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TechSurveillance

Revision of IEEE Standard 1547™

New Reactive Power and Voltage Regulation Capability Requirements

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*This article is the second 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**. This article focuses on related issue of voltage regulation; and subsequent articles will discuss disturbance performance and 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. One of the areas in the standard that is being changed dramatically involves the requirements regarding DER reactive power and voltage regulation. The present (2003) version of this standard imposes no reactive power capability requirements and prohibits active voltage regulation by DER. The new standard, now in the final draft stage, includes major reversals on these requirements.

What is the impact on cooperatives?
Reactive power capability and control functions that deploy reactive power are a potentially powerful tool that can be used to mitigate the voltage impacts of DER interconnections, if these functions are applied correctly. If applied incorrectly, these functions may also interfere with proper feeder voltage regulation and can result in voltage instability. Also, the use of DER reactive power capability to mitigate voltage rise caused by DER power export can reduce a cooperative's power factor and increase losses. Developers proposing to interconnect DER to cooperatives may request to use this capability in lieu of more costly options to reduce voltage impacts, such as feeder reconductoring. Cooperatives need to understand the pluses and minuses of using these new capabilities.

Continued

ARTICLE SNAPSHOT (CONT.)

What do cooperatives need to know or do about it?

Cooperatives need to understand the implications of the proposed reactive power and voltage regulation changes to IEEE Standard 1547, including the opportunities these changes provide, as well as their potential pitfalls. Rural electric cooperatives often have long distribution feeders with relatively small conductors and long single-phase taps; situations that are less frequently encountered by investor-owned utilities and municipalities. **As the standard's draft development is now concluding, co-op engineers are encouraged to join the ballot pool when it opens to ensure that the standard adequately addresses the needs of the cooperative community.**

When the penetration of DER becomes large, unacceptable voltage impacts can result.

INTRODUCTION

For the past thirteen years, IEEE Standard 1547™-2003 has been the model distributed energy resource (DER, i.e., distributed generation or storage) interconnection standard used widely across the U.S. and Canada. This standard is now undergoing major revision to bring it up to date with the changes in DER technology and DER penetration levels seen in many places across the country. The standard revision process is now in the final draft stage, with the proposed standard scheduled for industry ballot in early 2017.

Some of the major changes proposed for the standard are with regard to DER reactive capability and the control functions necessary to deploy this reactive power. This *TechSurveillance* article is the second in a series of four that describe the changes that are proposed for this standard, provide the rationale for these changes, and describe how they will affect the planning, design, and operation of rural electric cooperative distribution systems into the future. This article focuses on the reactive power and voltage regulation related changes in the new IEEE 1547 draft. **Although it is now in the final draft stage of the development process, 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.** (Details on how to participate are available in the first article.)

INCREASING DER PENETRATION IMPACTS VOLTAGES

The incremental current flow from DER, no matter how limited the penetration, has some effect on the voltage levels along the feeder. When the penetration[1] of DER becomes large, unacceptable voltage impacts can result. This penetration can be either from one, or a few, large DER facilities, or the aggregate result of many small DER, such as behind-the-meter rooftop solar photo voltaic (PV) units. DER can create two different kinds of voltage impact. One is changes in the voltage profile along the feeder; the other is variability of voltage due to DER that have rapid variations in their output, such as solar PV and distribution-connected wind generation.

Voltage Profile Impacts of DER

Voltage magnitude drop due to load on a section of distribution feeder is approximately equal to the real current (kW/kV) times section resistance plus lagging current (kVAR/kV) times section reactance. Shown in equation form, this is:

$$\Delta|V| \cong \frac{P}{V} \cdot R + \frac{Q}{V} \cdot X$$

[1] DER "penetration" is a measure of how much DER is connected relative to the characteristics of a system. There are a number of ways in which DER penetration can be quantified. Each of these metrics has particular relevance to different DER impacts. Examples are aggregate DER capacity relative to peak circuit load, minimum circuit load, and minimum daytime circuit load (the latter particularly applicable to PV).

If the DER output is large enough, voltage can be pushed above the upper limits of the voltage range allowed by ANSI C84.1.

DER output is, for purposes of voltage evaluation, equivalent to a negative load. So, the flow of power from a DER into the distribution system results in a voltage rise due to its interaction with circuit resistance. Most DER today are operated at unity power factor, so the discussion of DER reactive power will be addressed later in this article.

When DER power output exceeds the load demand downstream of the point of interconnection to the feeder, power flow will reverse at that point on the feeder. As a result, voltage will rise with increasing distance along the feeder from the substation. This is opposite of the normal tendency for voltage to steadily decline with increasing distance, except where a mid-line voltage regulator or capacitor bank is used to boost the voltage. If the DER output is large enough, voltage can be pushed above the upper limits of the voltage range allowed by ANSI C84.1. Figure 1 shows the voltage profile for an example case where a large DER is interconnected at the end of the feeder, compared with voltage profile on the same feeder without the DER.

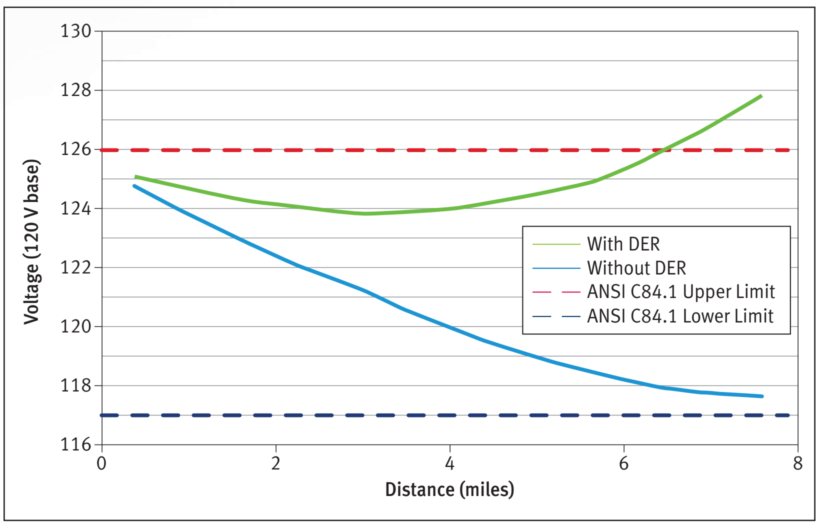

FIGURE 1: Example of a large DER at the end of a feeder pushing voltage above limits.

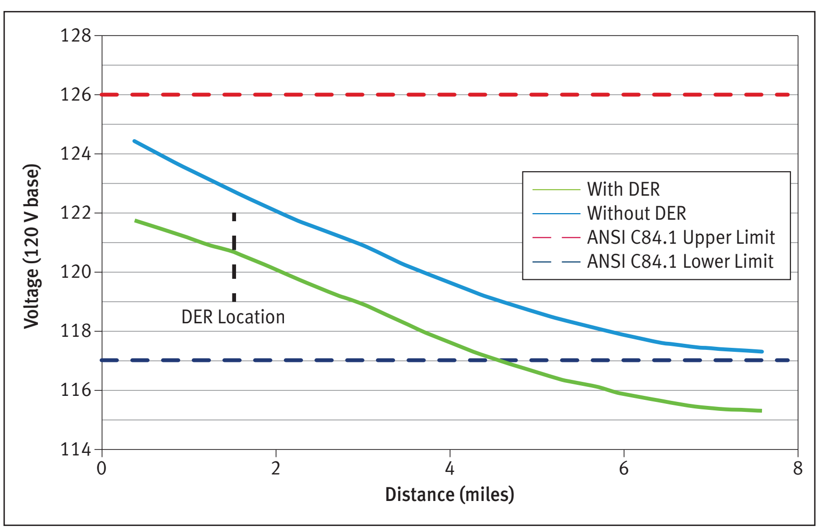

FIGURE 2: Example of DER interacting with substation transformer tapchanger control to depress feeder voltage below limits.

DER can also result in low voltage conditions on a distribution feeder, primarily by interacting with the line-drop compensation (LDC) functions of feeder voltage regulator or substation transformer tapchanger controls. LDC adjusts the voltage regulation setpoint, based on the current measured at its location, in order to accommodate normal feeder voltage drop. This function is based on the assumption that the flow measured at the regulator or substation is representative of the loading situation downstream along the feeder. A large DER unit located downstream, but near, to the regulating device results in a decreased or reversed flow at the device. As a result, the amount of voltage setpoint boost provided by the LDC is reduced, and voltage may not be sufficient at that location in order to keep voltage at the far end above the minimum acceptable level. This situation is illustrated in Figure 2.

Simultaneous high and low voltage situations can occur when large DER penetration is present on one feeder of a substation where the bus voltage is regulated using LDC. The flow through the substation transformer is reduced by the DER, causing less LDC boost to the tapchanger control. The voltage at the bus may be too low to provide adequate voltage at the end of other feeders without DER, but at the same time, the bus voltage may be too high

Voltage variability due to solar and wind DER can also cause temporary excursions outside of acceptable voltage ranges.

such that the feeder with DER may have excess voltage at the DER connection point.

The present IEEE 1547-2003 version prohibits DER from causing voltage at any other customer's service point outside the limits of ANSI C84.1 Range A. Accommodating high DER penetration can sometimes require modification of feeder voltage management practices (e.g., tap and capacitor bank switching control setpoints), physical relocation of capacitor banks or regulators, or even feeder reconductoring in order to avoid excessive voltage. A cooperative will avoid making any changes that can reduce the quality of service to other customers, so the opportunities for simple low-cost solutions, such as control setpoint changes, are limited.

Voltage Variation

A DER can have objectionable impact even if it does not drive voltage outside of the ANSI C84.1 limits. DER that have inherent variability in their output, specifically solar PV and wind generation, can cause very frequent voltage variations. Figure 3 shows an example of PV facility power output, comparing a clear "blue sky" day with a partly-cloudy day where cloud shadows frequently pass over the solar arrays. The resulting voltage variations are often termed "flicker" but in most realistic situations, the voltage variations produced by solar and wind generation are not sufficiently rapid or large to meet the definitions of objectionable flicker as defined in IEEE Standard 1453™. IEE1453 is based solely on human perception of incandescent lamp flicker and does not address other voltage variation impacts. Instead, the voltage variations from PV and wind become objectionable by causing too-frequent operation of cooperative voltage regulating devices, such as feeder voltage regulators, substation transformer on-load tapchangers, and capacitor switches. The resulting excessive operations can require increased maintenance costs for these cooperative devices and may result in premature device failure.

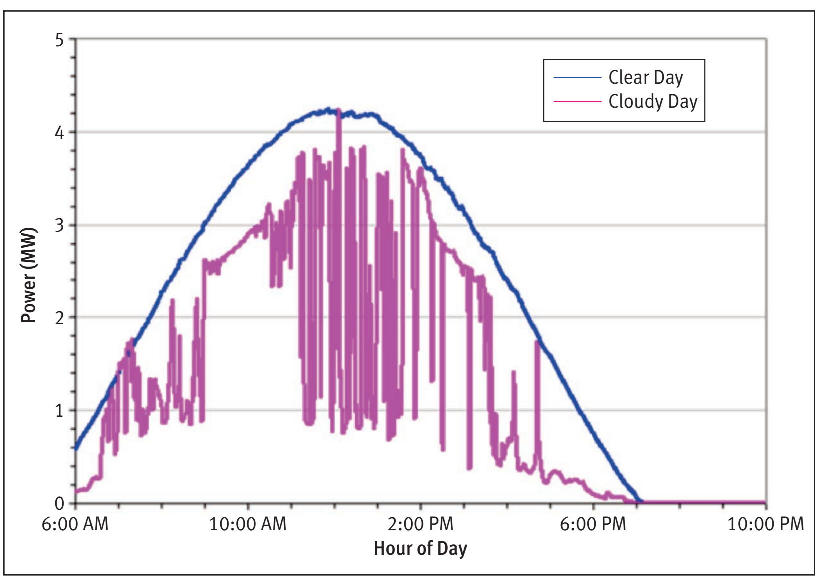

FIGURE 3: Typical PV facility power output during clear and partly-cloudy days. *(Source: R. Walling, DistribuTech 2012)*

Voltage variability due to solar and wind DER can also cause temporary excursions outside of acceptable voltage ranges, because the voltage ramps can be much faster than the response time of mechanical feeder voltage regulation equipment. Decreasing the device operation counts by using wider regulation deadbands or longer delay times tend to aggravate the temporary voltage excursion problem. Voltage variability problems often require feeder reconductoring or may cause a DER interconnection request to be denied.

REACTIVE POWER AS MITIGATION

The costs of feeder modification to accommodate a DER project, particularly large modifications such as reconductoring, are typically the responsibility of the DER project proponent. In some states, these requirements are included in interconnection regulations. Therefore, parties seeking to interconnect, as well as cooperatives wishing to accommodate DER while protecting their other members from adverse impacts, desire alternative ways to mitigate DER voltage impacts.

Reactive power absorption by DER interacts with feeder reactance to create a voltage drop that opposes the voltage rise caused by the interaction of active (i.e., real) current with feeder resistance. Both rotating generators and inverters are inherently capable of both reactive power production and absorption that are smoothly variable and can be changed frequently without wear and tear, such as that experienced by mechanical voltage regulation equipment. Reactive power can be changed almost instantaneously by inverters and within a few seconds by rotating generators. Reactive current, therefore, can be used to mitigate both the steady-state voltage impacts and voltage variability impacts of DER.

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The use of DER to mitigate DER-caused voltage rise is not without its own adverse impacts. Any reactive power consumed by DER must be replaced elsewhere in the cooperative system. The source of this replacement reactive power will normally be at or near the substation end of the feeder in order for it to be effective in raising the substation power factor without increasing feeder voltage near the DER. This may necessitate installing capacitor banks at or near the substation in order to maintain the power factor of the substation.

This may be counterintuitive for those who work primarily with correcting power factor for typical loads, where capacitors are added closer to the loads on the feeder to help reduce losses and increase voltages. With DERs, adding capacitors near the DER would still improve the substation power factor, but voltages near the DER could be increased beyond ANSI C84.1 limits.

Means must also be provided to control the DER reactive power in order to achieve the voltage impact mitigation objective. The various control techniques vary in their effectiveness, application complexity, and potential for interference with other cooperative voltage regulation schemes.

INCREASING SYSTEM IMPACTS DRIVE STANDARD CHANGES

DER penetration growth over the last decade has been explosive in many parts of the US. Most of this growth has been in solar PV, in the form of both utility-scale power generating facilities in the MW range and behind-the-meter retail installations. Many utilities today have distribution feeders where the connected DER capacity exceeds the load demand. Consequently, critical voltage impacts created by DER have become a more prevalent issue.

The levels of DER penetration seen in many places today are far greater than were commonly foreseen when the original IEEE 1547 was adopted in 2003. Although it was known then that DER reactive power could reduce voltage impacts, it was also realized that coordination of this capability with utility voltage regulation complicates the interconnection process. In order to minimize the amount of utility and developer interaction, IEEE 1547-2003 prohibited DER from "actively regulating" the voltage at the point of interconnection. Although this has often been misinterpreted as a requirement that DER only operate at unity power factor (no reactive power flow), the intent of the standard was to prohibit controls that vary reactive power in response to measured voltage. As a consequence of this prohibition, DER has been denied interconnection in some cases where constructive use of DER reactive power would eliminate objectionable voltage impacts and, in other cases, the DER developers have had to pay for feeder reconductoring or construction of a dedicated feeder in order to interconnect.

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The use of DER reactive power can sometimes be a satisfactory alternative to expensive distribution system upgrades. Today's DER situation is far different than in 2003, and the draft revision of IEEE 1547 reverses the stance on DER reactive power capability and voltage regulation. The new standard will instead require DER

It must be emphasized that this reactive power and voltage regulation functionality is to be utilized only with the express consent of the cooperative.

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to have reactive power production and absorption capability and the DER must possess a number of prescribed control functions in order to regulate this reactive power. And, because new DER will be required to have these capabilities, the cooperative can demand its utilization when necessary to address feeder voltage issues caused by DER. **It must be emphasized, however, that this reactive power and voltage regulation functionality is to be utilized only with the express consent of the cooperative.**

Point of Applicability

Now that the reactive power and control functionalities will be required, the point where the requirements will apply has become a more controversial subject. Providing a certain amount of reactive power at the DER terminals is not equal to providing the same amount at the Point of Common Connection (PCC) with the cooperative system, due to reactive power losses (e.g., from transformer reactance) and gains (e.g., due to solar farm cable charging capacitance) between these locations. Likewise, regulating the DER terminal voltage to a certain value does not result in the PCC voltage being regulated to that value.

DER vendors prefer to have the requirements apply at the DER terminals because they want to market self-contained systems that are certified to be compliant without regard to the details of the customer's balance of system (i.e., transformers and cables between the DER and the PCC). Utilities, on the other hand prefer to have capabilities defined at the boundaries of their system, and do not wish to consider the details of the customer's system. After much debate, the IEEE P1547 working group[2] has reached a compromise where "retail" DER interconnections will have the requirements apply at the DER terminals and "wholesale" DER will have requirements apply at the PCC.[3] "Wholesale" DER are facilities where the aggregate DER rating exceeds 500 kW, and the annual average load demand of the facility is less than 10 percent of the rating. The intent is to cover pure generation facilities, with some allowance for auxiliary loads, security lighting, etc. All other DER facilities, including DER rated greater than 500 kW, but within a facility having significant load, would be considered "retail" and the requirements are applicable at the DER terminals.

VOLTAGE LIMITS

The existing IEEE 1547-2003 requirement that a DER not cause any other customer's service voltage to go outside of ANSI C84.1 Range A is retained in the draft P1547. However, additional limitations are also applied. The DER customer's own PCC voltage must also not go outside of Range A, unless the customer is served by a dedicated transformer. This is to ensure that future customers added to the same secondary system have acceptable service voltage. Another new requirement is that the cooperative's primary voltage should also not be driven outside of Range A.

REQUIREMENTS FOR REACTIVE CAPABILITY

The draft P1547 requires DER to have reactive production and absorption capability in proportion to the DER kVA rating, over the range of power output from 20 percent power up to full power rating. The DER can produce active power (kW) in excess of the power rating, up to the kVA rating, as long as it remains capable of meeting the reactive power requirements if

[2] The "P" in P1547 designates a standard under development. After the standard draft is developed and successfully balloted, the P is dropped from the standard number. The P1547 now under development, when adopted, will replace the existing IEEE 1547-2003.

[3] The terms "retail" and "wholesale" are not used, per se, in the standard. However, these terms are used in this article for clarity to reflect the intent of the standard.

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demanded, presumably by reducing the active power in order to maintain the DER within its apparent power (kVA) rating.

IEEE 1547 has been, and will continue to be a technology-neutral document. However, the inherent ability of certain types of DER to meet reactive power requirements differ, and setting requirements that exclude some DER technologies would not be acceptable. In many cases, the potentially-excluded technologies perform beneficial roles that cannot feasibly be performed by other technologies. Specifically, synchronous generators have limitations to their reactive absorption capability (under-excited operation). Synchronous generators, however, are the preferred technology for recovering energy from biogas, backup generation, and other functions beneficial to society. Because IEEE is a technical group, it is outside of their scope to make policy decisions based on total societal benefit. Therefore, the standard has defined "performance categories" that apply to the reactive power and regulation functions described in this article, as well as disturbance performance requirements that will be discussed in the next article in this series. For reactive power and control requirements, two categories have been defined. Category A has requirements that are feasible for all known DER technologies to meet. Category B has enhanced requirements that are beneficial to the power system, but may not be achievable by all technologies. The draft standards punts on the decision regarding which performance category will be required on the basis of application and DER technology, deferring this decision to the "Authority Governing Interconnection Requirements" (AGIR). The AGIR could be a regulatory agency, or could be the cooperative itself.

The proposed reactive power capability requirements for Category B are for reactive power from 44 percent of the DER nameplate apparent power (kVA) rating in the kVAR absorbing direction to 44 percent of nameplate kVA in the kVAR producing direction. This is equivalent to 0.9 power factor at rated load. However, this is not strictly a power factor requirement because the DER must be able to inject or absorb this same amount of reactive power for power levels as low as 20 percent. The reactive power capability requirements for Category B DER are depicted in Figure 4. The semicircular area for power greater than rated kW is the optional area where a DER may operate if the reactive power that is demanded at that moment is within the region. If greater reactive power is required, the DER may need to reduce its active power in order to supply the reactive power. For Category A, the kVAR-absorption requirement is reduced to 25 percent of the nameplate kVA, primarily in order to accommodate synchronous generators.

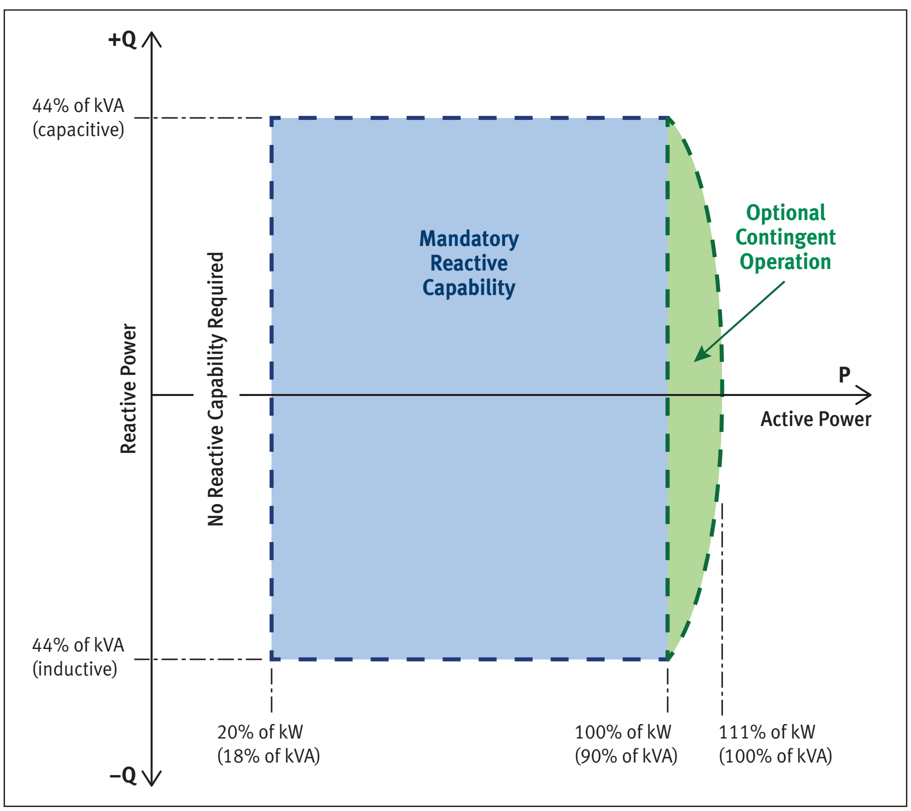

FIGURE 4: Reactive power capability requirements for Category B DER.

The 20 percent minimum power level for reactive capability has its roots in interconnection requirements used around the world for renewable resources. The original intent of these other requirements was to accommodate wind plants at low wind speeds where only a few turbines have wind speed above the turbine startup value and, thus, the overall plant has reduced capability to meet reactive power requirements under marginal wind conditions. The rationale is that all wind turbines can be assumed to be on line when 20 percent power level is reached. The extension of this lower power limit to DER in IEEE P1547 has raised some concerns of voltage steps when a DER's output dithers above and below this 20 percent power threshold and the reactive capability could cut in and out.

A reactive power magnitude that is good for one power level may adversely affect voltage at a different DER output.

REGULATION MODES

For reactive power to be applied for DER voltage impact mitigation, the reactive power magnitude needs to be controlled automatically. This is particularly true for DER having inherently variable output, such as PV. A reactive power magnitude that is good for one power level may adversely affect voltage at a different DER output.

There are a wide variety of distribution system designs and situations, so there is no one control scheme that fits all circumstances. P1547, therefore, specifies a number of different control modes that can be applied to deploy reactive power in the best way to meet system objectives. These control modes are:

- Constant power factor
- Constant reactive power
- Reactive power as a function of active power (watt-VAR mode)
- Reactive power as a function of voltage (volt-VAR mode)
- Volt-VAR mode with voltage reference tracking

The choice of DER control mode and its parameters are to be at the discretion of the cooperative.

Both Category A and B DER are required to have each of the above control modes available, with the exception that the watt-VAR mode is optional for Category A.

The choice of DER control mode and its parameters are to be at the discretion of the cooperative. The proposed standard defines ranges of control parameters for which the DER must have full adjustability, and a default value is provided for each parameter that is to be used where the cooperative has not specified otherwise.

Constant Power Factor

In the constant power factor mode, reactive power is directly proportional to the active (kW) power. The power factor is settable between 0.9 in the kVAR producing direction to 0.9 in the kVAR absorption direction.[4] This control mode is both simple and, at the same time, quite effective if the correct power factor setting is chosen. It can be shown mathematically that a constant kVAR-absorbing power factor equal to the sine of the arctangent of the reactance to resistance ratio ($\sin(\text{Tan}^{-1}(X/R))$) of the cooperative system results in cancellation of the voltage changes caused by DER power variations. The voltage variations, however, are only nulled at the point where the power factor is held constant (DER terminals for retail applications, and the PCC for wholesale generating facilities). Voltage may still vary elsewhere in the system, particularly if there is a large difference in the X/R ratio of the system impedance at any point along the distribution system toward the substation.

This is a situation where the requirement for wholesale generating facilities to achieve their performance at the PCC is particularly beneficial. Such facilities typically have their PCC at the primary voltage level. At points along primary feeder ahead of the PCC, the X/R ratio is most often reasonably constant except where there is a

[4] The definitions for leading and lagging power factor for generation are opposite of the definitions for loads. In order to avoid confusion between load and generation power factor conventions, leading and lagging are not used here.

very large change in conductor size or a transition from overhead to underground. This allows the constant power factor mode to largely mitigate most of the DER facility's voltage impact.

For retail DER connected at the secondary level, there is frequently a large change in the upstream X/R ratio between the secondary and primary sides of the service transformer. For example, a large three-phase transformer may have an X/R ratio of ten, but the primary feeder's X/R ratio is more typically around two or three. The constant power factor can be set such that the secondary voltages variations are nulled, but primary variations are not. This is less of an issue when small DER are interconnected because they, on an individual basis, do not usually have significant primary voltage impact. Where there is high penetration of small DER, utilities may have voltage variability issues at both secondary and primary levels.

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The constant power factor control mode is an "open-loop" control function, meaning the response of the cooperative system does not affect what the function does. As a result, this mode is unlikely to adversely interact with the cooperative system's voltage regulation controls. One exception is when the cooperative's feeder capacitor banks are controlled on the basis of measured reactive current flow on a feeder. The reactive power absorbed by the DER in order to cancel resistive voltage rise may also cause the cooperative capacitor banks to switch on with consequent voltage increase. This defeats the purpose of the power factor mode.

Constant Reactive Power Mode

In the constant reactive power mode, the DER injects or absorbs a constant amount of reactive power independent of the active (kW) power. An exception is where the active power drops below 20 percent of rating, at which point the DER is no longer required to have reactive power capability (it may hold the reactive power, or it may not, depending on the DER design). Effectively, this makes the DER act like a capacitor or shunt reactor from the reactive power standpoint. There may be special circumstances where this mode is useful, but it is not likely to have wide application except for DER that have constant power output. One such special circumstance can be where a cooperative has an integrated volt-VAR control (IVVC) and reactive power levels are dispatched on a continuous basis by the IVVC to individual DER. This is an advanced "smart grid" concept that might be applied in the future, and having this simple function available in DER is desirable, even if it has very limited application today.

Reactive Power as a Function of Active Power

The "watt-VAR" function varies reactive power according to a defined function of the active (kW) power. This function differs from the constant power factor mode because the relationship can be nonlinear. The relationship is defined by a two-slope line. Figure 5 illustrates some of the Q vs P characteristics that can be defined within the range of parameter adjustments. Some example application cases for this function are to:

- Minimize cooperative system reactive burden when the DER output is moderate to low, but increase the reactive power absorption at higher levels of active power in order to mitigate voltage rise. (Example shown in **Figure 5a**.)
- Compensate for the reactive power losses of the service transformer reactance, so that a DER following this curve on the secondary side produces a roughly constant power factor on the primary side, thereby minimizing primary voltage impact. (Example shown in **Figure 5b**.)
- Provide the cooperative system with lagging (i.e., capacitive) reactive power except when the DER output is high and it must go to unity power factor to avoid creating an overvoltage. (Example shown in **Figure 5c**.)

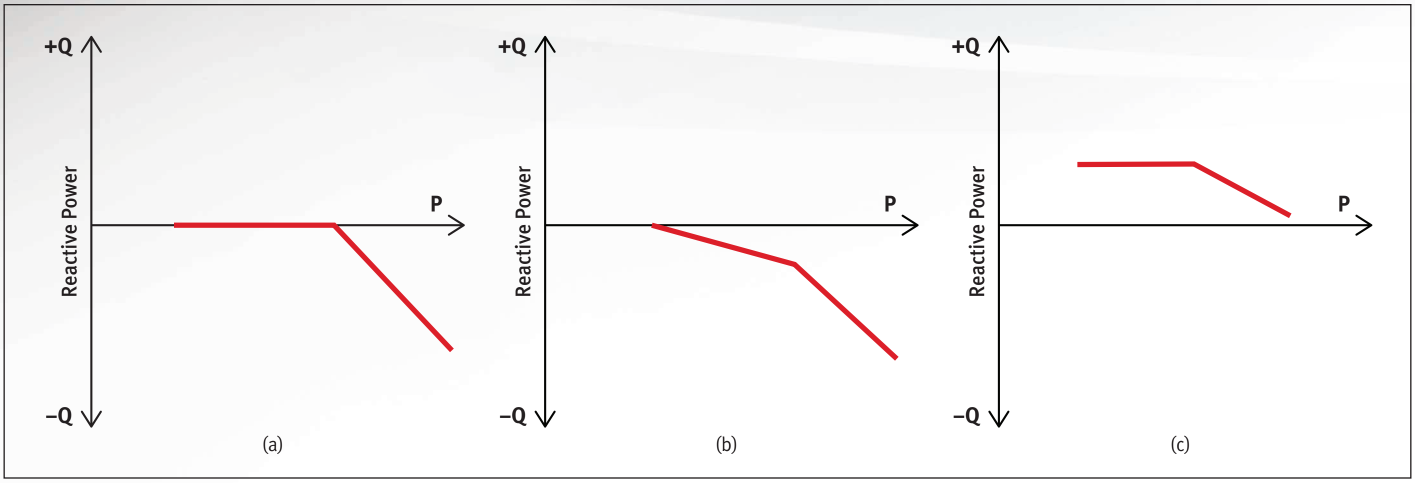

FIGURE 5: Example watt-VAR mode characteristics.

"Volt-VAR" or Voltage Regulation Mode

Perhaps the most powerful of the required reactive power regulation modes specified in the draft P1547 is the "volt-VAR" mode in which the reactive power output is a function of the measured voltage (at the DER terminals in the case of retail applications, and at the PCC for wholesale generation applications, as defined previously in this article). Figure 6 illustrates the reactive power versus voltage characteristic used for this control mode. The parameters defining this characteristic are required to have a substantial range of adjustability. Therefore, the function can be customized to a particular application situation. As with all of the reactive control modes discussed in this article, the parameter settings, as well as whether this mode is even used, are to be at the discretion of the cooperative.

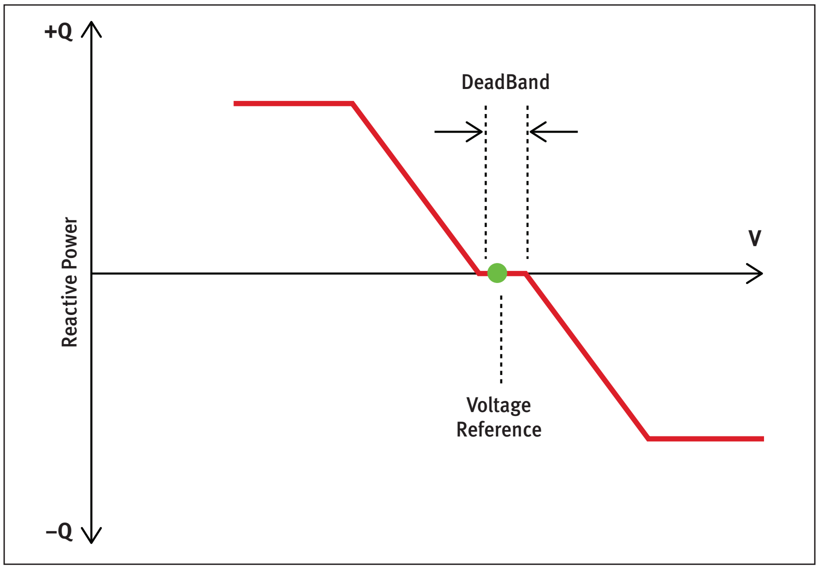

FIGURE 6: Reactive power versus voltage characteristic of the voltage regulation mode.

Because reactive power affects voltage, and voltage affects the reactive power injected or absorbed by the DER, the volt-VAR mode is a "closed-loop" control. Effectively, this mode is essentially the same as the voltage regulation function that has been used with synchronous generators for the last century. The reference value for the voltage regulation, i.e., the voltage that the control attempts to achieve, is the voltage at which the specified characteristic yields zero reactive power. The parameters of the function allow definition of a deadband; a range of voltages for which there is no change in the reactive power. Usually, the reactive power in the deadband region is zero and the reference, or target voltage, can be considered to be the center of the deadband range. On each side of the deadband is a slope; the amount of reactive power change for a given change in measured voltage. This, from a control engineering standpoint, is the "gain" of the regulation function. If this gain is too high (i.e., the slope is too steep), voltage regulation from the DER may become unstable. The gain where instability occurs is proportional to the stiffness of the system. Regulator instability can cause oscillatory variations in the voltage and should definitely be avoided.

This volt-VAR mode is powerful, because it can automatically regulate distribution voltage towards a desired value, but also requires considerable engineering attention because of the instability issue mentioned above and the potential for this function to interfere with other feeder voltage regulation schemes if not carefully coordinated. The draft standard has default parameter settings recommended, which should generally be safe from stability issues in most cases. But, even these settings can interfere with voltage regulation. For example, the default setting for the reference voltage is the nominal value. It is typical practice for a cooperative to run the head of a feeder at higher than nominal voltage in order that the far end is within the acceptable range. A DER connected near the head of the feeder using the volt-VAR mode with default parameters will fight with the intended voltage profile by absorbing reactive power in an attempt to pull the feeder head voltage towards nominal (1.0 p.u. or 120 V). A different interaction can be caused by a large DER in volt-VAR mode located near a feeder voltage regulator, which causes the regulator control to "hunt," continuously raising and lowering the tap setting. Interactions can also occur with voltage-controlled capacitor banks.

Engineering studies are needed to properly apply the DER volt-VAR mode. There is an inherent tradeoff between the aggressiveness of the function and the risks of unintended consequences. It may be possible, however, for a cooperative to develop standardized application rules that allow the mode to be successfully applied without detailed study of the specific DER interconnection. For example, an application rule might be to set the voltage reference according to the DER's location on the feeder. For feeders that may be part of a loop scheme, the location of the DER relative to the head and tail of the feeder will change depending on which end the feeder is energized at any given time. This can make the choice of acceptable volt-VAR mode parameters more difficult.

There is an inherent tradeoff between the aggressiveness of the function and the risks of unintended consequences.

Voltage Regulation Reference Tracking

The draft P1547 also specifies a variation of the volt-VAR mode in which the reference value, or regulation objective, tracks the long-term average of the actual voltage. This mode adapts to the prevailing voltage, so that the DER does not fight with the feeder voltage profile but instead preserves the dynamic range of the DER's reactive power to mitigate shorter-term voltage variations. This can be a very effective way to address the propensity of large PV installations to cause excessive regulator, tapchanger, and capacitor switch operations. However, this mode does not allow the DER to correct long-term voltage profile issues caused by DER penetration. In many cases, it may be more efficient to address long-term voltage issues with regulators and capacitor banks, and reserve the DER's ability to make fast and frequent reactive power changes for the short-term voltage impacts.

Voltage-Power Mode

There is one control function specified in P1547 that is related to voltage regulation but does not involve reactive power. The "volt-watt" mode limits active (kW) power in response to high voltage conditions. This mode is not intended for routine voltage regulation as the frequent limitation of power can have a profound economic impact on the DER owner. Instead, this function is intended to address excessive voltage levels that might be caused by DER power export. The standard recommends a default value of 105 percent of nominal voltage (126 V) for the beginning of power limitation; this parameter is to be adjustable from 103 to 110 percent. The value of voltage where power export is limited to zero is adjustable up to 110 percent. Thus, this function can be considered to be a "partial trip" function that is perhaps a better alternative for the distribution system than an abrupt trip of the entire DER output when a moderate overvoltage threshold is reached. (Rapid tripping for more severe overvoltage remains in the standard and will be discussed in the next article of this series.)

CONCLUSIONS

Interconnection of large DER facilities, or high levels small DER penetration, can cause significant cooperative voltage issues, both in terms of out-of-limit voltages and voltage variability. The revision of IEEE 1547 provides a solution toolbox by mandating DER to have reactive power capability, along with a variety of control functions by which this reactive power can be deployed to mitigate voltage issues. Although DER reactive power is very effective, use of it to reduce voltage rise caused by DER power export tends to increase distribution system losses and can reduce the system's net power factor at the substation. Some degree of distribution engineering attention is needed to implement DER reactive controls depending on regulation mode utilized and the degree of mitigation aggressiveness desired.

DER reactive capability is to be used only as approved by the cooperative, and the control mode parameters are to be specified by the cooperative. These changes to the standard can be helpful to cooperatives in many cases. Options will have to be evaluated and settings developed for different situations. The tools provided will be available if needed or desired, but the revised standard does not change the effective status quo if the cooperative does not agree to use the reactive control tools.

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 previous ***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

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