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Revision of IEEE Standard 1547™

New Disturbance Response Requirements

BY **REIGH WALLING,** WALLING ENERGY SYSTEMS CONSULTING, LLC.

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This article is the third in a four-part series regarding the IEEE standard 1547 and its impact on the electric grid. The background and purpose of this standard was reviewed in the first article, ***Revision of IEEE Standard 1547™ — The Background for Change****; and the second focused on the impact on voltage regulation,* ***Revision of IEEE Standard 1547™ — New Reactive Power and Voltage Regulation Capability Requirements****. This article focuses on the related issue of disturbance performance; and the final article will address a number of additional issues, including power quality. A primary purpose of this series is to ensure cooperatives are well informed of the importance of this standard and the upcoming related balloting session, and of the opportunity to be involved in the process to ensure their perspective is reflected in upcoming changes to the standard. Details on how to participate in the balloting process are defined in the* ***first article****.*

ARTICLE SNAPSHOT

What has changed?

IEEE Standard 1547, which defines interconnection requirements for distributed energy resources (DER), is presently undergoing a major revision. The standard's coverage of system disturbance response — response to faults, abnormal voltages, and frequency deviations — has been greatly expanded and fundamentally changed in approach. The present (2003) version of this standard only requires that DER trip off for disturbances, and makes no requirements for DER to remain connected and in service. The voltage and frequency tripping thresholds in the existing standard are quite sensitive. This provides exceptional protection coordination and safety for distribution systems, but raises the potential for a Bulk Electric System (BES) fault or frequency disturbance to cause a large amount of DER across a wide area to trip off simultaneously. With ever-increasing DER penetration levels, the loss of generation can be significant, introducing risks to power system security. The new standard, now in the final draft stage, modifies tripping requirements and also imposes mandatory DER disturbance ride-through requirements.

Continued

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ARTICLE SNAPSHOT (CONT.)

What is the impact on cooperatives?
The proposed changes to IEEE 1547 may require cooperatives to consider more closely the impact of DER on distribution circuit protection coordination. The standard will also require the cooperative to make choices regarding DER disturbance performance that may impact transmission-level security and reliability, inevitably expanding the distribution engineer's role and horizons. Some of the proposed changes to the standard could be perceived as compromising distribution level protection and even safety in order to preserve BES security. This perception, however, deserves a closer look to consider the practical potential for distribution system impacts and the measures included in the standard to address these issues.

What do cooperatives need to know or do about it?
Cooperatives need to understand the proposed changes to IEEE Standard 1547 because they may affect the way that co-ops design, protect, and operate their systems. Cooperatives' distribution systems often have characteristics and constraints that differ from the suburban and urban systems dominating most of the investor-owned and public utilities. It is important that the standard provides adequate recognition of the special nature of the typical cooperative distribution system. As the standard's draft development is now concluding, **co-op engineers are encouraged to join the ballot pool to ensure that the standard adequately addresses the needs of the cooperative community.**

The most dramatic changes in the standard relate to the performance required of DER during system disturbances such as faults, abnormal voltage conditions, and frequency variations.

INTRODUCTION

IEEE Standard 1547™-2003 is the model distributed energy resource (DER, i.e., distributed generation or storage) interconnection standard, used widely across the U.S. and Canada. Since the time when this standard was first adopted thirteen years ago, there has been tremendous growth in DER across the continent, to the degree where the power grid has begun to develop dependency on DER as an operating resource in some areas. Driven by this changing environment, the standard is now undergoing major revision. **The revised standard is now in the final draft stage, with balloting by industry stakeholders scheduled for this spring.**

The most dramatic changes in the standard relate to the performance required of DER during system disturbances such as faults, abnormal voltage conditions, and frequency variations. Whereas the original standard covered this area in less than two pages, the new DER disturbance performance requirements extend over twenty pages and introduce substantial complexity to DER design and interconnection. This complexity is considered necessary to balance the need for safety against the increasing impact DERs can have on the BES.

This *TechSurveillance* article is the third in a **series of four articles** that describe the changes proposed for this standard, provide the rationale for these changes, and describe how they will affect the planning, design, protection, and operation of rural electric cooperative distribution systems into the future. The **first article** of the series provided the background of IEEE 1547 and the drivers behind the present revision effort. The **second article** focused on DER reactive power and voltage regulation performance requirements that will be mandated. This article focuses on the changes to required DER disturbance performance proposed in the new

IEEE 1547 draft. **Although it is now in the final draft stage, cooperative engineers are encouraged to become involved in the review and balloting of this proposed standard revision to ensure that it sufficiently addresses their system circumstances.**

CURRENT IEEE 1547 DISTURBANCE PERFORMANCE REQUIREMENTS

The original 2003 version of IEEE 1547 imposed mandatory tripping requirements in response to voltage and frequency deviations that can be viewed as rather sensitive (i.e., responding to relatively small deviations from normal). Due to increasing concern over the widespread loss of DER generation due to BES events, the tripping requirements were modified in an amendment to the standard adopted in 2014. The under-frequency tripping thresholds in the original standard removes DER generation from the system at a frequency deviation less severe than the threshold for under-frequency load shedding in some regions. Loss of generation inherently aggravates an under-frequency event and can help drive a system to the point of no return — system breakup and blackout.

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Neither the original IEEE 1547-2003 nor the IEEE 1547a amendment impose any requirement whatsoever for a DER to ride through a system disturbance. The imposed tripping limits are upper limits on duration for a particular deviation magnitude; there is no restriction on a DER tripping prior to this time. For example, under the current standard, a DER experiencing 85 percent voltage on one phase must trip within two seconds, but nothing prohibits it from tripping in one cycle.

Sudden and simultaneous loss of large amounts of DER can be problematic today and even more so in the future.

The context in which IEEE 1547-2003 was developed is far different from today. The original standard provides no consideration of impact due to DER output loss. While this was reasonable in 2003 due to very low levels of DER penetration, sudden and simultaneous loss of large amounts of DER can be problematic today and even more so in the future.

The original standard required tripping of DER for any fault on the utility circuit to which it is connected. Also, should an "island" form after a cooperative protective device trips, the original standard called for the island to be eliminated within two seconds. (Feeder "islands" are energized solely by DER after a feeder is isolated by a utility breaker or recloser.) These requirements are both reasonable and necessary. Also, the sensitive voltage tripping specified in the original standard made it much easier for DER vendors and integrators to achieve these requirements using rather crude and unselective approaches.

The original standard also required that DER "cease to energize the Area EPS (i.e., utility system) circuit to which it is connected prior to reclosure by the Area EPS." Despite the obviousness of this requirement from a utility perspective, it was widely misinterpreted by the DER industry as limiting the utility's ability to reclose faster than the maximum DER island duration of two seconds.

INCREASED GRID DEPENDENCY ON DER

DER penetration has grown from minimal levels at the time IEEE 1547 was originally developed to quite significant levels in some areas today. Trending to the future, politically-driven policy decisions, environmental restrictions, renewable energy mandates, and tax incentives will probably continue to drive overall U.S. DER penetration levels higher. DER penetration, however, is unevenly distributed and tends to be concentrated in areas where policy drivers, natural resources (e.g., solar irradiance), and utility energy costs are the greatest. Utilities in higher-penetration areas are already seeing DER capacity exceeding load demand on individual feeders and even at distribution substations.

Although DER is not typically considered as a capacity resource for planning purposes, the power system dispatch must account for the impacts of DER output in operation.

Although DER is not typically considered as a capacity resource for planning purposes, the power system dispatch must account for the impacts of DER output in operation. BES generators are dispatched according to the net load (i.e., customer load minus the "negative" load of generators that are not dispatched, such as DER). Therefore, simultaneous tripping of a large amount of DER creates a jump in the net load and upsets the generation-to-load balance that is essential to keep the grid frequency in control. Also, jumps in net load change transmission flows and can aggravate the dynamic power system "swings" that occur following faults. This potential loss of generation requires more generation reserves to be committed. The load pickup of these reserves, however, is not instantaneous and, thus, wide-scale tripping of large amounts of DER capacity can still result in a severe frequency deviation.

Fault Sensitivity

If DERs have sensitive undervoltage thresholds, a large amount of generation may potentially trip as the result of a transmission system fault. Transmission faults can cause a substantial voltage dip over a wide area. On a per-unit basis, the voltage levels on a distribution system during a transmission fault can be depressed to an even greater extent, and for a longer duration, than the voltage of the transmission bus at the distribution substation. This is primarily due to the dynamic characteristics of customer motor loads, which tend to stall during faults and draw a large amount of reactive current. The reactive current remains large as the motors spin back up to speed, and thus, the distribution voltage depression can last much longer than the relatively brief transmission fault. This "delayed voltage recovery" phenomenon was documented in field measurements performed in recent years by Southern California Edison.

Distribution systems can also suffer consequences due to unnecessary DER tripping. An example is a distribution feeder with a large DER facility, such as a landfill gas powered generator, near the remote end. The power export from the facility tends to prop up the feeder voltage, and voltage regulators, substation transformer load (or on-load) tap changers (LTC)s, and switched capacitor banks will adjust accordingly. If, for example, a fault occurs on an adjacent feeder, and the resulting voltage dip causes the DER facility to trip, voltages on the feeder with the DER may sag below acceptable levels because the taps and capacitor switches are at the wrong position to support the feeder voltage without the DER. This undervoltage can persist until the taps and switches can respond and recover. If the DER had less sensitivity to undervoltage, the facility might ride through the adjacent feeder fault and avoid this power quality issue. Unlike the transmission fault impact, where it is DER penetration over a large region that matters, these distribution level issues are related to the individual feeder or local distribution system DER penetration. Few cooperatives have large overall DER penetration today, but many have significant penetrations on specific feeders due to relatively large DER facilities.

With ever-increasing DER penetration nationwide, tripping of DER for system frequency deviations is an increasing concern.

Frequency Variations

With ever-increasing DER penetration nationwide, tripping of DER for system frequency deviations is an increasing concern. System frequency is consistent across an entire synchronous interconnection area — the Eastern Interconnection (east of Colorado), WECC (Rocky Mountains states and west), and ERCOT (comprising most of Texas). There are also some small isolated systems, such as in Hawaii and Alaska. The frequency of these interconnections is governed by the balance between the total generation and the total load. Any frequency deviation within an interconnection area appears nearly equally across the entire area, so any DER within the interconnection area may trip. Local and even regional penetration levels are not a factor.

While the burden of compliance falls primarily on DER vendors and integrators, co-ops need to work with them to ensure their methods, settings, and testing are acceptable to the co-ops' systems.

As mentioned previously in this article, the present IEEE 1547 standard requires DER to trip for an under-frequency deviation for which the grid should be able to recover, if it were not for the disturbance-aggravating loss of DER generation. The over-frequency trip thresholds of the present standard can also be problematic. This issue was discovered, albeit too late, in Germany. The original DER interconnection standards there required tripping at 50.2 Hz, 0.2 above their nominal 50 Hz frequency. After a large amount of DER had been installed, it was found that an overfrequency deviation (such as might be caused by a sudden loss of load) would cause a sudden loss of DER generation so large as to then cause the system frequency to dive to a dangerously low value. As a result of this discovery, a large, complicated, and expensive DER retrofit program had to be initiated to change the behavior of hundreds of thousands of existing installed DER units. Clearly, it is in the best interests of all concerned if a similar situation is avoided in the U.S. We are not yet at the DER penetration levels that are present in Germany, but some parts of the country are headed in that direction.

A NEW BALANCE POINT IN IEEE 1547 REVISION

As mentioned in the opening of this article, IEEE 1547 is now undergoing complete revision.[1] In the area of DER system disturbance performance, the current near-final draft of the revised standard makes a determined effort to balance BES security concerns with protection of distribution systems and public and worker safety. P1547[2] mandates DER to have the capability to ride through voltage and frequency disturbances of defined magnitude and duration. No longer may a DER trip whenever desired, as long as it is before the trip threshold. The proposed requirements now require that the DER ***must not*** trip before the end of the prescribed ride-through duration, but also ***must*** trip prior to a prescribed trip time. The trip times and associated disturbance severity levels have been modified to allow for the ride through performance needed to achieve grid security objectives.

Achieving these performance goals is easier with the current IEEE 1547-2003 tripping thresholds (even as amended by IEEE 1547a-2014) than with the new ride-through and trip thresholds defined in P1547. However, P1547 continues to require DER to cease energization of the feeder to which it is connected if the feeder is faulted or if the feeder becomes isolated or "islanded" from the main grid. The burden of compliance falls primarily on the DER vendors and integrators to use more advanced and innovative measures to achieve all of the required performance.

The challenge for cooperative will be to work with vendors and integrators to ensure that their methods, settings, and testing are acceptable for the cooperative's system once the final standard becomes effective. Also, cooperatives will need to review internal E&O procedures and methods in order to adjust to the new requirements. This includes both disturbance ride-through for events where tripping is not allowed, as well as satisfactory compliance with fault detection and anti-islanding requirements.

Performance Categories

IEEE 1547 is a national/ international standard and consequently needs to address a wide range of situations (e.g., DER penetration levels, system characteristics, etc.) as well as a

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[1] A more complete discussion of the history of IEEE 1547 and the reasons behind the present revision effort is provided in the first TechSurveillance article of this series.

[2] The "P" designation is an IEEE designation of a standard undergoing development. P1547 in this article refers to the current draft of the revised IEEE 1547 standard.

range of DER types. Different types of DER have varying inherent capability to meet the various ride-through requirements. To maintain technology neutrality, P1547 defined DER disturbance performance requirements in terms of "performance categories".[3] The categories allow customization of the requirements to the particular situation. It is left to the Authority Governing Interconnection Requirements (AGIR) to assign different types and applications of DER to the categories.[4] An informative annex of the P1547 provides voluntary guidelines for the AGIR to consider when making decisions regarding performance category assignment.

The new standard establishes 'performance categories' to customize requirements to the abilities of different types of DERs to meet ride-through requirements.

The categories for disturbance performance are similar to, but independent of the reactive power and voltage regulation performance Categories A and B that were discussed in the **previous article** in this *TechSurveillance* series. The separate disturbance performance categories are described below along with their basis:

- **Category I** — is a level of disturbance performance that is compatible with most BES security needs, and is feasible for all current DER technologies to achieve. Because engine-driven synchronous generators have the greatest inherent difficulty meeting low-voltage ride-through performance requirements, the performance requirements are based on the German grid codes for medium-voltage connected synchronous generators, a performance level for which engine-generator vendors have been able to comply.
- **Category II** — is a level of disturbance requirements that is believed to be fully consistent with BES security needs. These requirements are harmonized with the NERC PRC-024 protection-setting standard applicable for BES generators, with adaptation related to the fact that low-voltage events may have a more protracted duration at the distribution level due to load dynamics.
- **Category III** — is an enhanced level of disturbance robustness that is intended for situations where continued DER operation is considered important for the benefit of the distribution system. This would normally be used in very high local-area DER penetration situations. Unlike Categories I and II, which are primarily intended to keep the DER in operation for BES faults, the Category III requirements are also designed to maintain DER output for subtransmission and distribution system (e.g., adjacent feeder) faults as well. The requirements of this category are harmonized with California Rule 21, and were added to IEEE 1547 at the request of the California utilities. It should be noted that presence of the advanced Category III requirements in IEEE 1547 does not obligate any cooperative to apply this category.

FAULT AND VOLTAGE DISTURBANCE RESPONSE

In this part of the article, the technical requirements proposed in P1547 are discussed and contrasted with the existing IEEE 1547-2003 standard, as amended by IEEE 1547a in 2014.

Fault Detection Requirements

The existing requirement that DER must trip for faults on the distribution circuit to which it is connected remains in the revised standard,

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[3] Further discussion regarding the rationale for performance categories can be found in the previous article in this *TechSurveillance* series on the IEEE 1547 revision.

[4] The standard doesn't not define normatively (ie: as an established rule) who or what the AGIR is to be. In an informative annex, it suggests that the AGIR could be the utility regulatory agency, the BES operator, or the utility. The designation of this entity as the Authority Having Jurisdiction (AHJ) was purposely avoided as AHJ is commonly a local electrical inspector who is unlikely to have understanding of the BES needs and utility protection needs. The determination of who will be the AGIR is determined on a state-by-state or locality-by-locality basis, depending on what entity has the final authority regarding DER interconnection rules.

The revised standard effectively allows "hot" reclosing into a feeder energized by DER, if it does not cause excessive stress or disturbance.

but with further clarification. P1547 adds the statement that DER is not required to detect faults that the utility protection systems cannot detect. For example, a conductor dropped onto dry pavement creates a very high impedance fault that conventional utility relaying will not detect. It would be unreasonable to expect DER to detect this either. Effectively, this provision also makes it possible for the DER to rely on sequential tripping. In other words, the DER may only be able to detect the feeder fault after the utility source has tripped.

Most DER, particularly inverter-interfaced DER (e.g., PV), have very low short-circuit current capability. This makes it very difficult for the DER to detect a feeder fault that does not make a large drop in voltage at the DER location while the feeder is connected to the substation. Once the feeder is tripped by the feeder breaker or recloser, the voltage should drop to a very low value due to the small amount of DER current available to feed the fault, and the DER will detect this and trip.

The draft standard delegates the specification of trip thresholds and time, within defined ranges, to the utility.

Reclosing Coordination

The reclosing coordination requirement has been modified in P1547 to be more qualitatively explicit, but it is now quantitatively open ended. The revised standard says that means should be implemented such that utility circuit reclosing does not result in "unacceptable stresses or disturbances" due to out-of-phase reclosing resulting from continued DER energization of the opened feeder section. The standard does not assign responsibility for implementing these means, but an informative footnote lists common solutions, such as voltage-supervised reclosing and direct transfer trip, and also indicates that reclosing may not be an issue where DER penetration is sufficiently low.

The revised standard effectively allows "hot" reclosing into a feeder energized by DER, if it does not cause excessive stress or disturbance. This is to accommodate situations where it can be determined that the voltage on the DER-energized feeder section will not drift far enough out of phase from the utility source during the reclosing delay such that an unacceptable transient occurs upon reclosing. The standard draft, however, does not define quantitatively what stress or disturbance is "unacceptable." During deliberations regarding this clause, specific phase angle and magnitude differences were considered, but rejected in favor of this more vague specification.

Voltage Tripping

The objective of undervoltage and overvoltage tripping is to remove the DER for conditions that are indicative of a local fault (e.g., a fault on the same feeder), or disturbances for which there is no reason to maintain DER operation. The latter includes overvoltage conditions which might be produced by the DER. Because of the low short-circuit contribution of DER, particularly inverter-interfaced DER, undervoltage is the primary means of distribution system fault detection by DER.

Voltage trip thresholds are specified by P1547 to be on an individual phase basis, based on the least voltage phase magnitude for undervoltage tripping, and greatest phase voltage for overvoltage tripping. Ranges of undervoltage and overvoltage thresholds and clearing times[5] are specified for each disturbance performance category. The draft standard delegates the specification of the thresholds and times, within these defined ranges, to the utility. With few exceptions, the trip ranges are beyond the mandated ride-through requirements, which are discussed later in this article. The draft

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[5] Clearing time is the total time until cessation of energization by the DER, so it includes detection time, intentional delay, and the time required to perform the cessation (e.g., open a circuit breaker).

The performance of a DER while riding through a voltage disturbance depends on the severity of the disturbance and the performance category to which the DER is assigned.

Debate persists in the P1547 working group as to how the concept of “cease to energize” will be defined.

standard also specifies default settings. These are the voltage thresholds and clearing times that will be used unless otherwise specified by the utility. Generally, DER will come from the manufacturer to the installer set with these default parameters.

As defined in the P1547 standard, “trip” means the DER disconnects and does not restart again until the voltage is within Range B of ANSI C84.1 and frequency within 59.5 to 60.1 Hz continuously for a minimum time delay that is adjustable from zero to ten minutes. When the DER re-enters service from the tripped state, it must ramp up its output over a period adjustable from one to 1,000 seconds.

Voltage Ride-Through Requirements

Unlike the original IEEE 1547-2003 standard, which only specifies when DER must trip off, P1547 specifies the conditions for which DER must not trip off and must continue to ride through. The performance of a DER while riding through a voltage disturbance depends on the severity of the disturbance and the performance category to which the DER is assigned. There are three different ride-through operating modes: (1) Mandatory Operation, in which the DER must continue to inject current; (2) Permissive Operation, in which the DER may continue to inject current or it may stop injecting current but must remain able to immediately resume operation after the voltage returns to the “Continuous Operating Region”; and (3) Momentary Cessation, in which the DER must cease to energize the grid, but must also remain able to immediately resume operation after the return of voltage to the Continuous Operating Region. The Continuous Operating Region for voltage magnitude is between 0.88 and 1.10 times the nominal voltage.

At the time this article was written, debate persists in the P1547 working group as to how the concept of “cease to energize” will be defined. It is universally agreed that DER should not continue to inject real power (kW) into the system while in this state. However, the debate is focused on reactive current. While larger DER may open some form of contactor or circuit breaker to achieve this state, some small inverters may suspend gating of their transistors (cause the transistors to not conduct). In either case, output filters, consisting of small shunt capacitors (typically a few percent of the DER rating in terms of kVAR), inductors, and perhaps resistors remain connected to the grid. Even where a circuit breaker opens to isolate a conventional synchronous generator, a tiny amount of reactive current is supplied to the potential transformers that are necessary to monitor the grid voltage. Therefore, it is not possible to mandate that the current be absolutely zero; the argument centers around how much reactive current, what devices may produce it, and for how long.

Figures 1, 2, and 3 plot the ride-through requirements for the three disturbance performance categories in terms of voltage magnitude and the cumulative duration. The DER may not “trip” while the voltage magnitude and cumulative duration are within the ride-through regions.

As discussed previously, P1547 also specifies that the DER must trip for prescribed voltage thresholds and durations. In addition to the ride-through behavior, Figures 1 to 3 show the default tripping characteristic and the trip parameter adjustment range. DER manufacturers may provide longer trip times within the range of adjustability, but may not provide shorter trip times than the minimum shown. This is to avoid trip settings that compromise BES security.

Where any of these ride-through modes are specified, and the maximum duration of the ride-through period is not exceeded, the DER may not trip and must return to 80 percent of its pre-disturbance current within 0.4 seconds of the voltage returning to the Continuous Operating Region. Although it is not explicitly stated, the standard does not prohibit DER from starting to recover as soon as the voltage rises above the upper Momentary Cessation threshold.

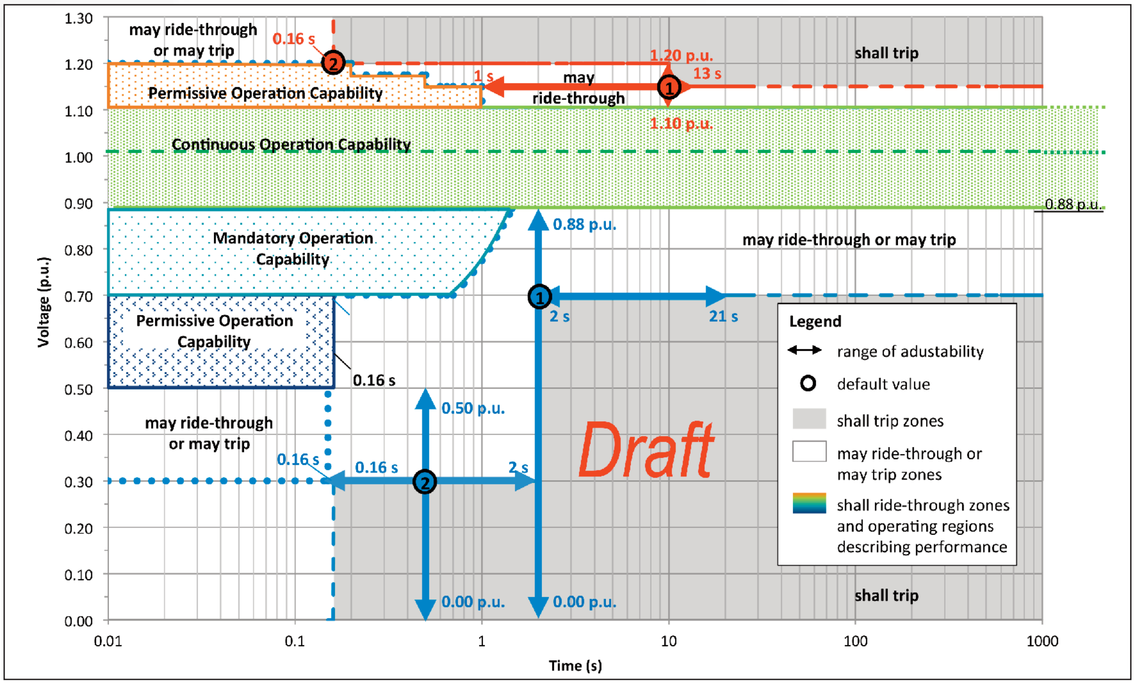

FIGURE 1: Voltage ride-through and tripping characteristics in the current P1547 draft applicable to Category I DER.

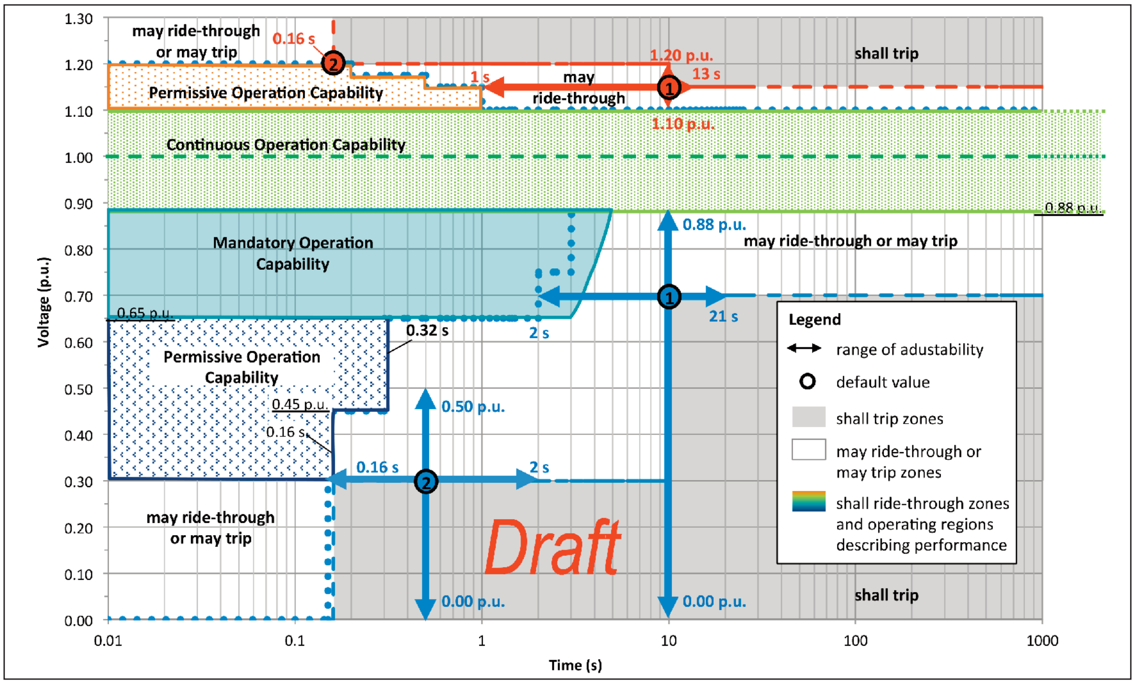

FIGURE 2: Voltage ride-through and tripping characteristics in the current P1547 draft applicable to Category II DER.

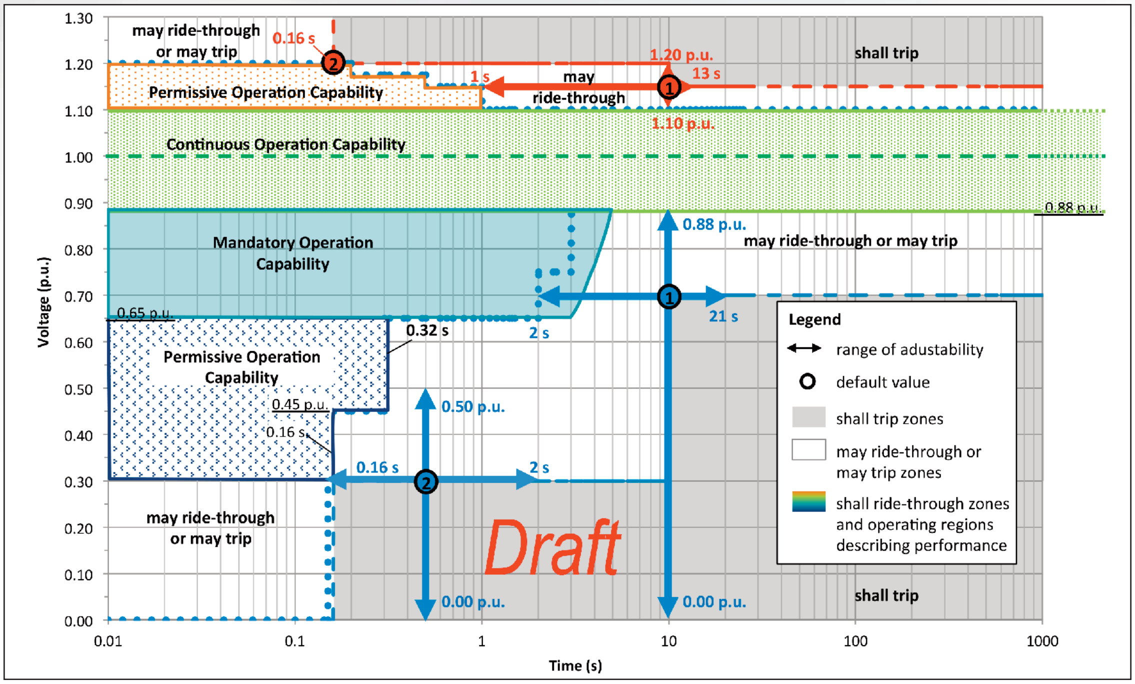

FIGURE 3: Voltage ride-through and tripping characteristics in the current P1547 draft applicable to Category III DER.

The Momentary Cessation mode is only specified for Category III. Using conventional circuit breakers and synchronization systems, it is not feasible for synchronous generators to achieve Category III performance.

Consecutive Disturbance Ride Through

Voltage disturbances can sometimes appear in sets of multiple disturbances interspersed with period of near-normal voltage. Some examples are multiple faults in short succession during severe storm events, unsuccessful reclosing attempts on the transmission or distribution system, and dynamic voltage oscillations that can occur after transmission system faults. The ride-through and tripping requirements of P1547 are based on cumulative durations of undervoltage or overvoltage. Therefore, the draft standard also defines the periods over which the voltage deviations accumulate, as well as the definition of when the accumulations are reset.

The draft standard also defines the periods over which the voltage deviations accumulate, as well as the definition of when the accumulations are reset.

Tripping During Normal Conditions

P1547 mandates that DER shall not trip as a result of voltage deviations that remain in the Continuous Operating Region. An exception is for utility voltage imbalance (in terms of the negative sequence component) exceeding 5 percent for more than 60 seconds or 3 percent for more than ten minutes. There is no restriction on DER tripping or output reduction that are unrelated to the grid voltage and frequency condition.

Frequency Disturbance Performance

P1547 continues to specify DER tripping for frequency deviations, but also introduces mandatory frequency ride-through performance as well. The following section of this article summarizes the new requirements.

Frequency Tripping

The primary objective of under- and over-frequency tripping is to remove the DER for conditions indicative of an "islanded" feeder, isolated from the grid and energized by DER. Because all of the continental U.S. interconnections have a very stable frequency, rarely deviating by more than 0.05 Hz, very sensitive frequency protection could eliminate DER islands very quickly in most cases. However, with the increased penetration of DER across the U.S., sensitive frequency protection applied to generation resources can aggravate the imbalance between load and generation that is the cause of any frequency deviation.

> **The robustness to ride through frequency deviations is a function of the DER design, and is not a "setting."**

The rapid increase of DER penetration was not foreseen during the development of the original IEEE 1547 standard, and the impact of DER tripping on grid frequency stability was not a consideration. Now with thousands of MW of DER in the WECC interconnection alone, the situation is far different. Therefore, P1547 has opened up the frequency trip parameters substantially. These parameters are the same for all three disturbance performance categories.

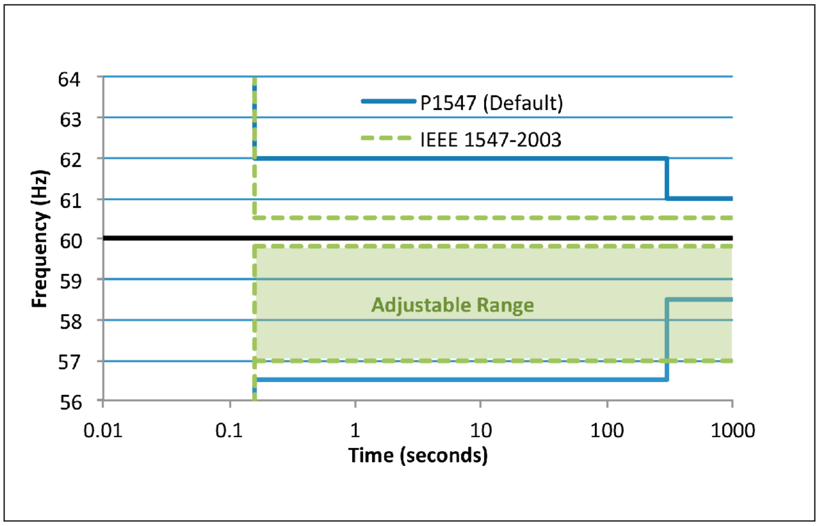

FIGURE 4: Comparison of P1547 and IEEE 1547-2003 frequency trip characteristics.

Figure 4 compares the frequency trip characteristics specified in IEEE 1547-2003 with the default characteristics defined in the revised P1547 standard. P1547 also provides a range of adjustability for both frequency thresholds and durations (not shown in Figure 4), primarily to accommodate special grids, such as those on the Hawaiian Islands and in Alaska. Regional reliability entities (e.g. SERC, MRO, etc.) may specify DER frequency trip characteristics other than the default values, but within the ranges of adjustability. It is expected that the default values will be used in most cases.

As in the case of voltage tripping, DER tripped for frequency variations beyond the defined characteristics are to remain off line until the grid frequency and voltage stabilizes for a specified period. Only then may the DER return to operation, and it must then ramp up power gradually.

Frequency Ride-Through

In addition to the mandatory frequency tripping characteristics, P1547 also mandates that DER ride through frequency disturbances of defined magnitude and duration. The robustness to ride through frequency deviations is a function of the DER design, and is not a "setting." Unlike voltage ride through, which is challenging for many types of DER to achieve, most DER technologies are relatively insensitive to frequency deviations. Because of this, and because system frequency is an interconnection-wide parameter and not a local or regional penetration-related issue, the same frequency ride-through requirements apply to all three disturbance performance categories. The frequency ride-through performance requirements are plotted, along with the mandatory frequency trip characteristics for comparison (including ranges of adjustability), in Figure 5.

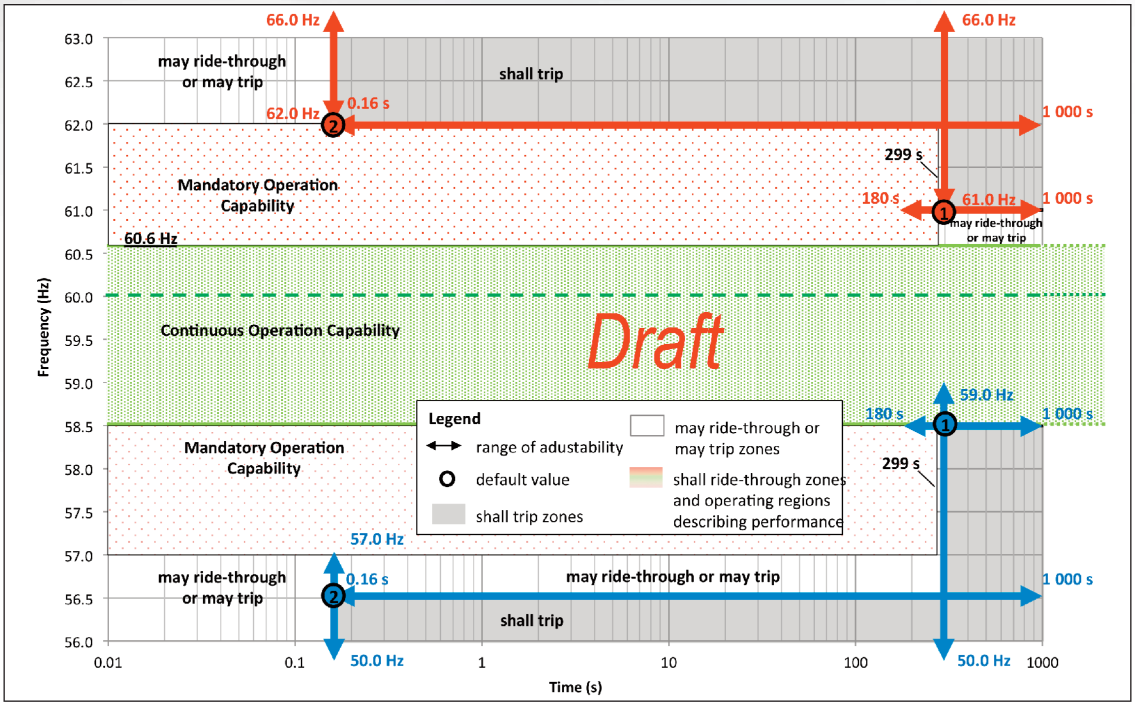

FIGURE 5: Frequency ride-through and tripping characteristics in the current P1547 draft applicable to Categories I, II, and III DER.

DER may not trip as a result of frequency deviations within the Continuous Operating Region, which is defined by P1547 as 58.5 Hz to 60.6 Hz. However, an exception is allowed if the ratio of voltage to frequency exceeds 1.1 times nominal. This "Volts per Hertz" exception is because overexcitation of magnetics (transformers and inductors) and rotating generators could otherwise be problematic. DER may not trip for abrupt shifts in voltage phase less than 20°, although they may momentarily interrupt output while their controls get back into synchronism with the system. Phase jumps can occur when there are large step changes in the BES power flow, such as caused by loss of a major line, dropping of a large load, or a major generation trip. DER also may not trip off for ramps of frequency change that are less than 0.5, 2.0, or 3.0 Hz per second for Categories I to III, respectively. Rate of Change of Frequency (ROCOF) has been used as an inadvertent island detection scheme in some DER designs, and this ROCOF ride-through requirement will constrain this approach and may require DER manufacturers to adopt other schemes to meet the anti-islanding requirements of IEEE 1547.

P1547 provides a "Volts per Hertz" exception for when the ratio of voltage to frequency exceeds 1.1 times normal.

Primary Frequency (Governor) Response

In the power grid, the primary means to control frequency is the governor action of generators, changing power output in response to frequency variation. Presently, all of this "primary frequency response" is provided by BES generators. As DER penetration increases, the amount of BES generation capacity on line will inevitably decline, as will the amount of frequency regulation available. Compounding this erosion of frequency stability is the decrease of system inertia. Inertia is the characteristic that slows frequency changes and is primarily provided by large synchronous generators. Small synchronous generators used for DER have much lower per-unit inertia factors and most DERs installed today are inverter interfaced (e.g., PV, microturbines, etc.), which have no inertia at all. With decrease in system inertia, system frequency variations

PREVIOUS VIEW

caused by mismatch of load and generation output occur faster and are more severe. Therefore, P1547 now requires DER to provide primary frequency response to a limited extent.

Similar to the governor characteristics used in BES generators, DER are to have a frequency "droop" characteristic causing the DER power output to change in proportion to the frequency deviation from 60 Hz. For over-frequency deviations, the DER reduces power and for under-frequency deviations the DER increases power, if it is capable of doing so. A majority of DERs are powered by renewable resources, and normally deliver the maximum amount of power that is available at all times. These DER are not expected to increase their output in response to frequency, unless their output has been previously curtailed for another reason.

DER must be considered as a critical grid resource that cannot be allowed to trip simultaneously in large numbers unless absolutely necessary.

INCREASING DER PENETRATION ADDS NEW DIMENSION TO INTERCONNECTION

Unlike 14 years ago when the present IEEE 1547 standard was adopted, DER can no longer be disregarded as insignificant to the grid at large. Impacts of DER are no longer limited to issues related to local-area penetration. Effects can now be seen within regions or even across entire interconnect areas of the BES. The current and expected future trajectory continues to indicate increasing DER penetration levels. DER must, therefore, be considered as a critical grid resource that cannot be allowed to trip simultaneously in large numbers unless absolutely necessary. Doing so can lead to significant consequences for overall system stability and security.

The DER equipment being installed today will be in service for many years. The experience gained in Europe, where DER penetration is much more extensive than it is presently in most of the U.S., has shown that appropriate DER characteristics need to be implemented in the equipment being installed now; retrofitting existing equipment when the situation reaches a critical stage in the future is extremely expensive and administratively complex.

At the same time, distribution system reliability, safety, and power quality must also be preserved. While there is inherent tension between the BES security and local distribution-oriented objectives, the solution lies in improved DER technology that allows both objectives to be achieved without excessive compromise.

With the draft P1547 now being finalized, the opportunity for participation in draft development has come to a close. However, there is an opportunity for more co-op engineers to participate in the standard balloting process. The IEEE-SA standards balloting process, and the procedure to join the ballot pool was described in the **first *TechSurveillance* article in this series**. Review of the new IEEE 1547 by co-op engineers and participation in balloting will help to ensure that the needs of the rural cooperative segment of the power industry are appropriately addressed. ■

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About the Author

Reigh Walling is a utility and renewable energy industry consultant, focusing his practice on the technical issues related to DER interconnections and renewable energy integration, as well as a variety of transmission-related areas. He has long been heavily involved in standards related to interconnection of DER and transmission-scale renewable energy plants, including participation in the inner writing group of the original IEEE 1547, several of the IEEE 1547.x companion standards, NERC PRC-024, and the NERC Integration of Variable Generation Task Force, and as well as a co-facilitator in the current IEEE 1547 revision working group. Prior to establishing Walling Energy Systems Consulting in 2012, he was a key member of GE's Energy Consulting group for 32 years. While at GE, he was the program manager for the Distribution Systems Testing, Application, and Research utility consortium, of which NRECA is a long-standing member.

Questions or Comments

- Robert Harris, PE, Principal, Transmission & Distribution Engineering Work Group: **Robert.Harris@nreca.coop**
- Business and Technology Strategies **feedback line**.
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