIONS

ROCOF and Phase Angle Changes

- IEEE 1547-2018 Section 6.5.2.5 Within the continuous operation region and the low-frequency and high-frequency ride-through operating regions (frequency range and corresponding cumulative duration, minimum time), the DER shall ride through and shall not trip for frequency excursions having magnitudes of rates of change of frequency (ROCOF) that are less than or equal to the values specified in Table 21 per abnormal operating performance category. 103 As specified in 4.3, the ROCOF shall be the average rate of change of frequency over an averaging window of at least 0.1 s.

Table 21 —Rate of change of frequency (ROCOF) ride-through requirements for DER of abnormal operating performance Category I, Category II, and Category III

Category I	Category II	Category III
0.5 Hz/s	2.0 Hz/s	3.0 Hz/s

- IEEE 1547- 2018 Clause 6.5.2.6 Multi-phase DER shall ride through for positive-sequence phase angle changes within a sub-cycle-to-cycle time frame of the applicable voltage of less than or equal to 20 electrical degrees. In addition, multi-phase DER shall remain in operation for change in the phases angle of individual phases less than 60 electrical degrees, provided that the positive sequence angle change does not exceed the forestated criterion. Singlephase DER shall remain in operation for phase angle changes within a sub-cycle-to-cycle time frame of the applicable voltage of less than or equal to 60 electrical degrees. Active and reactive current oscillations in the post-disturbance period that are positively damped or momentary cessation of the DER having a maximum duration of 0.5 s shall be acceptable in response to phase angle changes.

Compliance and Certification

- 1547.1 Interconnection System Testing
  - Standard for testing compliance with 1547
- UL1741 Standard for Inverters, Converters, Controllers, and Interconnection system Equipment for Use with Distributed Energy Resources
  - UL1741-SA Grid Support Interactive Inverters
  - Being use for certifying compliance with SRDs
- UL1741-SB directly refers to 1547.1-2020 and is the only test procedure to certify IEEE 1547-2018 compliance

COMPARISON OF NEW SETTINGS

ISO-SRD & New Voltage Trip Settings

Shall Trip – IEEE Std 1547-2018					
Shall Trip Function	ISO SRD Settings (CAT II)		New Settings (CAT III)		
	Voltage (p.u. of nominal voltage)	Clearing Time(s)	Voltage (p.u. of nominal voltage)	Clearing Time(s)	Within ranges of allowable settings?
OV2	1.20	0.16	1.20	0.16	Yes
OV1	1.10	2.0	1.10	2.0	Yes
UV1	0.88	2.0	0.88	**3.0**	Yes
UV2	0.50	1.1	0.50	1.1	Yes

ISO-SRD Voltage Ride-Through Capability and Additional Operational Requirements

Voltage Range (p.u.)	Operating Mode/ Response	Minimum Ride-Through Time(s) (design criteria)	Maximum Response Time(s) (design criteria)	Comparison to IEEE Std 1547-2018 for Category II
V > 1.20	Cease to Energize	N/A	0.16	Identical
1.175 < V ≤ 1.20	Permissive Operation	0.2	N/A	Identical
1.15 < V ≤ 1.175	Permissive Operation	0.5	N/A	Identical
1.10 < V ≤ 1.15	Permissive Operation	1	N/A	Identical
0.88 ≤ V ≤ 1.10	Continuous Operation	infinite	N/A	Identical
0.65 ≤ V < 0.88	Mandatory Operation	Linear slope of 8.7 s/1 p.u. voltage starting at 3 s @ 0.65 p.u.: $T_{VRT} = 3\text{ s} + \frac{8.7\text{ s}}{1\text{ p.u.}}(V - 0.65\text{ p.u.})$	N/A	Identical
0.45 ≤ V < 0.65	Permissive Operation [a,b]	0.32	N/A	See footnotes a & b
0.30 ≤ V < 0.45	Permissive Operation [b]	0.16	N/A	See footnote b
V < 0.30	Cease to Energize	N/A	0.16	Identical

The following additional operational requirements shall apply for all inverters:

a. **In the Permissive Operation region above 0.5 p.u., inverters shall ride-through in Mandatory Operation mode, and**

b. **In the Permissive Operation region below 0.5 p.u., inverters shall ride-through in Momentary Cessation mode with a maximum response time of 0.083 seconds.**

New Settings Voltage Ride-Through Capability and Additional Operational Requirements

Voltage Range (p.u.)	Operating Mode/ Response	Minimum Ride-Through Time(s) (design criteria)	Maximum Response Time(s) (design criteria)	Comparison to IEEE Std 1547-2018 (2nd ed.) for Category III
V > 1.20	Cease to Energize	N/A	0.16	Identical
1.10 < V ≤ 1.20	Momentary Cessation	12	0.083	Identical
0.88 ≤ V ≤ 1.10	Continuous Operation	infinite	N/A	Identical
0.70 ≤ V < 0.88	Mandatory Operation	20	N/A	Identical
0.5 ≤ V < 0.70	Mandatory Operation	10	N/A	Identical
V < 0.50	Momentary Cessation	N/A	0.083	Identical

ISO-SRD & New Settings Frequency Trip Settings (No Changes)

Shall Trip Function	Required Settings		Comparison to IEEE Std 1547-2018 (2nd ed.) default settings and ranges of allowable settings for Category I, Category II, and Category III		
	Frequency (Hz)	Clearing Time(s)	Frequency	Clearing Time(s)	Within ranges of allowable settings?
OF2	62.0	0.16	Identical	Identical	Yes
OF1	61.2	300.0	Identical	Identical	Yes
UF1	58.5	300.0	Identical	Identical	Yes
UF2	56.5	0.16	Identical	Identical	Yes

ISO-SRD & New Settings Frequency Ride-Through Capability (No Changes)

Frequency Range (Hz)	Operating Mode	Minimum Time(s) (design criteria)	Comparison to IEEE Std 1547-2018 (2nd ed.) for Category II & III
f > 62.0	No ride-through requirements apply to this range		Identical
61.2 < f ≤ 61.8	Mandatory Operation	299	Identical
58.8 ≤ f ≤ 61.2	Continuous Operation	Infinite	Identical
57.0 ≤ f < 58.8	Mandatory Operation	299	Identical
f < 57.0	No ride-through requirements apply to this range		Identical

ISO-SRD & Newly Proposed SRD Grid Support Utility Interactive Inverter Functions Status

Function	ISO SRD Default Activation State	Newly Settings Default Activation State
SPF, Specified Power Factor	OFF	On @ Unity
Q(V), Volt-Var Function with Watt or Var Priority	OFF	OFF
SS, Soft-Start Ramp Rate	ON Default value: 2% of maximum current output per second	DER shall enter service in accordance with IEEE 1547-2018 Clause 4.10.3, part c.
FW, Freq-Watt Function	OFF	ON

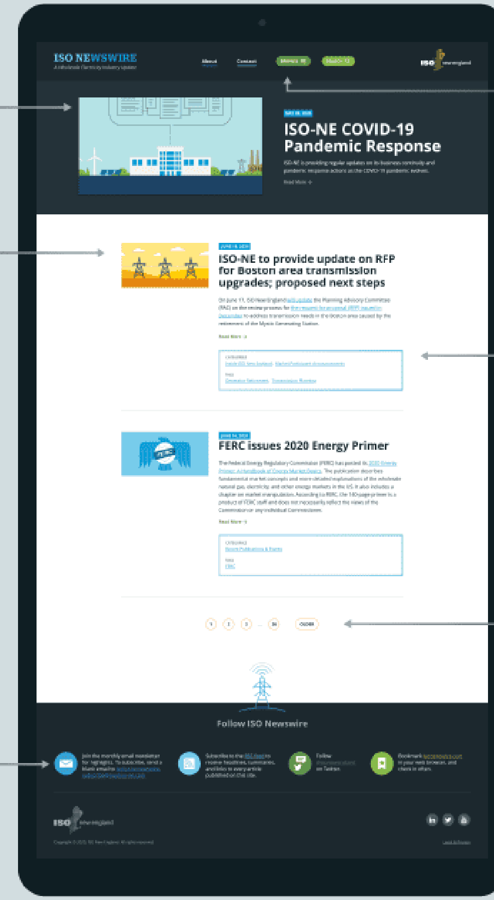
New Settings Document

- Document can be found on the MA-TSRG website:
  - Default IEEE1547-2018 Settings Requirements 2022_12_13_V2.pdf

ISO Website: New Information and New Look

The New iso-ne.com Homepage

The New isonewswire.com



Questions

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