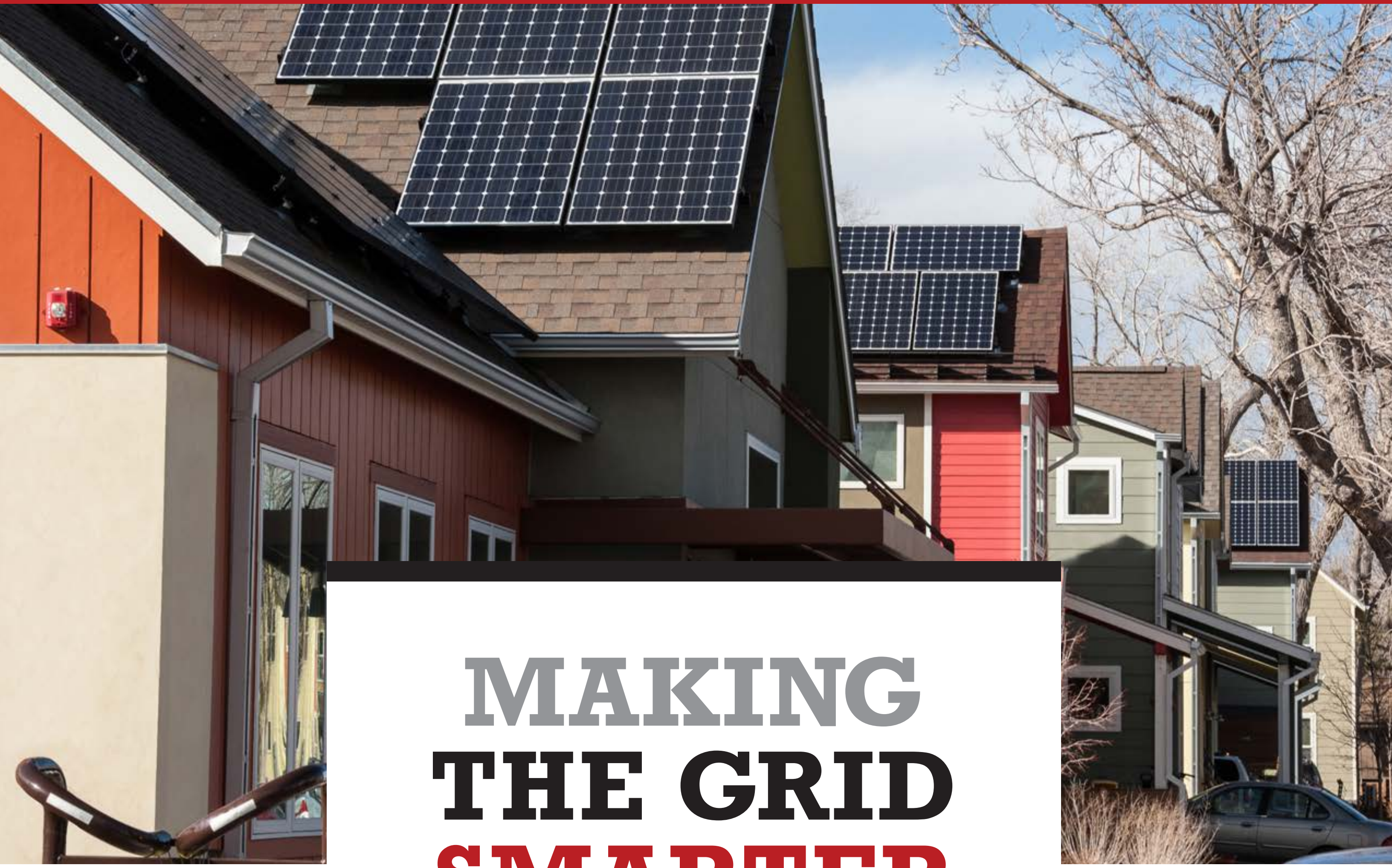

# MAKING THE GRID SMARTER

**Primer on Adopting the New IEEE 1547™-2018 Standard for Distributed Energy Resources**

JANUARY 2019


IREC
Interstate Renewable Energy Council

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Interstate Renewable Energy Council



January 2019



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# Table of Contents

Executive Summary ........................................ 4

I. Introduction to the IEEE 1547™-2018 Standard ........................................ 6

II. Anticipated Timeline for Full Rollout of IEEE Std 1547™-2018 ........................................ 8

III. Integration of IEEE Std 1547™-2018 into Interconnection Rules ........................................ 9

IV. Reference Point of Applicability and Evaluation, Commissioning and Verification of DERs..... 11

V. IEEE Std 1547™-2018 Categories, Functions and Issues for Consideration ........................................ 13

- A. Category Explanation and Assignment ........................................ 13
- B. Voltage Regulation Functions ........................................ 16
- C. Communications, Controls & Interoperability ........................................ 20
- D. Power Quality ........................................ 22
- E. Islanding ........................................ 23
- F. Secondary Network Distribution Systems ........................................ 24
- G. Fault Current ........................................ 24
- H. System Controls and Power Limitation at the PCC ........................................ 25

VI. Other Key Issues for Consideration ........................................ 27

VII. Conclusion: State Leadership to Implement IEEE Std 1547™-2018 ........................................ 29

VIII. Key Acronyms ........................................ 30

IX. Key Codes & Standards ........................................ 30

X. Key Terms ........................................ 31

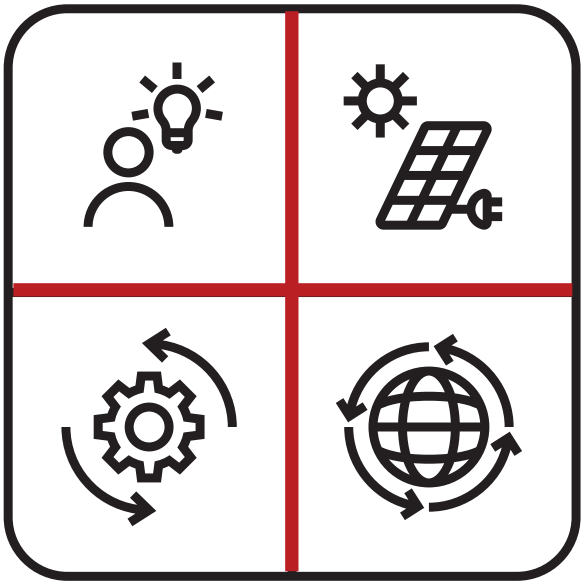
XI. Additional Resources ........................................ 33

**Table of Figures**

Figure 1: Anticipated Timeline for the Rollout of IEEE Std 1547™-2018 ........................................ 8

## Executive Summary

In April 2018, the Institute of Electrical and Electronics Engineers (IEEE) published the *IEEE Standard 1547™-2018 for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547™-2018 or the Standard)*, which is a voluntary, nationally-applicable Standard that will transform how distributed energy resources (DERs) interact with and function on the electric distribution system. It is the long-awaited update to *IEEE Standard 1547™-2003, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems (IEEE Std 1547™-2003)*.



The Standard requires DERs to be capable of providing specific grid supportive functionalities relating to voltage, frequency, communications and controls. Once widely utilized, these functionalities will likely enable higher penetration of DERs on the grid, while maintaining grid safety and reliability and providing new grid and consumer benefits. Even in states where DER penetration remains low today, implementing IEEE Std 1547™-2018 sooner rather than later will help ensure new DERs meet the most updated performance standards, provide enhanced grid functionality, and avoid high volumes of legacy systems that do not provide such capabilities.

State adoption and implementation of this Standard will require the attention of state regulators – who will be tasked with formally adopting the new Standard at the state level – as well as utilities who will integrate them into internal interconnection protocols. In addition, DER industry representatives, technology manufacturers, state and federal agencies, national laboratories and advocates will play key roles in the consideration and adoption of the new Standard. In contrast with the 2003 Standard, which provided one set of requirements for all DERs, IEEE Std 1547™-2018 features a menu of options that need to be considered and selected.

State implementation of IEEE Std 1547™-2018 will benefit from fair, balanced and transparent stakeholder processes to ensure that the perspectives of all impacted stakeholders, including consumers adopting DERs, are accounted for and reflected.

This primer provides an overview and explanation of the major revisions in IEEE Std 1547™-2018 and the issues that regulators, utilities and other stakeholders will need to consider as they work

**With this reference guide in hand, those working to address and integrate the updated standards will be better equipped to streamline the implementation process and optimize the rules governing the grid.**

through adopting and implementing the Standard. While not attempting to provide in-depth details of the entire Standard, this document provides an accessible overview and insights on the following topics:

- The key requirements and implications of IEEE Std 1547™-2018 and impacts on its adoption and implementation for regulators, utilities, DER developers, customers and the grid;
- The anticipated timeline for the full rollout of IEEE Std 1547™-2018, including the development of applicable test procedures and equipment certification standards;
- DER performance categories for reactive power, and performance during abnormal voltage and frequency conditions, and key issues for consideration;
- Voltage regulation functions and corresponding implications of these functions on the grid and DER developers;
- IEEE Std 1547™-2018 compliant communications protocols, controls and functional settings for DERs and issues surrounding their integration and harmonization across different networks and between technologies;
- Updates to power quality requirements, including new limits for rapid voltage changes, flicker and overvoltage;
- Issues surrounding grounding practices, islanding, secondary networks, fault current, and power limitations at the point of common coupling (all of which will likely impact state interconnection procedures and protocols);
- DER testing and verification, including DER design and as-built evaluations, as well as commissioning and periodic tests and DER settings verifications; and
- Key takeaways and overarching policy issues states and regulators should consider as they work to adopt and implement IEEE Std 1547™-2018.

With IEEE Std 1547™-2018 published and a few remaining years before full rollout (2022), now is the time for states and regulators to begin to implement the updated Standard. Early consideration and integration of IEEE Std 1547™-2018 and related standards will ensure states have ample time to navigate the complex issues that involve stakeholder coordination and pave a smooth path for widespread deployment of smarter DER technologies. With this reference guide in hand, those working to address and integrate the updated standards will be better equipped to streamline the implementation process and optimize the rules governing the grid.

## I. Introduction to the IEEE 1547™-2018 Standard

In April of 2018, the Institute of Electrical and Electronics Engineers (IEEE) published a major revision of the national Standard for interconnection of DERs known as the *IEEE Standard 1547™-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces (IEEE Std 1547™-2018 or the Standard)*.[1] The Standard requires DERs to provide capabilities for specific grid supportive functionalities, including voltage and frequency ride-through, voltage and frequency regulation, as well as communications and control functionality. In addition, they may provide enhanced functions, such as ancillary services. When utilized, these capabilities can help increase the amount of DERs that can be accommodated on the grid, improve power quality for all customers, and ensure that DERs can continue to be a reliable and optimized grid resource as penetration increases.

These new requirements will enable DERs to communicate with and receive signals from the grid operator or a third party (aggregator). Although applicable for any type of DER, the majority of new DERs interconnecting to the gird in the coming years are expected to be inverter-based DERs with so-called "smart inverters" or "advanced inverters" that can comply with the new Standard. Using more sophisticated communication infrastructure, these smart inverters can be controlled and monitored remotely. Among other advantages, these communications and controls will enable DERs to convey performance data with the utility (or an aggregator) to increase situational awareness and more quickly diagnose and address any operational or maintenance issues.

IEEE Std 1547™-2018 represents a considerable shift from the 15-year old IEEE Standard 1547™-2003, *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems* (IEEE Std 1547™-2003) in that the 2018 version has no single default set of DER capabilities and settings.

1 In June of 2018, IEEE published errata that corrected an erroneous sign in the frequency-droop formula of Table 23 of Clause 6.5.2.7.

**The Standard requires DERs to provide capabilities for specific grid supportive functionalities, including voltage and frequency ride-through, voltage and frequency regulation, as well as communications and control functionality.**

The updated Standard is a menu with options that need to be selected dependent on technology, location or other factors. Although each entity will be responding and adapting to the new Standard in different ways, IEEE Std 1547™-2018 will have an impact on DER developers, installers, manufacturers, customers and utilities. As they work to adopt and implement the new Standard, state utility regulators will play an important role in ensuring that all stakeholders' interests are balanced, with the overall goal of increasing the safety, security, resilience and reliability of the grid.

Once widely implemented, IEEE Std 1547™-2018 will result in the following primary changes:

- The interconnection process used for DERs connecting to the grid will change.
- The large number of optional functions and settings will require development of a process to verify the DER settings in the commissioning process.
- DERs will have the ability to automatically respond to certain grid conditions, which will help avoid potential negative impacts and optimize their grid benefits.
- More DERs will be capable of connecting to the grid under higher penetration scenarios, assuming their control functions are set up adequately to accommodate the grid conditions.
- Standardized communication protocol capabilities could allow for wider control of DERs through integration with Supervisory Control and Data Acquisition (SCADA) systems or Distributed Energy Resource Management Systems (DERMS).
- Customers installing DERs may see shifts in their distributed generation output under certain scenarios, which might require the adoption of new consumer protection measures.

The optionality inherent to IEEE Std 1547™-2018 may be more challenging to apply uniformly, with potential for different implications for certain functions based on DER system size, technology or local grid conditions. This document provides an overview and explanation of the major revisions in IEEE Std 1547™-2018 and a synopsis of some of the issues that states will need to consider as they work through adopting the updated Standard.

## II. Anticipated Timeline for Full Rollout

With IEEE Std 1547™-2018 now formally published, work to publish revisions to the accompanying IEEE Standard 1547.1™, *IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems* (IEEE Std 1547.1™), is underway. IEEE Std 1547.1™ will guide manufacturers as they test and certify their products to the IEEE Std 1547™-2018 Standard. IEEE Std 1547.1™ is expected to be published in 2019-2020. Underwriters Laboratories (UL) will then update its product certification standard, *Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources* (UL 1741), to which all equipment must be tested and certified. UL is coordinating closely with IEEE and has stated the revision to UL 1741 will likely be available within a few weeks following publication of the revised IEEE Std 1547.1™. From that point, it is anticipated that it will then take up to 18 months for all DER products to comply with the updated requirements and be made commercially available (see Figure 1).


*Figure 1: Anticipated Timeline for the Rollout of IEEE Std 1547™-2018*

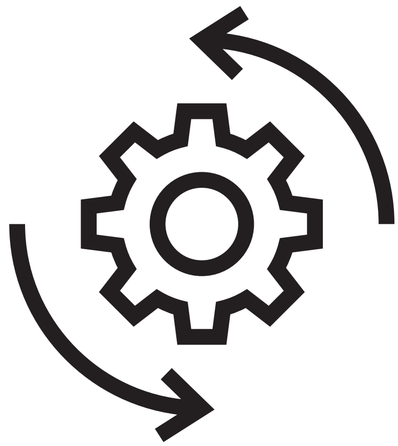
In addition to considering the above timeline, local, state or regional DER market conditions may inform whether a more expedited process to adopt the new Standard (or parts thereof) is warranted in advance of the development of IEEE Std 1547.1™ and UL 1741 updates. For example, California and Hawaii expended significant effort to initiate smart inverter implementation efforts in advance of the adoption of IEEE Std 1547™-2018 due to the prevalence of DERs on their respective utilities' grids. Implementation efforts in both states are still underway, and harmonization with IEEE Std 1547™-2018 will be required.[2]

For most states, given the increased menu of options within the updated Standard, it will likely be a worthwhile exercise to begin a stakeholder process or formal proceeding in the near-term in order to ready the state and utilities for the full rollout of IEEE Std 1547™-2018. Namely, to ensure the streamlined integration of DERs with enhanced capabilities and functions envisioned by IEEE Std 1547™-2018, it will be important to ensure that rules are in place by the time certified DER devices are available on the market. As part of its order adopting updated interconnection standards for its regulated utilities, the Minnesota Public Service Commission has already convened a workgroup to evaluate the integration of the IEEE Std 1547™-2018 as part of the state's development of the Minnesota Distributed Energy Resources Technical Interconnection and Interoperability Requirements.[3]

2 Currently, the requirements are state-specific and are predicated on the smart inverter test protocols of UL 1741 Supplement SA instead of IEEE Std 1547.1™.

3 Minnesota Public Service Commission, Docket Nos. E-999/CI-01-1023 and E-999/CI-16-521, Order Establishing Updated Interconnection Process and Standard Interconnection Agreement (August 13, 2018).

## III. Integration of IEEE Std 1547™-2018 into Interconnection Rules



The use of DERs is expanding quickly as more people are seeking to adopt distributed grid-integrated technologies in their homes, businesses, communities and public institutions. IEEE Std 1547™-2018 is a core standard that will maintain or increase the stability, reliability and intelligence of the distribution grid over time, as DER levels increase. The new Standard also addresses increasing aggregate DER impacts on the bulk power system. Even in states where DER penetration is low today, implementing the new Standard will help ensure new DERs meet the most updated performance standards, while giving latitude to utilize the enhanced grid functionality as the volume of DERs increases on the grid (avoiding the preponderance of legacy DERs).

Any current state rules and utility interconnection procedures that are based on IEEE Std 1547™-2003 will need to be updated to reflect these recent revisions. Clearly defining DER settings in statewide interconnection rules[4] will help increase efficiency, minimize confusion, and reduce costs. States or utilities that have not yet adopted interconnection rules could begin the process today with IEEE Std 1547™-2018 in mind, rather than retroactively adopting it (which could be inefficient and resource intensive for all involved stakeholders).

Rather than a single package of default settings that work in all instances and for all technologies, IEEE Std 1547™-2018 adds new features and requirements and includes more flexibility and options. Utilities and state regulatory commissions will need to evaluate, select and assign different "performance categories" for different DERs. In addition, as applicable, states and utilities will need to consult and coordinate with the Regional Reliability Coordinator and Regional Transmission Organization (RTO), Independent System Operator (ISO), or other transmission operator on certain issues within IEEE Std 1547™-2018 relating to reliability and performance. Starting now to adopt IEEE Std 1547™-2018 will give state regulators, utilities, DER developers and customers the time necessary to navigate some of the more complex issues to integrate and enhance the adoption of smarter grid technologies.

To make the most of the standard and prepare for higher DER penetration in the future, regulators and utilities should consider the opportunity to utilize certain functions before achieving higher penetration of DERs, so as to optimize future DER growth and avoid negative impacts as

4 As applicable to those utilities regulated by state public service commissions. Other utilities not regulated by a state regulatory commission could integrate IEEE Std 1547™-2018 into their applicable interconnection rules and tariffs (voluntarily or as directed by state statute).

Any current state rules and utility interconnection procedures that are based on IEEE Std 1547™-2003 will need to be updated to reflect these recent revisions. Clearly defining DER settings in statewide interconnection rules will help increase efficiency, minimize confusion, and reduce costs.

penetration increases. For example, as discussed below in Section V.B, high penetration of DERs on certain circuits can potentially affect the voltage of the grid, which could negatively impact power quality if not managed. IEEE Std 1547™-2018 requires DERs to be capable of participating in voltage regulation, through a number of functions that may be activated. Voltage regulation can help mitigate any negative grid impacts while also allowing DERs to connect to locations on the grid where once they might not have been able to do so. States and utilities will need to determine if and when voltage regulation functions should be turned on (since voltage regulation is disabled by default in the new Standard), which function should be utilized, which settings should be used, and how enabling these functions will interact with interconnection rules. The implementation of voltage regulation functions will also warrant consideration of the impacts on and protections for individual DER customers. The voltage regulation example is just one of many that states will be tasked with evaluating as part of their adoption of IEEE Std 1547™-2018.

Even though the full implementation of the updated Standard will take a few more years, it is not too soon for states, utility regulators, utilities and stakeholders to begin the process to adopt and integrate it into interconnection rules.

Alongside existing interconnection best practices, IEEE Std 1547™-2018 can support the optimized integration of new technologies, while maintaining grid safety and reliability. Even states and utilities with low levels of DER deployment could adopt IEEE Std 1547™-2018 in order to build up the functional capabilities, while still specifying settings close or equal to those from IEEE Std 1547™-2003. For states with multiple regulated utilities, statewide adoption of IEEE Std 1547™-2018 will provide greater consistency across utilities and enable a more streamlined rollout of the Standard, which will benefit consumers, utilities and DER developers alike.

# IV. Reference Point of Applicability and Evaluation, Commissioning and Verification of DERs

In adopting the IEEE Std 1547™-2018, it is important to clarify the physical point on the electric grid where compliance with the Standard's requirements will be assessed. This point is known as the *reference point of applicability*[5] and it determines which method is used to evaluate compliance with the Standard. For most large DER systems, this will be the Point of Common Coupling (PCC), which is the point of connection between the DER customer and the utility.[6] However, for some systems, especially smaller DER projects[7], the reference point of applicability for the IEEE Std 1547™-2018 requirements may be the Point of DER Connection (PoC), which is the point where a DER is electrically connected on a customer's site and meets the requirements of IEEE Std 1547™-2018, exclusive of any load present in the respective portion of the customer's site.

IEEE Std 1547™-2018 details specific DER evaluation[8] and commissioning testing requirements, and the tables therein indicate which evaluations or commissioning tests should be performed based on the reference point of applicability (and whether or not fully tested, fully compliant DER units are utilized). Further details on the extent of those evaluations and commissioning tests will be given in the next version of IEEE Std 1547.1™. Generally speaking, the DER project size, configuration and equipment determine the reference point of applicability and corresponding compliance methods. For example:

- **For DER projects that regularly export more than 500 kVA[9] (i.e., larger systems or dedicated generating facilities), the requirements of IEEE Std 1547™-2018 must be met at the PCC. In addition to evaluation by the utility to verify compliance, additional equipment commissioning testing may be required.**
- **For smaller DERs, using the PoC as the reference point of applicability allows the DER equipment type testing certification to be utilized as the main method by which compliance with the Standard is verified. The PoC might be the terminals of an inverter, for example, and utilizing a UL 1741 certified and listed inverter would be sufficient to demonstrate Standard compliance.[10]**

5 See IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, IEEE Std 1547™-2018, subclause 4.2.

6 Typically, at the utility revenue meter.

7 Either a) DER nameplate rating ≤ 500 kVA, or b) average load demand greater than 10% of DER nameplate and where it does not export more than 500 kVA for longer than 30 seconds, as with an "inadvertent export" system.

8 Evaluation is the review of the design of the DER system and/or a review of the "as-built" DER system, typically performed by a utility engineer.

9 See "Power limitation at the PCC" section for discussion on how export may be limited to 500 kVA or less.

10 If "zero-sequence continuity" is not maintained between PCC and PoC, then sensing for faults, open-phase and voltage must be accomplished at another appropriate location.

- A DER system comprised of a DER unit or DER units (e.g., individual inverters) that is type tested for full compliance with the Standard can be considered in compliance at the PCC as long as the interconnection system (between the PoC and PCC) does not interfere with proper operation of the required DER functionality.[11]
- A DER unit that is not fully compliant with IEEE Std 1547™-2018 could be utilized along with supplementary devices (e.g., additional equipment to provide reactive power capability) such that the system as a whole meets the requirements of the Standard, whether at the PCC or PoC. Given the increased challenge of verifying compliance where multiple pieces of equipment are utilized to meet the requirements, more detailed evaluation and commissioning testing may be required.[12] Given that this is an evolving field and verification practices may differ substantially among utilities, IEEE Std 1547™-2018 only gives some guidance and does not specify mandatory requirements.

Interconnection rules should allow for the appropriate level of evaluation and commissioning testing to be performed as part of the interconnection review process, dependent on the variables described in IEEE Std 1547™-2018. Any projects that go through fast track or supplemental review[13] should also align with the relevant evaluation and commissioning protocols, to maintain an expedited and streamlined process for systems eligible within this level of review.

Verification[14] of functional settings (e.g., trip and voltage regulation settings) is an important aspect of commissioning that becomes more complicated by the additional functions and variety of settings that IEEE Std 1547™-2018 allows. Many inverters include settings profiles (a.k.a., manufacturer-automated profiles) that allow all relevant operational parameters to be automatically loaded by selecting one of a few default options. Adopting IEEE Std 1547™-2018 default values for functional settings will help simplify the DER project verification process, since smart inverters will automatically be equipped with these default setting profiles. However, to the extent states and utilities across the country adopt different trip and functional settings, new processes and/ or verification measures may need to be developed to ensure that the DERs are commissioned appropriately.

At this juncture, efforts continue to simplify the process of quickly conveying settings from a utility (a.k.a. utility-required profile) to the DER (a.k.a. manufacturer-automated profile) in a standardized format (e.g., using digital means). Stakeholders should remain aware of those evolving discussions and adjust processes as necessary over time.

11 Lack of "interference" is defined in IEEE Std 1547™-2018 as having an impedance less than 0.5% between PoC and PCC.

12 The evaluation and commissioning tests can be simplified if the DER unit is certified in combination with the supplemental equipment.

13 Interstate Renewable Energy Council, *Priority Considerations for Interconnection Standards: A Quick Reference Guide for Utility Regulators*, p. 6, August 2017, available at: ***https://irecusa.org/priority-considerations-for-interconnection-standards***. "The Fast Track process consists of several technical screens intended to easily identify proposed interconnections that will not threaten the safety and reliability of the electric system, and allow these systems to proceed through an expedited review process. Although the technical screens decide whether a project will be able to interconnect without a full study, an overall size limit for Fast Track eligibility offers applicants a useful indicator as to whether or not their system is at all likely to pass those screens and serves an administrative function for utilities to help sort projects into the proper study track. In the former iteration of the FERC SGIP and in many states' procedures, Fast Track review is limited to systems up to 2 MW. More recently, FERC and several states have moved away from a broadly applicable cap to a more nuanced, table-based approach, which accounts for location-related factors that affect the likelihood of the generator to have adverse impacts on the electric system. Specifically, the table-based approach allows the size limit to increase as the voltage of the line increases and if a generator is closer to the substation." And "If an interconnection applicant fails one or more of the Fast Track screens, many states' procedures allow it to undergo 'supplemental review' or 'additional review' to determine whether or not it could interconnect without full study. . . In its most recent revision to SGIP, FERC integrated a more transparent supplemental review process that relies on three screens, including a penetration screen (Screen 1), set at 100 percent of minimum load. In most cases, if the proposed generation facility is below 100 percent of the minimum load measured at the time the generator will be online, then the risk of power back-feeding beyond the substation is minimal and thus there is a good possibility that power quality, voltage control and other safety and reliability concerns may be addressed without the need for a full study. The other two screens allow for utilities to evaluate any potential voltage and power quality (Screen 2) and/or safety and reliability impacts (Screen 3)."

14 See IEEE Std 1547™-2018, clause 11.

# V. IEEE Std 1547™- 2018 Categories, Functions and Issues for Consideration

## A. Category Explanation and Assignment

IEEE Std 1547™-2018 identifies two performance categories[15] relevant to DER grid functionality: the Normal Operating Performance Category and the Abnormal Operating Performance Category. The Normal Operating Performance Category specifies how the DER should perform with regards to voltage control during normal grid operations. The Abnormal Operating Performance Category specifies DER performance during a grid disturbance such as a transmission fault or loss of a generator. Within each, there are options to further clarify the performance and functional capability levels. The assignment of these categories will determine the interconnected DERs' capability to respond to changing grid conditions and support and maintain electric grid power quality and stability.

Certain DER technologies are capable of different levels of performance. As one example, inverters used with solar photovoltaic (PV) and energy storage systems are capable of the highest level of grid performance for both normal and abnormal conditions. Other technologies may not be able to accommodate the highest level of performance. As such, the category assignment and level of performance may need to be determined on a technology-specific or use case-specific basis. Annex B of IEEE Std 1547™-2018 contains further discussion of how categories might be selected. The two categories and the primary issues within each are as follows:

- The **Normal Operating Performance Category** (normal category) determines the level of *reactive power*[16] support a DER system must be capable of providing, and there are two options to determine the amount of reactive power support available: *Category A* and *Category B*. Category B provides the most reactive power support. IEEE Std 1547™-2018 requires all DERs to be capable of providing reactive power in order to regulate and maintain voltage within the American National Standards Institute (ANSI) C84.1 range A, which is considered the normal range for the U.S. electric grid (hereinafter normal range). The normal category mostly determines how well the DER can support local voltage to stay within the normal range.

15 See IEEE Std 1547™-2018, clauses 5 and 6.

16 Reactive power, measured in *vars*, is power that does not do work, but is stored or returned to the circuit every half cycle. Reactive power results whenever the voltage and current waveforms are shifted in time relative to one another (known as a phase shift or "out of phase"), rather than being aligned (crossing zero at the same time or "in phase").

- The **Abnormal Operating Performance Category** (abnormal category) determines the level of voltage and frequency *ride-through capability*, and within this are three options of performance: *Category I*, *Category II* and *Category III*. The assignment of the abnormal category will determine the aggregate DER impact on the bulk power system (i.e., the transmission system and wholesale electric grid). To a large extent, the voltage and frequency ride-through capabilities of the abnormal category will determine how reliably DERs can maintain generation during bulk-electric grid disturbances. Thus, as applicable, states should consult and collaborate with their Regional Reliability Coordinator and RTO, ISO or transmission operator when making decisions regarding the abnormal category. For the Standard to simultaneously be technology neutral and enable high penetration of DERs, different categories allow for different levels of performance. For example:

    - Category I is intended for certain types of DERs which are expected to remain at lower penetration on the grid (e.g., flywheel storage) or are not capable of higher performance but provide some societal benefits (e.g., combined heat and power).
    - Category II is intended to allow for protective settings similar to IEEE Std 1547™-2003, while still requiring sufficient performance capability to address the bulk electric system and reliability issues arising from increasing DER penetration, as well as distribution-level events such as Fault-Induced Delayed Voltage Recovery (FIDVR) to a certain extent.
    - Category III is intended to address very high DER penetration and distribution reliability issues, including adjacent feeder faults and more extreme FIDVR, in addition to bulk-system reliability. Category III offers the highest level of ride-through capability but does not allow for business-as-usual protective settings such as IEEE Std 1547™-2003 (due to limited ranges of adjustable settings).

One consideration for regulators is whether and to what extent customers should be informed regarding this potential reduction in active power and what potential compensation or other protections should be required as a result.

In addition to ride-through capability, the abnormal category contains a default *frequency-droop* (a.k.a. *frequency-power*) function which must not be disabled.[17] The default setting for frequency droop requires active power reduction from DERs when the frequency of the grid is above 60.036 Hz, and active power increase—to the extent possible, depending on DER power output—when frequency is below 59.964 Hz.

Automatic adjustments to active power output (in order to maintain normal frequency) may result in DER customers experiencing reductions in their generation, at times, which could potentially result in a reduced return on their investment, depending on if and how their generation is compensated.[18] As such, one consideration for regulators is whether and to what extent customers should be informed in advance of this potential reduction in active power and what potential compensation or other protections should be required as a result.[19] How energy losses will be accounted for and tracked matters and can help inform the discussion on consumer protections. As a starting point for tracking this data, utilities should have the ability to estimate energy losses over time using internal system frequency data. However, other means may be necessary to accurately assess the magnitude and regularity of energy losses incurred by DER customers.

Changing the category assignment for a DER *after* it has been interconnected to the grid poses potential challenges that should be duly considered in the process to adopt IEEE Std 1547™-2018. While changing DER settings to a different value than originally specified may be technically possible, it may not be done efficiently without widespread communications infrastructure in place. In addition, DER technologies that are certified to a lower performance category may not be configured with the full range of capabilities and would be unable to shift to operate in compliance of higher performance categories. For this reason, the category assignment and performance capability levels within each and applicability for different DER technologies should be given careful consideration at the outset of the Standard's adoption efforts. Note that DERs that are certified to a higher performance category can, in most cases, meet the requirements of a lower performance category.

17 The requirements are consistent with FERC Order No. 842. Distribution utilities are discouraged from desensitizing the frequency-droop function by specifying a frequency dead band much wider than the default setting of 36 mHz.

18 The frequency of the grid on the mainland of the United States is quite stable, and thus any resulting reductions in generation should be, for most customers, *de minimis*.

19 It should be noted that the three major interconnections (Eastern, Western and ERCOT) in the U.S. have not ventured outside the stated limits with any regularity in the past.

## B. Voltage Regulation Functions

Historically, DERs have not been required to support *voltage regulation*[20]. However, substantially higher volumes of DER on certain circuits can potentially cause the voltage of the grid to be affected, which could negatively impact power quality if not managed. As such, one of the major reasons for updating IEEE 1547 was to explicitly require DERs to be capable of participating in voltage regulation. It is important to note that other factors outside of DERs can impact voltage on the grid, including: a utility's voltage regulation practices, feeder design, and other DERs on the system. Different locations on a circuit will have different voltage regardless of the presence of a DER, with locations nearer to a substation or voltage regulation device generally having higher voltage, and locations further away having lower voltage.

Notwithstanding these external factors, according to IEEE Std 1547™-2018, states and utilities need to determine if and when voltage regulation functions should be turned on, which function should be utilized, and which settings should be used.[21] As previously noted, voltage regulation is *disabled* by default, so careful consideration should be given to determine what mode is desired.

Within IEEE Std 1547™-2018, there are several functions that may be activated in order to regulate voltage, and thus help mitigate any negative impacts on the grid. IEEE Std 1547™-2018 provides defaults and adjustable ranges for each of the voltage regulation functional settings, to the extent they are enabled.[22] Each of these functions interact with the grid differently and have differing impacts on the generation output of DERs. It should also be noted that the effectiveness of the reactive power functions depends on the characteristics of the circuit to which the DER is connected, so some variance in settings based on location may be desirable.[23]

One of the major reasons for updating IEEE 1547 was to explicitly require DERs to be capable of participating in voltage regulation. According to IEEE Std 1547™-2018, states and utilities need to determine if and when voltage regulation functions should be turned on, which function should be utilized, and which settings should be used.

20 The intentional adjustment of voltage with the goal of maintaining it within the normal range.

21 See IEEE Std 1547™-2018, clause 5.

22 The standard also prescribes "reactive power priority" over less effective "active power priority," the latter of which was utilized in California's interconnection rules (Rule 21).

23 For instance, the reference voltage for the volt-var function, Vref, could be chosen based on circuit location.

The following are reactive power functions defined within IEEE Std 1547™-2018 that affect voltage:

- **Constant power factor mode**:[24] In this mode, the power factor—which is the ratio of *active power* (a.k.a. real power or true power)[25] to *apparent power*[26]—is set to the desired value and remains the same, even as the power output from the DER fluctuates. It can be set to either absorb or inject reactive power. Absorbing reactive power tends to decrease voltage, while injecting reactive power tends to increase voltage. Of note, constant power factor is the default mode for voltage regulation in IEEE Std 1547™-2018 and the default setting is 1.0 (unity), which *does not* provide voltage regulation. Typical power factor settings that are useful for voltage regulation are 0.95 - 0.98 absorbing. Category A DERs can reach 0.97 absorbing, while Category B DERs can reach 0.90 absorbing.
- **Voltage-reactive power mode** *(a.k.a. volt-var)*: In this mode, the DER modulates its absorption or injection of reactive power in relation to the measured grid voltage. There can be a "dead band" near normal voltage where no reactive power is absorbed or injected. Values for the gain (or droop) setting of the function other than the default values must be carefully chosen because a high gain (small droop) value may cause the control to become unstable while a low gain (high droop) may be ineffective.
- **Active power-reactive power mode** (a.k.a. watt-var): In this mode, the DER modulates its absorption or injection of reactive power in relation to its active power output (and absorption of active power for DERs that can store energy).
- **Constant reactive power mode**: In this mode, the DER absorbs or injects a specified amount of reactive power regardless of its active power level (i.e., reactive power remains constant as power output from the DER fluctuates).

Of note, in addition to the reactive power functions, there is a mode that utilizes a reduction in active power to decrease voltage (normally only once voltage is outside of the normal range, or ANSI C84.1 range A). This mode is known as *voltage-active power mode* (a.k.a. *volt-watt*).

Of the above reactive power functions, the IEEE Std 1547™-2018 default is the constant power factor mode, with a setting of "unity" (i.e., no reactive power). Therefore, no voltage support nor its benefits will be realized with the IEEE Std 1547™-2018 default settings. States and utilities seeking to enable and utilize voltage regulation functions will want to clarify in rules which voltage regulation function DERs should utilize and adjust from IEEE Std 1547™-2018 defaults accordingly. Only one of the four reactive power functions can be activated at a time for an individual DER, while volt-watt may be activated independently of the reactive power functions.

24 This is also expressed as the cosine of phi (cos), the phase angle between the current and voltage waveforms, which is more technically correct than "power factor."

25 Active power does the actual work in the load. Active power is measured in watts (W) and is the power consumed by electrical resistance.

26 Apparent power is the combination of reactive power and active power. Apparent power is the product of a circuit's voltage and current, without reference to phase angle, and is measured in volt-amperes (VA).

**States and utilities seeking to enable and utilize voltage regulation functions will want to clarify in rules which voltage regulation function DERs should utilize and adjust from IEEE Std 1547™-2018 defaults accordingly.**

Constant power factor mode, watt-var mode, and constant reactive power mode all have largely predictable effects on both the distribution grid and on DER generation. All three modes will cause *var flow*[27], regardless of whether var flow is needed to regulate voltage. Excessive var flow reduces the efficiency of power delivery and reduces the active power capacity of a circuit. The volt-var mode aims to proportionately increase reactive power as voltage gets further from normal, thus reducing or eliminating var flow on the circuit when it is not needed. The default settings for volt-var (including response time) in IEEE Std 1547™-2018 are meant to be applicable in a wide range of scenarios where nominal voltage[28] is desired.

Individual DERs may interact more beneficially with the distribution system if the volt-var function's reference voltage (a.k.a. $V_{ref}$)[29] is adjusted for the particular location on the circuit, which would require the utility to convey the proper value or mode during the interconnection process via the utility-required profile. Should utilities wish to conduct a more detailed study to ensure a DER does not interact with other distribution system components in an undesirable manner, existing power flow tools should be able to model the impacts of volt-var functions.

When considering the adoption of voltage regulation functions, states and utilities should keep in mind their interaction with interconnection procedures and how these functions might impact whether a grid upgrade might be necessary to connect the DER to the grid. As DER penetration on the grid increases, enabling voltage regulation functions might allow certain DERs to connect to locations on the grid where previously they might not have been able to (i.e., without triggering a grid upgrade or a modification to the DER project to mitigate voltage impacts). Similarly, voltage regulation functions have the ability to increase the DER hosting capacity of a circuit, and thus should be accounted for in any formal hosting capacity analysis effort going forward.[30] As states and utilities proceed with DER hosting capacity analyses, the methodology should be refined to reflect the impact of default voltage regulation settings on hosting capacity values. The reactive power demand of DERs may also have impacts on the distribution system that need to be accounted for.[31]

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27 Var flow is the presence of reactive power on the distribution grid conductors and equipment. Though it does not deliver active power, it still causes heating effects on the conductors.

28 Nominal voltage is 120V on a 120V base. Generally, it is the center of the normal service voltage range specified by ANSI C84.1 range A.

29 A specific value for Vref can be set, or alternatively can be autonomously calculated by the DER based on local measurement.

30 Hosting Capacity is the amount of DERs that can be accommodated on the distribution system under existing grid conditions and operations without adversely impacting operational criteria or requiring significant infrastructure upgrades. For more information about hosting capacity analyses, see IREC's *Optimizing the Grid: A Regulator's Guide to Hosting Capacity Analyses for Distributed Energy Resources*, available for free download at: *https://irecusa.org/publications/optimizing-the-grid-regulators-guide-to-hosting-capacity-analyses-for-distributed-energy-resources/*.

31 Such impacts include the ability of the substation or transmission system to supply vars necessary to support the reactive power requirements of the DERs, and the reduction of active power capacity of conductors.

Voltage regulation has the possibility of reducing the generation output of certain DERs. For example, inverters may be "current-limited" at maximum rated power, especially those used for residential DERs.[32] Any requirement for the inverter to produce reactive power would cause a decrease in the maximum active power available. Additionally, the volt-watt function has the potential to drastically reduce active power and could contribute to major generation losses, if triggered regularly. At this juncture, it is challenging to predict how voltage-dependent functions (e.g., volt-var and volt-watt) will affect generation over the lifetime of the DER, especially since the voltage of a circuit is time-varying and could change over the course of several years.

To address potential impacts on DER customers resulting from the implementation of voltage regulation functions, regulators may want to consider adopting some consumer protection measures. To begin with, states and utilities can establish reporting procedures to track customer generation losses resulting from the utilization of voltage regulation functions, which can help regulators determine the scale and frequency of customer impacts over time. Regulators should consider clarifying the following issues to help inform the adoption of customer protection measures in the future:

- **Guidelines for tracking and reporting any customer generation losses;**
- **Methods and techniques for estimating losses and/or the extent of voltage excursions;**
- **Regular utility reporting, filed with the utility commission, of when, where, how often voltage regulation functions are utilized;**
- **Identification and consideration of possible corrective measures in the event losses are deemed excessive or unwarranted (e.g., DER settings adjustments, monetary reimbursement, etc.).**

In considering the consumer impacts of voltage regulation functions, regulators should aim to strike the appropriate balance of optimizing the functionality for the benefit of the grid and customers, while minimizing negative impacts on the economic value of an individual customer's investment.

Lastly, it is important to note that voltage regulation functions on the distribution system are optimized, particularly at higher DER penetration, if all or most of the DER systems are participating in voltage regulation. Implementing voltage regulation only for new DERs after higher DER penetration has been achieved may dramatically reduce the effectiveness of this function. In addition, such late-stage adoption of voltage regulation functions may disproportionately affect new DER customers seeking to connect to the grid after a significant amount of non-voltage regulating DER projects are connected. Hawaii, for example, learned that the grid would have been able to host higher penetration of DERs if they had been able to deploy these functions early on.[33]

32 For any active power level, reactive power production requires more current from the inverter. If all available current is being used to produce active power (i.e. at maximum active power) and the inverter is called on to produce reactive power, it must reduce active power so that some current capability can be utilized to provide the required reactive power. Some inverters have an apparent power (kVA) rating larger than the active power (kW) rating, allowing them to supply some reactive current even at maximum active power output. Since residential inverters are often connected on the load side of a customer's load center or panelboard, the maximum inverter current is limited by the circuit breaker used, per National Electrical Code rules. Depending on the size of the breaker and panelboard bus, it could be undesirable to utilize an inverter with a kVA rating higher than the kW rating.

33 Giraldez, Julieta, et al., *Simulation of Hawaiian Electric Companies Feeder Operations with Advanced Inverters and Analysis of Annual Photovoltaic Energy Curtailment*, National Renewable Energy Laboratory and Hawaiian Electric Company, pp. 80-82, September 2017, available at: *https://www.nrel.gov/docs/fy17osti/68681.pdf.*

## C. Communications, Controls & Interoperability

All the grid supportive functionality mentioned thus far can operate autonomously, by simply reacting to local measurements of voltage or frequency, as necessary. The autonomous functions are a large step in the direction of effectively integrating DERs into the grid. However, the eventual adoption of communications and controls will be key to unlocking the full potential of DERs on the grid. A key feature of IEEE Std 1547™-2018 is the requirement for DERs to include provisions for a local DER communication interface, with a minimum set of communications capabilities which could allow even more benefits to be realized, as well as allowing settings to be adjusted over time.

State interconnection rules (and in some cases utility interconnection handbooks or guidance documents) will need to specify which DERs will be required to integrate with communications systems (e.g., DERs that meet a certain kVA threshold), and what communications protocol the utilities will use at the DER communication interface. Ideally, there would be requirements for consistency across utilities, where possible, in order to minimize costs and confusion in the marketplace. Additionally, consideration should be given as to whether or not a particular physical communications port should be available at the DER.[34] Since communications services can be also be provided by third-party aggregators that control numerous DERs, requirements or agreements that address the aggregator relationships to the DER owner and the utility should also be considered. Lastly, additional consideration should be given to when and how utilities utilize these communications functions to control DER functionality, which may impact the operation of the DER. States and utilities should be specific about the conditions under which DERs may be remotely curtailed, turned off, and/or when changes to certain settings or functions may be warranted. Any controls that affect DER generation will have consumer protection implications (as noted above) that will need to be proactively addressed and documented in interconnection agreements.

States and utilities should be specific about the conditions under which DERs may be remotely curtailed, turned off, and/or when changes to certain settings or functions may be warranted.

34 IEEE Std 1547™-2018 standardizes the use of an Ethernet port with TCP/IP transport layer for any of the three protocols, with an option for an RS-485 port for SunSpec Modbus.

IEEE Std 1547™-2018 requires all categories of DERs to support at least one of three communication protocols through a specified local DER communication interface: IEEE Std 2030.5™ (SEP2), IEEE Std 1815™ (DNP3), or SunSpec Modbus.[35] IEEE Std 1547™-2018 also requires DERs to support specific parameters for monitoring information and for managing functional settings (including protection and controls). In the absence of communications infrastructure, access to the settings of the DER must be available through a hardware or software panel on site. Of note, given the inherent challenge of adjusting these settings after a DER has been commissioned (an in-person visit to the DER location would likely be necessary), it is important to adopt settings that will not likely require adjustment after commissioning.

Traditionally, larger DER projects and/or those with special interconnection agreements (e.g., DERs participating in wholesale markets) have been required to have communications and controls enabled in order to interface with the grid operators. However, these technical capabilities have not yet been standardized. Over time, it is expected that the communication protocols will continue to harmonize and be capable of communicating across different networks and between technologies that have distinct settings (a.k.a. *interoperability*[36]). These updated requirements for communications and interoperability will help optimize DERs on the grid and improve safety and reliability. Transitioning to IEEE Std 1547™-2018 compliant local DER communications interfaces will require time for widespread deployment of communications infrastructure by grid operators or third parties, and consideration of related issues, including cybersecurity and standardization of communication network performance requirements.[37]

The ease and cost of implementing new communication protocols will be highly dependent on the availability of existing infrastructure and a utility's existing capabilities. For states where the utility may have outdated or inefficient communications systems, regulators will need to carefully consider the cost impact (to all ratepayers and/or to individual DER customers) of updating and/or revamping existing systems to allow for more sophisticated communications to occur with DERs in order to utilize the IEEE Std 1547™-2018 required capabilities. To ensure transparency and alignment with IEEE Std 1547™-2018, states may want to evaluate the deployment of communications and controls infrastructure in the context of existing or planned Smart Grid, Grid Modernization, Distribution Resource Plan, and/or Integrated Resource Plan proceedings.

35 IEEE Std 2030.5™ is the IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard; IEEE Std 1815™ is the IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3); SunSpec Modbus is a standard that defines a set of common register values for devices such as three-phase inverters, single-phase inverters, meters, environmental units, and related measurement devices, see *https://sunspec.org* for more information.

36 See IEEE Std 1547™-2018, clause 10.

37 Performance or cybersecurity requirements related to DER management networks are outside the scope of IEEE Std 1547™-2018.

## D. Power Quality

IEEE Std 1547™-2018 introduces new limits for rapid voltage changes, flicker and overvoltage—all of which relate to power quality.[38] In addition, the Standard alters and clarifies harmonic distortion limits. These requirements ensure that other utility customers located on the same circuit as a DER, as well as the utility equipment, are not negatively affected. These requirements pertain to all categories without any optionality, so no decisions need be made regarding their application within interconnection rules. References or requirements for power quality in existing interconnection rules or utility handbooks should be updated to align with these new IEEE Std 1547™-2018 provisions.

The overvoltage limits in IEEE Std 1547™-2018 ensure that DER complies with *effective grounding* requirements.[39] These limits, along with compliance tests in IEEE Std 1547.1™, will help to clarify if and when grounding banks or grounding transformers are needed to limit *ground fault overvoltage*.[40] While equipment requirements for effective grounding for rotating machines are commonplace, recent research has shown that inverter-based DERs do not have similar responses in terms of overvoltage events.[41] IEEE Std C62.92.6™-2017[42] helps explain the concepts of inverter response and how grounding does or does not affect overvoltage. Whether effective grounding requirements are addressed in a state or utility's interconnection rules or not, it may be prudent to review utility practices in order to ensure that excessive grounding is not required for DERs and that DER customers do not bear the cost and time burden associated with unnecessary equipment.

The overvoltage limit in IEEE Std 1547™-2018 also addresses another effect known as *load rejection overvoltage*. In the scenario where a circuit breaker or other device initiates an island condition,[43] cutting off a portion of the load to which a DER was initially providing power, there is insufficient load available to consume the DER power being fed onto the grid. This results in an overvoltage situation called load rejection overvoltage. Historically, concerns over load rejection overvoltage have led utilities to limit DER penetration or take other conservative actions to prevent damage to other customers' or the utility's equipment. Initial research on inverter load rejection overvoltage response conducted by NREL noted "over-voltages were less severe than some observers had feared and have allayed some utility concerns."[44] Hawaiian Electric has required load rejection test data for inverters for several years. IEEE Std 1547.1™ will require similar testing and the DER must remain within the stated limits of IEEE Std 1547™-2018. This, in turn, will impact interconnection studies and the technical screening process for DERs seeking to connect to the grid. As such, states and utilities will need to address how interconnection requirements might change in light of these new mandatory limits that all DERs will be subject to once IEEE Std 1547™-2018 is fully rolled out.

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38 See IEEE Std 1547™-2018, clause 7.

39 Effectively grounded systems limit overvoltage to 139% of nominal.

40 Single line to ground faults on a system that has lost its ground reference, where a breaker has opened and before DER disconnects or ceases production, can potentially cause large overvoltages on the order of 173% of nominal.

41 Hoke, Andy, et al., *Inverter Ground Fault Overvoltage Testing*, National Renewable Energy Laboratory and SolarCity Corporation, August 2015, available at: *https://www.nrel.gov/docs/fy15osti/64173.pdf*.

42 Guide for Application of Neutral Grounding in Electrical Utility Systems, Part VI- Systems Supplied by Current-Regulated Sources.

43 Islanding is the condition in which a distributed generator continues to power a portion of a circuit even though power from the electrical grid is no longer present.

44 Nelson, Austin, et al., *Inverter Load Rejection Over-Voltage Testing*, National Renewable Energy Laboratory and SolarCity Corporation, February 2015, available at: ***https://www.nrel.gov/docs/fy15osti/63510.pdf***.

## E. Islanding

Requirements for a DER to avoid unintentional islanding[45] remain mostly unchanged in IEEE Std 1547™-2018, however certain provisions have been modified.[46] For example, according to the Standard, the time limit (a.k.a. *clearing time*) for DERs to detect islands and cease energization may be extended from the current 2 seconds up to 5 seconds, by mutual agreement of the utility and the DER customer. In cases where risk of islanding for longer than 2 seconds is an identified possibility, this longer time may allow anti-islanding methods to operate or for the voltage to collapse on its own, eliminating the island. The 5 second time limit may require that any recloser upstream of the DER also have sufficiently long reclose time (i.e., greater than the DER clearing time or greater than the time at which the island would collapse). Another option is to use voltage-permissive reclosing, where the reclose is blocked if an island is present on the isolated feeder section. Where it can be determined that an increased DER clearing time can be utilized without negatively affecting safety and reliability, recloser settings can be coordinated to accommodate DER connection that may otherwise be subject to *Direct Transfer Trip* (DTT)[47] or other costly upgrades. The benefit of this increase in DER clearing time would apply to all DER downstream of the relevant recloser, though it may only initially be proposed as a mitigation strategy for a single DER (or group of DERs) that may be at risk of having to go through a costly or time-intensive interconnection study.

IEEE Std 1547™-2018 also addresses, to a more limited extent, intentional islands (a.k.a. *microgrids*) that are fully behind the PCC[48] (a.k.a *intentional Local Electric Power System (EPS) island*) or that include a portion of the Area EPS (a.k.a *intentional Area EPS island*). Intentional Area EPS islands, sometimes called "utility microgrids," could include DERs from multiple owners, load-only customers and utility equipment. IEEE Std 1547™-2018 specifies special requirements for DERs that participate in intentional Area EPS islands. Utilization of such capabilities is subject to mutual agreement with the DER owner and the utility.

The Standard gives special exemptions to DERs in intentional islands from the ride-through performance and trip requirements and allows them to disconnect from the grid and form an island as long as certain power balance criteria are met.

As states, communities and utilities seek to improve and enhance grid resilience and reliability, especially during inclement weather or severe electric system disruptions, adopting state regulations and standards surrounding intentional islands can provide important clarity for how these islands interact with and function on the existing grid. For example, it may be prudent to include some language in state and utility interconnection requirements to make it clear that such intentional islands are explicitly allowed and subject to certain appropriate technical requirements.

45 Islanding is the condition in which a distributed generator continues to power a portion of a circuit even though power from the electrical grid is no longer present.

46 See IEEE Std 1547™-2018, clause 8.

47 DTT usually consists of a fast communications link from breakers or reclosers upstream of the DER to a relay at the DER location which can disconnect the DER whenever the upstream devices disconnect. These are generally bespoke solutions that can include new telephone wire or other communications channels to be put in place, as well as additional equipment or adjustments at the utility device and DER locations.

48 Point of Common Coupling (the point of connection between the DER customer and the utility, typically at the utility revenue meter).

## F. Secondary Network Distribution Systems

IEEE Std 1547™-2018 clarifies the provisions for meeting operational requirements for DERs interconnecting to secondary spot networks and secondary grid networks.[49] Any existing language in interconnection rules addressing network interconnection may need updating based on the new Standard. However, the additional requirements are more akin to secondary networks design and DER operations considerations and do not alter requirements from IEEE Std 1547™-2003. The new language does allow DERs to be connected to Area Networks, where that was not addressed in the earlier Standard. IEEE Std 1547.6™ provides more explanation on recommended practices.

## G. Fault Current

Operators of electronically coupled (i.e., inverter-based) DERs with an aggregate rating of 500 kVA and larger are required by IEEE Std 1547™-2018 to provide the utility with detailed voltage and current data for faults obtained during certification testing.[50] No additional changes to the interconnection process are likely necessary, beyond specifying this data requirement. However, as this data is collected over time, attention should be paid as to whether changes to the interconnection processes are warranted based on the utilities' evolving understanding of inverter fault current.

**As states, communities and utilities seek to improve and enhance grid resilience and reliability, adopting state regulations and standards surrounding intentional islands can provide important clarity for how these islands interact with and function on the existing grid.**

49 See IEEE Std 1547™-2018, clause 9.

50 See IEEE Std 1547™-2018, subclause 11.4.

## H. System Controls and Power Limitation at the PCC

IEEE Std 1547™-2018 implies that certain export control systems can be used to prevent DERs from exporting onto the grid beyond designated specifications (e.g., for DERs that are designed to be non-exporting[51] or limited exporting[52]).[53] However, the Standard does not give specific guidance on how these system controls should be implemented. As such, further definition of related requirements may be prudent to include in interconnection rules to address these systems.

For example, IEEE Std 1547™-2018 notes that the reference point of applicability may be determined based on whether or not the DER is prevented from exporting power more than 500 kVA for longer than 30 seconds. This implies that a DER may include a plant controller that measures export power and controls the DER units to serve on-site load, while ensuring a specific power limit is not exceeded. Similar controls may be used to implement the volt-watt function, such that on-site load can be served even when voltage is high. The concept might also be extended to the limit active power function, where an external control demands power export reduction. Furthermore, a DER system may also include export-limiting controls in order to comply with other relevant compensation policies pertaining to exported or excess generation (e.g., net energy metering).

As another option to control the output of a DER, IEEE Std 1547™-2018 allows for the possibility of a "configured" nameplate rating[54] to be used. This relatively new concept would allow for the use of a configuration setting to limit the nameplate capacity of the DER to a lower capacity than its actual nameplate capacity, and this setting would effectively prevent the DER from exporting power beyond the configured nameplate rating at the reference point of applicability (e.g., the PoC).

**One important consideration in the discussion surrounding limiting power export and system controls is the concept of inadvertent export.**

51 DER systems primarily designed to serve on-site customer load that never or rarely export energy onto the grid.

52 DER systems designed to never or rarely export energy beyond a certain limited power level.

53 See IEEE Std 1547™-2018, subclauses 4.2, 4.6.2 and 5.4.2 footnote 65.

54 See IEEE Std 1547™-2018, subclause 10.4

While the Standard does not specify the details of using this setting, a state or utility's interconnection rules could define and allow for this as an option for system control. Alternatively, or in addition, the details could be determined and defined through mutual agreement between the utility and the DER customer (likely via the interconnection agreement).

One important consideration in the discussion surrounding limiting power export and system controls is the concept of *inadvertent export*[55], which occurs when power higher than the specified limit may incidentally be exported onto the grid for short periods of time. Introducing and defining this concept in state interconnection rules may be important to allow for limited-export and non-exporting DERs to be sufficiently addressed, namely in the context of interconnection standards. Similar requirements that include the concept of inadvertent export have been introduced in interconnection rules in Hawaii, California, Nevada[56] and elsewhere in relation to non-exporting systems. Consideration should be given to how the application of inadvertent export and export limitations impact interconnection eligibility and how technical screens are applied. This is an evolving area of discussion and applicable requirements and testing standards for controls are still under development.

55 When non-exporting or limited-export DERs inadvertently export limited amounts of power for very short durations, it is typically due to transient mismatch between system output and load consumption (when unanticipated load fluctuations occur). This can occur for customers whose systems are sized to closely match their load, or those with larger loads that may abruptly turn off while being supplied by the DER system. Importantly, inadvertent export is different from "islanding".

56 For instance, Hawaiian Electric Rule 22, Appendix II; PG&E Rule 21, section Mm; and NV Energy Rule 15, section I.4.b.

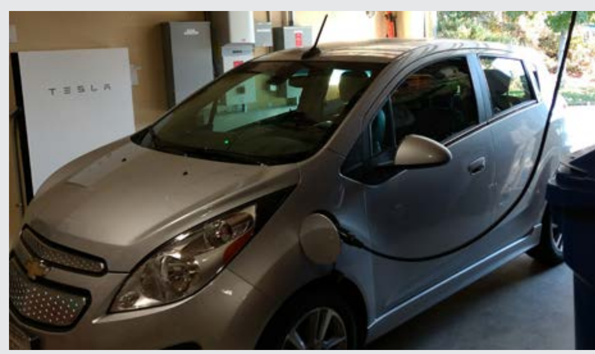
## VI. Other Key Issues for Consideration

As states work to adopt and implement IEEE Std 1547™-2018, the following overarching policy issues warrant careful consideration:

- **Opportunities and Impacts of Frequency and Voltage Regulation**: Utilization of frequency regulation and DER design for improved power quality will be *required by default* in IEEE Std 1547™-2018. However, voltage-regulating functions are *not required to be turned on by default*. To make the most of the Standard and prepare for higher DER penetration in the future, regulators and utilities should consider the opportunity to utilize voltage regulation functions *before* achieving higher penetration of DERs. Reaching high penetration *before* implementing these functions can limit their effectiveness to increase the grid's hosting capacity for more DER over the long-term.

- **Consumer Impacts and Protections**: Utilizing IEEE Std 1547™-2018 enabled functions can (dependent on the settings) reduce a DER system's generation at certain locations, which can impact a consumer's investment and project economics. Care must be taken to ensure customers are not unduly affected by the required settings. Since the performance of voltage regulation functions depend on a customer's location on the grid as well as factors outside of the customer's control, such as utility voltage regulation practices, introducing these functions may complicate system performance modeling and potentially reduce a consumer's expected return on investment. Adopting explicit consumer protection provisions may be necessary to ensure that customers are aware of any potential loss of generation over time and/or that recourse exists to the extent a single customer experiences a disproportionate amount of generation loss. Similarly, DER system designers need to understand and model the effects of the new functions on DER output power to convey accurate information to customers regarding anticipated lifetime generation.

Utilizing IEEE Std 1547™-2018 enabled functions can (dependent on the settings) reduce a DER system's generation at certain locations, which can impact a consumer's investment and project economics.



- **Updates to State Interconnection Procedures and Protocols**: The adoption and integration of IEEE Std 1547™-2018 into state and utility interconnection procedures will impact the review process for all DER, and states should work to ensure as much consistency and harmonization as possible among the different utilities within their jurisdiction. State public service commissions can set forth "preferred" IEEE Std 1547™-2018 settings that apply to all regulated utilities in the state, which will help ensure greater consistency across service territories and increased clarity for stakeholders navigating the interconnection process. Enabling advanced functions for DERs will also help ensure a smoother glidepath to adopt and integrate more DERs on the grid over time. In certain situations, individualized site-specific settings may be a viable option for DER customers seeking to interconnect in lieu of an identified grid upgrade. However, state interconnection rules will need to provide clarity around the circumstances under which this can occur to maintain a fair and equitable process for all DER customers.

- **Requirements for DER System Modifications and Maintenance**: As DER system components require maintenance or replacement over time, states should address how these upgrades will be handled in the context of IEEE Std 1547™-2018. Such system upgrades are often dealt with through interconnection procedures, sometimes referred to as *material modifications*[57]. IEEE Std 1547™-2018 acknowledges that "substitutive components" compliant and tested to the Standard may be used as replacements without invalidating certification testing. Field demonstration or commissioning tests may still be required to confirm proper operation and settings of the DER after the equipment is updated. Clear guidance in interconnection rules on these requirements will ensure that existing DERs can be cost-effectively maintained over time.

States should work to ensure as much consistency and harmonization as possible among the different utilities within their jurisdiction.

57 A change to a DER system that impacts its operational characteristics.

## VII. Conclusion: State Leadership to Implement IEEE Std 1547™-2018

The rules governing the grid have been evolving for many years and will continue to evolve as more DERs are integrated and optimized as resources. With IEEE Std 1547™-2018 published and a few remaining years before full rollout, now is the time for states and regulators to begin to implement the updated Standard. The optionality included in the new Standard will require thorough discussion of the technical, process and consumer impacts of adopting the new Standard. The Standard will not only affect DER customers, developers, and utilities, but project financiers and investors. There are additional issues outside the scope of this primer that will need to be addressed in addition to those directly related to adoption of the Standard. Stakeholder engagement and thoughtful navigation of the process will help ensure a smooth and transparent transition from old to new grid paradigms. States that work swiftly to address the new Standard will be better equipped to integrate new technologies, optimize the benefits of DERs, and improve system power quality. Even states that may not expect a significant increase in DER interconnections over the next decade, can ensure adequate DER capabilities by adopting IEEE Std 1547™-2018. Now is the time to commence the process and pave the path for a more distributed and clean energy future.

States that work swiftly to address the new Standard will be better equipped to integrate new technologies, optimize the benefits of DER, and improve system power quality.

## VIII. Key Acronyms

| | |
|---|---|
| ANSI | American National Standards Institute |
| DER | Distributed Energy Resource |
| DERMS | Distributed Energy Resource Management System |
| DTT | Direct Transfer Trip |
| EPRI | Electric Power Research Institute |
| EPS | Electric Power System |
| FERC | Federal Energy Regulatory Commission |
| FIDVR | Fault-Induced Delayed Voltage Recovery |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISO | Independent System Operator |
| kVA | kilovolt-ampere (measure of apparent power in an electrical circuit) |
| NREL | National Renewable Energy Laboratory |
| PCC | Point of Common Coupling |
| PoC | Point of DER Connection |
| PV | Photovoltaic |
| RTO | Regional Transmission Organization |
| SCADA | Supervisory Control and Data Acquisition |
| SGIP | Small Generator Interconnection Procedures |
| UL | Underwriters Laboratories |

## IX. Key Codes & Standards

| | |
|---|---|
| ANSI C84.1 | American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hz). "ANSI C84.1 Range A" refers to the normal service voltage range for the U.S. electric grid |
| IEEE Std 1547™-2003 | IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems |
| IEEE Std 1547™-2018 | IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces |
| IEEE Std 1547.1™ | IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems |
| IEEE Std 1815™ | IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol |
| IEEE Std 2030.5™ | IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard |
| SunSpec Modbus | A standard that defines a set of common register values for devices such as three-phase inverters, single-phase inverters, meters, environmental units, and related measurement devices |
| UL 1741 | Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources |

# X. Key Terms

**Abnormal Operating Performance Category** – Specifies DER performance during a grid voltage or frequency disturbance such as a transmission fault or loss of a generator.

**Active power** – The real power consumed by electrical resistance; measured in watts.

**Active power-reactive power mode** (watt-var) – In this mode, the DER modulates its absorption or injection of reactive power in relation to its active power output (and absorption of active power for DERs that can store energy).

**Apparent power** – The combination of reactive power and active power; measured in volt-amperes, it is the product of a circuit›s voltage and current, without reference to phase angle.

**Area Electric Power System** – The electric power distribution and delivery system that includes facilities typically owned by a utility.

**Clearing time** – The time limit for DERs to detect a condition which requires tripping (such as an island) and cease energization.

**Commissioning testing** – The evaluation of a DER system after installation but before final energization to inspect the system and verify that it was installed properly and to confirm that it functions as designed.

**Constant power factor mode** – Mode in which power factor is set to the desired value and remains the same, even as the power output from the DER fluctuates.

**Constant reactive power mode** – In this mode, the DER absorbs or injects a specified amount of reactive power regardless of its active power level (i.e., reactive power remains constant as power output from the DER fluctuates).

**Effective grounding** – Limits the fault current via neutral connections to ground, grounding banks or reactors to allow a limited and safer amount of overvoltage; effectively grounded systems limit overvoltage to 139% of nominal.

**Evaluation** – The review of the design of the DER system and/or a review of the "as-built" DER system, typically performed by a utility engineer.

**Fault current** – An abnormal electric current between conductors or conductors and ground, typically due to physical contact.

**Flicker** – The changing light intensity (e.g., a change in brightness from a lamp) caused by voltage fluctuations.

**Frequency regulation** – The adjustment of active power input during temporary frequency disturbances; also referred to as "frequency-droop" or "frequency-power" when in relation to DER.

**Frequency-droop** – See "frequency regulation."

**Ground fault overvoltage** – A phenomenon that occurs when a single line faults to ground on a system that has lost its ground reference, where a breaker has opened and before DER disconnects or ceases production, which can potentially cause large transient or temporary overvoltages on the order of 173% of nominal.

**Hosting capacity** – The amount of DERs that can be accommodated on the distribution system under existing grid conditions and operations without adversely impacting operational criteria or requiring significant infrastructure upgrades.

**Inadvertent export** – The unscheduled export of power onto the grid from non-exporting or limited-export DERs; it is typically due to transient mismatch between system output and load consumption (when unanticipated load fluctuations occur) and lasts for very short durations.

**Intentional Area Electric Power System Island** – A microgrid that includes a portion of the Area Electric Power System.

**Intentional Local Electric Power System Island** – A microgrid that is fully behind the point of common coupling.

**Interconnection rules** – Regulations that govern the processes required for generating facilities to connect to the grid; also called "interconnection standards" or "interconnection procedures."

## Key Terms continued

**Interoperability** – The capability of two or more different systems, networks or technologies to communicate and exchange information.

**Islanding** – The condition in which a distributed generator continues to power a portion of a circuit even though power from the electrical grid is no longer present.

**Limited-export system** – A DER system designed to never or rarely export energy beyond a certain limited power level.

**Load rejection overvoltage** – A transient condition that results from a situation in which there is insufficient load available to consume the DER power being fed onto the grid.

**Local Electric Power System** – The electric power system that typically includes only customer power delivery facilities and load on the load side of the point of common coupling.

**Material modification** – Change to a DER system that impacts its operational characteristics.

**Microgrid** – A localized power grid that can operate independently from the traditional grid through the use of intentional islanding.

**Nameplate capacity** – The maximum output of a generator as determined by the manufacturer; also referred to as "rated capacity" or "nominal capacity."

**Nominal voltage** – The center of the normal service voltage range specified by ANSI C84.1 range A.

**Non-exporting system** – A DER system primarily designed to serve on-site customer load that, while connected in parallel, never or rarely exports energy onto the grid.

**Normal Operating Performance Category** – Specifies how a DER should perform with regards to voltage control during normal grid operations.

**Point of Common Coupling** – The point of connection between the DER customer and the utility, typically at the utility revenue meter.

**Power factor** – Ratio of active power to apparent power.

**Power quality** – The relative frequency and severity of deviations in power supplied to consumer equipment; voltage changes, flicker and harmonics can impact power quality.

**Reactive power** – Measured in vars, it is power that does not do work, but is stored or returned to the circuit every half cycle; reactive power results whenever the voltage and current waveforms are shifted in time relative to one another, rather than being aligned.

**Reference point of applicability** – The physical point on the electric grid where compliance with the Standard's requirements will be assessed.

**Ride-through capability** – The capability of a DER to continue operating (i.e., not trip) during abnormal frequency and voltage events (i.e., significantly high or low voltage or frequency).

**Secondary Network Distribution Systems** – An AC power distribution system that serves customers using low-voltage circuits supplied by two or more network transformers connected to the circuits through network protectors.

**Unity** – A DER power factor setting that allows no reactive power and does not provide voltage regulation.

**Var flow** – The presence of reactive power on the distribution grid conductors and equipment; though it does not deliver active power, it still causes heating effects on the conductors, reducing active power delivery capacity.

**Voltage** – The difference in electrical potential measured in volts.

**Voltage regulation** – The intentional adjustment of voltage with the goal of maintaining it within the normal range.

**Voltage-active power mode** (volt-watt) – This mode utilizes a reduction in active power to decrease voltage (normally only once voltage is outside of the normal, or ANSI C84.1 range A, range).

**Voltage-reactive power mode** (volt-var) – In this mode, the DER modulates its absorption or injection of reactive power in relation to the measured grid voltage; there can be a "dead band" near normal voltage where no reactive power is absorbed or injected.

# XI. Additional Resources


Electric Power Research Institute, IEEE 1547 – *New Interconnection Requirements for Distributed Energy Resources: Fact Sheet*, June 2017, available at: https://www.epri.com/#/pages/product/000000003002011346/.

Electric Power Research Institute, *IEEE Standard 1547™ – Communications and Interoperability: New Requirements Mandate Open Communications Interface and Interoperability for Distributed Energy Resources*, July 2017, available at: https://www.epri.com/#/pages/product/000000003002011591/.

Electric Power Research Institute, *IEEE Standard 1547™ Power Quality Considerations for Distributed Energy Resources*, Dec. 2017, available at: https://www.epri.com/#/pages/product/000000003002010282/.

Electric Power Research Institute, *Recommended Settings for Voltage and Frequency Ride-Through of Distributed Energy Resources*, May 2015, available at: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002006203.

Giraldez, Julieta, et al., *Simulation of Hawaiian Electric Companies Feeder Operations with Advanced Inverters and Analysis of Annual Photovoltaic Energy Curtailment*, National Renewable Energy Laboratory and Hawaiian Electric Company, September 2017, available at: https://www.nrel.gov/docs/fy17osti/68681.pdf.

Hoke, Andy, et al., *Inverter Ground Fault Overvoltage Testing*, National Renewable Energy Laboratory and SolarCity Corporation, August 2015, available at: https://www.nrel.gov/docs/fy15osti/64173.pdf.

IEEE Std 1547™-2018 (Revision of IEEE Std 1547™-2003), IEEE Standards Coordinating Committee 21 (SCC21), available at: http://sites.ieee.org/sagroups-scc21/standards/1547rev/.

Interstate Renewable Energy Council, *Model Interconnection Procedures*, April 2013, available at: https://irecusa.org/publications/model-interconnection-procedures/.

Interstate Renewable Energy Council, *Priority Considerations for Interconnection Standards: A Quick Reference Guide for Utility Regulators*, August 2017, available at: https://irecusa.org/priority-considerations-for-interconnection-standards/.

Interstate Renewable Energy Council, *Optimizing the Grid: A Regulator's Guide to Hosting Capacity Analyses for Distributed Energy Resources*, Stanfield, Sky, et al., Dec. 2017, available at: https://irecusa.org/publications/optimizing-the-grid-regulators-guide-to-hosting-capacity-analyses-for-distributed-energy-resources/.

Nelson, Austin, et al., *Inverter Load Rejection Over-Voltage Testing*, National Renewable Energy Laboratory and SolarCity Corporation, February 2015, available at: https://www.nrel.gov/docs/fy15osti/63510.pdf.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