STATE OF CALIFORNIA
ENERGY COMMISSION

# SIWG Phase 3 DER Functions: Recommendations to the CPUC for Rule 21, Phase 3 Function Key Requirements, and Additional Discussion Issues

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**FINAL**

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# Executive Summary

**SIWG Phase 3 functions for Rule 21**. As identified by the SIWG in March 2017, the eight (8) Phase 3 functions that are summarized in Table 1 are recommended to be included in Rule 21 as mandatory or optional capabilities for all inverter-based DER systems. These recommendations result from the additional SIWG discussions held during February and March, 2017, resolving the issues that remained after SIWG discussions were paused in 2016 in order to determine what decisions would be made during the development of IEEE 1547 revision.

**Rule 21 vs. IEEE 1547 requirements.** For each of the Phase 3 functions that are also covered in IEEE 1547 Draft 6.7, it is recommended that Rule 21 use or reference the same definitions, requirements, and values provided in that draft document. However, it is further recommended that if the final balloted revision of IEEE 1547 includes conflicting requirements for the functions, the requirements in Rule 21 will take precedence. Nonetheless, it is expected that those Rule 21 requirements for Phase 3 functions will eventually need to be reviewed and updated if there is a conflict.

**Guidelines outside of Rule 21**. It is recommended that these functions and the data exchange requirements are discussed in more detail in a separate Phase 3 guidelines document and/or in the utility Interconnection Handbooks, so that the concepts and interactions are clearly understandable. Sections 5 through 12 of this document provide initial content for that separate Phase 3 guidelines document.

**Table 1 summarizes the SIWG Phase 3 discussions** and final recommendations for the functions to include in Rule 21.

Table 1: Summary of SIWG Phase 3 Recommendations

| Proposed Function | Recommendations |
|---|---|
| Function One – Monitor Key DER Data | • Use IEEE 1547 data requirements in the “Interoperability, information exchange, information models, and protocol” section.<br>• Also identify all additional alarms, status, measurement, and forecast monitoring requirements in a separate document such as the Interconnection Handbook, which can be developed after modifications to Rule 21.<br>• Rule 21 will take precedence in case of conflict with the final revised IEEE 1547<br>• State of Charge will be represented as Available kWh, not % of maximum. |
| Function Two – DER Disconnect and Reconnect Command (Cease to Energize and Return to Service) | • Use IEEE 1547 Cease to Energize and Return to Service for communication commands |
| Function Three – Limit Maximum Active Power Mode | • Use IEEE 1547 Limit Maximum Active Power.<br>• Use percent of the maximum active power capability.<br>• Add clarification how to specify which point (PCC or POC) will be used for the function: at interconnection time, as an updatable setting, or as part of a command in real-time<br>• Would need to monitor which point is being used and the results of whether the command is complied with completely due to local load or for other reasons<br>• The accuracy of compliance to the requirement would need to take into account the settling time for meeting the requirement plus tolerance around the requested value, plus changes in load/generation. |

| Proposed Function | Recommendations |
|---|---|
| | • Need the capability to monitor dynamic behavior |
| Function Four – Set Active Power Mode | • Since this function is not in IEEE 1547, it will be optional in Rule 21<br>• (Could use the Limit Power function to set active power for energy storage systems, such that the limit value indicates the active power setting, or could optionally use a set active power function) |
| Function Five – Frequency Watt Mode | • IEEE 1547 values are fine since there is the ability to change those values. This means that this function can be used during normal and/or abnormal conditions<br>• Add time-domain response times from 1547 Category III<br>• Although hysteresis is allowed, there are no known requirements at this time, so hysteresis requirements will not be covered in Rule 21 |
| Function Six – Volt- Watt Mode | • Use IEEE 1547 values.<br>• The Volt-Watt mode may be used in coordination with the Volt-Var mode to avoid excess vars or to increase the combined impact on the voltage. In general, Volt-Var would be used first, with Volt-Watt used if necessary. |
| Function Seven – Dynamic Reactive Current Support | • Since this function is optional in IEEE 1547, it will also be optional in Rule 21.<br>• This function could provide support for voltage stability |
| Function Eight – Scheduling Power Values and Modes | • Schedules shall be capable of setting active and reactive power values as well as enabling and disabling of any DER modes for specific time periods. Either the DER system or a proxy, such as a facility energy management system or aggregator, shall have the capability to handle schedules.<br>• Schedule requirements will be described in the Interconnection Handbook |

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# 1. Scope of this Document

This document provides the recommendations of the Smart Inverter Working Group (SIWG) on the Phase 3 Distributed Energy Resource (DER) functions for inclusion in Rule 21.

- Section 2 describes the key requirements for the eight (8) Phase 3 DER functions that are recommended to be included in Rule 21.
- Section 3 identifies the proposed timeframe for implementing the mandatory requirements.
- Section 4 covers the general informative background and terminology used in describing the Phase 3 functions
- Sections 5-12 provide informative material on the Phase 3 DER functions to better ensure common understandings of the functions

# 2. Key Requirements of Recommended SIWG Phase 3 Functions

## 2.1 Key Concepts for Phase 3 Functions

**SIWG Phase 3 functions for Rule 21**. As identified by the SIWG in March 2017, the eight (8) Phase 3 functions that are included in Table 2 are recommended to be included in Rule 21 as mandatory or optional capabilities for all inverter-based DER systems. These recommendations result from the additional SIWG discussions held during February and March, 2017, resolving the issues that remained after SIWG discussions were paused in 2016 in order to determine what decisions would be made during the development of IEEE 1547 revision. These capabilities would only be enabled or permitted after contractual or market agreements are made; those contractual and market arrangements are out-of-scope for this SIWG document.

**Rule 21 vs. IEEE 1547 requirements.** For each of the Phase 3 functions that are also covered in IEEE 1547 Draft 6.7, it is recommended that Rule 21 use or reference the same definitions, requirements, and values provided in that draft document. However, it is further recommended that if the final balloted revision of IEEE 1547 includes conflicting requirements for the functions, the requirements in Rule 21 will take precedence. Nonetheless, it is expected that those Rule 21 requirements for Phase 3 functions will eventually need to be reviewed and updated if there is a conflict.

**Guidelines outside of Rule 21**. It is recommended that these functions and the data exchange requirements are discussed in more detail in a separate Phase 3 guidelines document and/or in the utility Interconnection Handbooks, so that the concepts and interactions are clearly understandable. Sections 5 through 12 of this document provide initial content for that separate Phase 3 guidelines document.

**Concept of Referenced Point (Local or Remote).** The term “Point of Connection (PoC) is defined in IEEE 1547 Draft 6.7 as the “*The point where a DER unit is electrically connected in a Local EPS* …”. An additional broader term defined in IEC standards is “Electrical Connection Point (ECP)” which includes the PoC point of DER interconnection, but can also be the connection point between a group or aggregation of DER systems and the local EPS. If loads can be controllable, then they can also have a ECP. The point of common coupling (PCC) is the ECP between the local EPS and the area EPS. An external location can also have a remote ECP at its PCC.

The reason for including the ECP in this document is that many Phase 3 functions must reference a point that is not the PoC. In particular, utilities usually expect a function to take effect at the PCC, so some functions would need to have access to measurement data from the local PCC. However other remote points could also be referenced, such as an energy storage system referencing a PV plant a few miles away at a separate facility in order to counteract PV fluctuations. Synchrophasors would also need to collect data from other remotely located synchrophasors.

Therefore many of the Phase 3 functions use the term “Referenced Point” or “Referenced ECP” to indicate that the identifier of the ECP must be one of the parameters. It is assumed, of course, that these Referenced Points have been mutual agreed to, and that some means of receiving the necessary power system measurements from the Referenced Point is available to the DER system.

## 2.2 Recommended SIWG Phase 3 DER Functions and Key Requirements for Inclusion in Rule 21

Table 2 describes the recommended SIWG Phase 3 DER functions and their key requirements. The SIWG recommends that these requirements be included in Rule 21.

Table 2: Discussions on Phase 3 DER Functions and Key Requirements for Rule 21

| SIWG Phase 3 DER Functions | Discussions on Key Requirements for Rule 21 |
|---|---|
| **Monitor Key DER Data:** Provide key administrative, status, and measurements on current energy and ancillary services (Section 5) | **Monitor Key DER Data**: All DER systems shall have the capability to provide key DER data at the DER’s Point of Connection (PoC) and/or at the Point of Common Coupling (PCC) and/or aggregated at some other ECP. Utilities shall define in their Interconnection Handbooks when and under what conditions the data exchange requirements shall be provided, including what types of data, whether and how it may be aggregated, frequency of monitoring, time latency, etc.<br>Key data requirements include as a minimum:<br>• **IEEE 1547 data requirements** in the “*Interoperability, information exchange, information models, and protocol*” section. However, Rule 21 will take precedence in case of conflict with the final revised IEEE 1547.<br>• **The data items listed in Section 2.3, Table 3**, including:<br>– **Administrative Data**: DER system identification, facility identification, updates to nameplate information, updates to DER ratings, indications of which functions are supported, and other essentially static data.<br>– **Monitored Data**: Individual and/or aggregated DER state of readiness – define this more clearly (on/off, changes from nameplate, major alarms), real-time measurements, metered data, and any forecast states that deviate from planned or scheduled states.<br>– **Error conditions:** If the mutually agreed upon exchanges of data are not taking place within the agreed upon time latency and completeness, these conditions shall be reported. |

| SIWG Phase 3 DER Functions | Discussions on Key Requirements for Rule 21 |
|---|---|
| **DER Cease to Energy and Return to Service Command** (Section 6)<br>Cease to energize and return to service at the PCC | **DER Cease to Energize:** The cease to energize command shall cause a “cease to energize” state at the PCC or optionally shall allow the opening of a switch. The cease to energize shall cause the DER to cease exporting active power and (*close to zero*) reactive power flow.<br>Key requirements include:<br>• **Use the IEEE 1547 Cease to Energize and Return to Service** definitions and requirements<br>• **Cease to energize command** received via communications shall cause the DER to enter the cease to energize state.<br>• **A ramp rate** or **open loop response time** for complying with the command shall be settable.<br>• **Reversion time** shall be included determining when the DER can return to service if communications are not available.<br>• **Acknowledge command** and/or **monitor the power data** at the PCC.<br>• **Error conditions:** If DER did not cease to energize at the PCC, this condition shall be reported.<br>**DER Return to Service:** The “return to service” command shall end the “cease to energize” state or shall initiate the closing of the switch. Additional key requirements include:<br>• **Ramp rate or a time window** for random return to service shall be settable.<br>• “**Permission to return to service**” shall be supported to allow actual return to service to take place at some later time.<br>• **Acknowledge command** and/or **monitor the data** at the PCC.<br>• **Error conditions:** If DER is not ready or capable of returning to service, this condition shall be reported. |

| SIWG Phase 3 DER Functions | Discussions on Key Requirements for Rule 21 |
|---|---|
| **Limit Maximum Active Power Mode** (Section 7)<br>Limit active power at the Referenced Point | The **Limit Maximum Active Power Percent** mode shall limit the active power level at the Referenced Point as a percent of the maximum active power capability.<br>Key requirements include:<br>• The **IEEE 1547 Limit Maximum Active Power** requirements in section "*Response to active power limit set points*" shall be met.<br>• **Set active power limit command with limit value**: Value of percent of maximum active power capability.<br>• **Referenced Point identifier:** The identity of the Referenced Point shall be provided where the active power is measured or calculated for the PoC, the PCC or other Referenced Point.<br>• **Accuracy setting:** Delta active power allowed to exceed the limit and time allowed to exceed the limit shall be settable, indicating the precision required for the functional requirements to be met.<br>• **Monitoring the Accuracy of Compliance** to the limit requirement shall take into account the settling time for meeting the requirement plus tolerance around the requested value, including during dynamic changes in load and generation.<br>• The **open loop response time** within which the active power limit shall be met shall be settable.<br>• **Reversion Timeout** in seconds shall be settable, after which the active power limit is removed. A reversion timeout = 0 means that there is no timeout.<br>• **Enable** and **Disable** settings for the Limit Maximum Active Power mode shall be provided. When enabled, the active power at the Referenced Point shall be limited to be within the percent established. When disabled, the DER shall revert to a previously defined state at the established ramp rate.<br>• **Acknowledge and/or monitor the data at the Referenced Point**: Receipt of the mode parameters and the enable/disable commands shall be acknowledged or the active power at the Referenced Point shall be capable of being monitored.<br>• **Error conditions**: If the commanded limit at the Referenced Point cannot be met or is not being met, this condition shall be reported. |

| SIWG Phase 3 DER Functions | Discussions on Key Requirements for Rule 21 |
|---|---|
| **Set Active Power Mode** (Section 8)<br>Set active power at the Referenced Point | **Since this function is not in IEEE 1547, it shall be optional in Rule 21.** (Alternatively, the Limit Power function could be used to set active power for the DER system, such that the limit value indicates the active power setting).<br>For DER systems that implement this mode and which can control their active power output (such as energy storage, synchronous generators, etc.), the **Set Active Power Percent** mode shall set the active power value to be output at the Referenced Point.<br>Key requirements include:<br>• **Set Active Power value**: Value of active power to be output at the Referenced Point.<br>• **Referenced Point identifier:** The identity of the Referenced Point shall be provided where the active power is measured or calculated for the PCC or other Referenced Point.<br>• **Accuracy setting:** Delta active power allowed to deviate from the active power value and time allowed to deviate shall be settable, indicating the precision required for the functional requirements to be met.<br>• **Monitoring the Accuracy of Compliance** to the set active power requirement shall take into account the settling time for meeting the requirement plus tolerance around the requested value, including during dynamic changes in load and generation.<br>• The **open loop response time** within which the active power level shall be met shall be settable.<br>• **Enable** and **Disable** settings for the Set Active Power mode shall be provided. When enabled, the active power at the Referenced Point shall be set to the requested value. When disabled, the DER shall revert to a previously defined state at the established ramp rate.<br>• **Acknowledge and/or monitor the data at the Referenced Point**: Receipt of the mode parameters and the enable/disable commands shall be acknowledged or the active power at the Referenced Point shall be capable of being monitored.<br>• **Error conditions:** If the commanded active power level at the Referenced Point cannot be met or is not being met, this condition shall be reported. |

| SIWG Phase 3 DER Functions | Discussions on Key Requirements for Rule 21 |
|---|---|
| **Frequency-Watt Mode** (Section 9)<br>Counteract frequency deviations by decreasing or increasing active power | The **Frequency-Watt mode** shall counteract frequency deviations by decreasing or increasing active power. The change in active power may be provided by changing generation, changing load, or a combination of the two.<br>**IEEE 1547 requirements and values in the section** *"Frequency-droop (frequency/power)"* **shall be used as the default,** including time-domain response times, but those values may be changed to meet different requirements. This means that this function can be used during normal and/or abnormal conditions.<br>Key requirements include:<br>• **High and low frequency thresholds to initiate changing active power:** This mode applies to both decreasing active power output on high frequency and increasing active power output on low frequency for units that can provide that capability at that point in time.<br>• **Rate of active power change** shall be settable.<br>• **High and low frequency stop settings** at which to stop changing active power, including a ramp rate.<br>• **Hysteresis (optional):** If hysteresis capability is available and is enabled, then the rate of change is also set for returning from the hysteresis level to the normal active power level.<br>• **Enable** and **Disable** settings of the Frequency-Watt mode shall be provided. When enabled, the DER shall counteract frequency deviations during H/LFRT events by decreasing or increasing active power.<br>• **Acknowledge and/or monitor the data at the Referenced Point**: Receipt of the mode parameters and the enable/disable commands shall be acknowledged or the active power at the Referenced Point shall be monitored.<br>• **Error conditions:** If the frequency-watt mode requirements cannot be met or is not being met, this condition shall be reported.<br>Capability to use this **Frequency-Watt function for frequency smoothing** during normal operations shall be permitted but is not mandatory. |

| SIWG Phase 3 DER Functions | Discussions on Key Requirements for Rule 21 |
|---|---|
| **Volt-Watt Mode** (Section 10)<br>Respond to changes in the voltage at the Referenced Point by decreasing or increasing active power | The **Volt-Watt mode** shall respond to changes in the voltage at the Referenced Point by decreasing or increasing active power. The change in active power may be provided by changing generation, changing load, or a combination of the two. The Volt-Watt mode may be used in coordination with the Volt-Var mode to avoid excess vars or to increase the combined impact on the voltage. In general, Volt-Var would be used first, with volt-watt used if necessary.<br>**IEEE 1547 requirements and values shall be used** as specified in the section "*Voltage-active (real) power (Volt-Watt) mode*"**.**<br>Key requirements include:<br>• **High and low voltage thresholds to initiate changing active power:** This mode applies to both decreasing active power output on high voltage and increasing active power output on low voltage for units that can provide that capability at that point in time.<br>• **Referenced Point identifier:** The identity of the Referenced Point shall be provided where the voltage is measured or calculated for the PCC or other Referenced Point.<br>• **Rate of active power change** shall be settable to establish a maximum rate of change of active power.<br>• **Enable** and **Disable** settings for the volt-watt mode shall be provided. When enabled, the DER shall respond to voltage levels at the Referenced Point by modifying active power according to the volt-watt curve parameters. When disabled, the DER shall revert to a previously defined state at the established ramp rate.<br>• **Acknowledge and/or monitor the data at the Referenced Point**: Receipt of the mode parameters and the enable/disable commands shall be acknowledged or the active power at the Referenced Point shall be monitored.<br>• **Error conditions:** If the Volt-Watt mode requirements cannot be met or are not being met, this condition shall be reported. |
| **Dynamic Reactive Current Support Mode** (Section 11)<br>Provide reactive current support in response to dynamic variations in voltage rather than the voltage itself | The **Dynamic Reactive Current Support mode** shall provide reactive current support in response to dynamic variations in voltage (rate of voltage change) rather than changes in voltage. This function could provide support for voltage stability.<br>Since this function is **optional in IEEE 1547's section "***Dynamic voltage support***"**, it will also be **optional in Rule 21**.<br>If implemented, key requirements include:<br>• **Enable** and **Disable** settings for the dynamic reactive current support mode shall be provided. When enabled, the DER shall respond to voltage variations at the Referenced Point by modifying reactive current according to the mode settings. When disabled, the DER shall revert to a previously defined state at the established ramp rate.<br>• **Acknowledge and/or monitor the data at the Referenced Point**: Receipt of the mode parameters and the enable/disable commands shall be acknowledged or the power measurements at the Referenced Point shall be monitored.<br>• **Error conditions:** If the dynamic reactive current support mode requirements cannot be met or are not being met, this condition shall be reported. |

| SIWG Phase 3 DER Functions | Discussions on Key Requirements for Rule 21 |
|---|---|
| **Scheduling power values and modes** (Section 12)<br>Scheduling of active and reactive power, as well as the enabling and disabling of DER modes | **Schedules** shall be capable of setting **active and reactive power values** as well as enabling and disabling of **DER modes** for specific time periods (minutes, hours, days, seasons, etc.). Either the DER system or a proxy, such as a facility energy management system or aggregator, shall have the capability to handle schedules<br>Schedule requirements have not been identified in IEEE 1547, so the schedule details for Rule 21 shall be described in the **Interconnection Handbook**, which will define the key requirements such as:<br>• **Time synchronization accuracy and precision** requirements for meeting scheduling requirements.<br>• **Schedule consisting of an array of time periods** that define the offset from a starting date and time.<br>• **Scheduled value or mode:** Each time period shall be associated with a real or reactive value or shall indicate which mode, which set of parameters for the mode, and whether to enable or disable the mode.<br>• **Starting date and time:** The start date and time shall be provided before the schedule is enabled.<br>• **Referenced Point identifier:** The identity of the Referenced Point shall be provided where the relevant measurements or calculations are provided for the PCC or other Referenced Point.<br>• **Open loop response time** within which the value or mode shall be achieved or a **Ramp Rate** shall be settable.<br>• **Schedule repeat interval:** Schedules shall be able to be repeated periodically.<br>• **Schedule event trigger:** Schedules shall be able to be initiated by an event<br>• **Multiple schedules** which may be active at the same time shall be supported<br>• **Schedule priority** to determine which schedules take precedence if they overlap with mutually exclusive requirements.<br>• **Schedule ending process**: When a schedule ends, the default state of the DER shall be reverted to, with any ramping or other settings to arrive at that default state.<br>• **Enable** and **Disable** settings for the schedules. When a schedule is enabled, the schedule shall take effect at the first scheduled time. The DER shall then modify its output to achieve the scheduled value at the established ramp rate. When a schedule ends or is disabled, the DER shall revert to a previously defined state at the established ramp rate.<br>• **Acknowledge and/or monitor the data at the Referenced Point**: Receipt of the mode parameters and the enable/disable commands shall be acknowledged or the power measurements at the Referenced Point shall be monitored.<br>• **Error conditions:** If the schedule requirements cannot be met or are not being met, this condition shall be reported.<br>**Additional scheduling capabilities** may optionally be supported, such as providing pricing signals for different scheduled times. |

## 2.3 Key Monitored Information

As identified during the Phase 2 discussions, Table 3 describes the recommended SIWG Phase 3 key monitored data that DER systems shall be capable of providing at a minimum. Guidelines will be described in more detail in the utility Interconnection Handbooks, covering issues such as:

- Utilities will need to determine at what point this data will be required from any particular DER system, facility, or aggregator. For instance, high penetration scenarios will require this data sooner, while lower penetrations may not yet need this data right away. This data could also be used in future DRPs to determine locational benefits.
- Utilities will need to specify the retrieval rates for collecting the data for different scenarios. Data from some DER systems may be needed in "real-time" (seconds), but most will only be needed over many minutes, hours, or even days.
- Utilities will need to specify latency and accuracy requirements of information (SCADA timeframes vs. "loosely-coupled" monitoring, time skew, available data, revenue-grade, etc.)
- Utilities will need to determine which DER systems need to provide individual data, which may aggregate their data by "group", and which may only need to provide the metered data from "smart meters".
- Who pays for this communications is out of scope for Rule 21, but needs to be discussed in other forums – in a rate setting process.

Table 3: Utility data monitoring and control requirements

| | |
|---|---|
| ***Administrative Messaging Requirements*** | |
| **Information in headers** | |
| | Unique Plant or FDEMS ID |
| | Meter ID, Service Point ID, or other ECP ID |
| | Utility ID |
| | Timestamp of message and other header information |
| **Nameplate and/or "as installed" base information of DER System (for each DER System registered with utility)** | |
| | DER system manufacturer |
| | DER system model |
| | DER system software version |
| | DER system serial number |
| | DER system type |
| | Location (latitude/longitude and/or street address) |
| **Basic information of DER system or of facility or plant (FDEMS) (ratings are the installed ratings which are different from capabilities which may change or be forecast based on customer or market issues)** | |
| | Operational authority (role) |
| | Watt rating |
| | VA rating |
| | Var rating |
| | Current rating |
| | PF rating |
| ***Monitoring Data Sets*** | |
| **Monitored analog measurements, aggregated by the FDEMS to reflect the ECP and/or the PCC** | |
| | Watts |
| | VArs |
| | Power Factor |

| | |
|---|---|
| | Hz, Frequency |
| | VA, Apparent Power |
| | A, Phase Currents |
| | PPV, Phase Voltages |
| | State of Charge as available kWh (not % of maximum usable capacity) |
| | *{Type of data collection or aggregation, e.g. indication of whether instantaneous, average over period, max, min, first, last}* |
| **Monitored status, aggregated by the FDEMS for the ECP and/or the PCC** | |
| | DER Connection Status |
| | PCC or Referenced Point Connection Status |
| | Inverter status |
| | De-rated active power due to inability to meet stated rating |
| | Available active power |
| | Available vars |
| | Status of limits (flags that get raised when a specified limit is reached) |
| | Active modes (flags that get raised when a control (mode) is enabled) |
| | Ride-through status (flags on instantaneous ride-through state; does not count R-T events) |
| **Metered DER system values, aggregated by the FDEMS for the PoC and/or the PCC** | |
| | Wh, Watt-hours, lifetime (or from reset time) accumulated AC energy |
| | VAh, VA-hours, lifetime (or from reset time) accumulated |
| | VArh, VArh, lifetime (or from reset time) accumulated |
| **Notification of alarms** | |
| | Binary alarm values (flags that get raised for specific types of alarms of a specific DER) |
| | Binary alarm values (flags that get raised for specific types of facility/plant alarms) |

## 3. Timeframe for Implementing Mandated Phase 3 Functions

Just as with Phase 1, there will need to be testing and certification requirements before these Phase 3 functions can have mandatory implementation requirements. Therefore it is expected that the implementation of mandatory functions will require at least a 12-month window between the approval of such testing and certification requirements and mandatory date of implementation.

**Discussion Issues** that have been raised and need further resolution before these requirements are included in Rule 21:

- May need to be tied to 1741 SA for some functions and to other testing sources for other functions.
- The industry needs testing and certification requirements as rapidly as possible. Utilities don't need certification, but would like it to be tested.
- Also need communications testing. IEEE 2030.5 is also open to revision and then will need to be tested. Whichever protocols are used, cyber security testing will need to be included.
- Self-certification of some functions could be done rapidly after the completion of 1741 SA, but NRTL certification would need 1547.1 completion.

- Maybe involve the creation of 1741 SB, which could then be rolled into the revision of IEEE 1547.1. It is hoped that IEEE 1547.1 would be essentially completed by the time IEEE 1547 goes to ballot. Any additional Phase 3 functions would be placed into UL 1741 revision as optional.
- Will need to harmonize all of the schedules of these efforts.

# 4. Background Information

## 4.1 DER Functions: Direct Actions and Modes

The term “function” encompasses single “*DER direct commands*” as well as “*DER modes*” which entail continuous autonomous internal analysis and actions by the DER once the mode is enabled.

DER modes usually require the DER system to receive some measurement either at the DER’s PoC, from a remote PoC within the facility, or from an external PoC (termed the “Referenced Point” in mode descriptions), or reacting to some event, and then responding to that measurement or event according the mode’s parameters. These modes are defined in IEC/TR 61850-90-7 (now incorporated into the IEC 61850-7-520 Guidelines for IEC 61850-7-420) and described in EPRI Common Functions version 3.

## 4.2 Use of EPRI Report as Input for SIWG Phase 3 Functions

The EPRI report *“Common Functions for Smart Inverters”*, Version 3, 3002002233[1], describes many of the SIWG Phase 3 functions in enough detail to provide good understanding of their purposes and capabilities. It also includes references to parameters which can be used to establish the settings for these functions. These parameters are useful for helping to understand the functions but are not necessarily exactly the same as communication controls and settings, since some parameters may just be preset values while other parameters may be exchanged using different communication protocols with different types and structures. Nonetheless, the EPRI report provides an excellent base for describing the SIWG Phase 3 functions, and is therefore used as the core input to this SIWG Phase 3 document.

Over the past few years, additional functions have been identified, and the SIWG review of the EPRI document has also modified some of the descriptions of the functions. Therefore, this SIWG Phase 3 document is an extraction, modification, and update of the original EPRI document. In turn, this document may be used by EPRI to update their document to version 4.

***Background of EPRI Report***

*“The genesis of this body of work dates to 2009, when EPRI began working with a number of utilities doing large scale Smart Grid demonstrations. These demonstrations were focused on the deployment of Distributed Energy Resources (DER) and the communication integration of these resources with the utility. Many of these projects involved the integration of inverter-based systems, such as solar photovoltaic and energy storage systems, including diverse sizes and manufacturers.*

*EPRI worked together with the Department of Energy, Sandia National Laboratories, and the Solar Electric Power Association to form a collaborative team to facilitate this initiative. Several face-to-face workshops have been conducted, and a focus-group of volunteers have met every 1-2 weeks over a two year period to discuss, debate, and develop a proposed set of common approaches to a range of high-value functions. This document, “Common DER Functions, version 3, 3002002233”, compiles the results of this work thus far.*

*As a result, this work has been a useful and significant contribution to several standards groups and activities. The common functions support use cases collected by the NIST Priority Action Plan (PAP) 07, have provided technical input into work in the IEC TC57 WG17 and IEEE 1547.8, and have been or are being mapped into the DNP3, SEP2.0, and ModBus protocols.”*[2]

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[1] Electric Power Research Institute, “*Common Functions for Smart Inverters, Version 3*”, Product ID:3002002233, February 2014

[2] EPRI, *Common Functions for Smart Inverters*, Version 3, 3002002233, Extract from Chapter 1

## 4.3 Use of IEC 61850-7-420 Information Model for DER System Interactions

Formed in April 2004, the International Electrotechnical Commission (IEC) Technical Committee (TC) 57 Working Group (WG) 17 started the development of the requirements for interacting with DER systems using the IEC 61850 information model. Over the years many efforts provided input to first IEC 61850-7-420:2009 for the basic DER functions, and a couple of years later to the IEC 61850-90-7 for “smart DER” functions. Instrumental in the development of the IEC 61850 information model was EPRI projects, the IEEE 1547.3 Communications for DER, reports from the Smart Grid Interoperability Panel (SGIP), and, more recently, the SIWG Phase 1 functions. The IEC 61850-7-420/90-7 DER information model has also been used as a source for developing mappings to other protocols, such as IEEE 1815 (DNP3) and IEEE 2030.5 (SEP 2) which is recommended to be the default protocol for the SIWG Phase 2.

IEC 61850 consists of three main components:

- An **abstract information model** in which each data item has a human-understandable name that uniquely identifies it, along with standardized formatting. These are the “nouns.” The IEC 61850-7-420 is the abstract information model for DER systems.
- An **abstract definition of communication services** that can be used to read and write data as well as metadata, issue control commands, receive alarms and events, and manage audit logs. These are the “verbs.”
- **Communication protocols** that map the information model data and the services to the actual “bits and bytes” for transporting between interfaces. These are the instantiation of the abstract models to the real world. The current standardized protocols include the Manufacturing Messaging Specification (MMS) ASN.1 data structures, MMS services, and the GOOSE protocol, specified in IEC 61850-8-1. An “Internet of Things” protocol using XML/XER over XMPP is in the final stages of standardization as IEC 61850-8-2. This IoT protocol is expected to be used for communication with DER systems.

Therefore, it is suggested that the IEC 61850-7-420 standard be regarded as the information model for the information exchanges required by the Phase 3 functions.

## 4.4 Use of Parameters to Help Describe the Phase 3 Functions

The functions are described both in terms of what they are expected to accomplish as well as the various parameters which define the settings and actions of the DER systems. These parameters are not necessarily set through communications – they may be preset or manually entered – but they provide one means for clearly and explicitly describing the key requirements of the functions.

Although these parameters can also be used for external parties to interact with the DER functions, no assumptions are made on the types of communications that might be used and indeed the functions may operate autonomously. Any interactions with external parties can be viewed as “requests” with the understanding that the DER systems will validate any changes to parameters and will perform the function to the best of its ability within its capabilities, while still protecting itself as a first priority.

Some Phase 3 functions may need to identify specific values. If those values are included in the revision to IEEE 1547 or other standards, then those documents should be identified and included as references. If they need to be defined in Rule 21, then we will need discussions to develop those values.

## 5. Basic Device Settings and Limits

### 5.1 Electrical Connection Points (ECP) and Referenced Points

The term “Point of Connection (PoC) is defined in IEEE 1547 Draft 6.7 as the “*The point where a DER unit is electrically connected in a Local EPS* …”. An additional broader term defined in IEC standards is “Electrical Connection Point (ECP)” which includes the PoC point of DER interconnection, but can also be the connection point between a group or aggregation of DER systems and the local EPS. If loads can be controllable, then they can also have a ECP. The point of common coupling (PCC) is the ECP between the local EPS and the area EPS. An external location can also have a remote ECP at its PCC.

As illustrated in Figure 1, the term “Electrical Connection Point (ECP)” is used to denote any point on the local electric power system (EPS). An ECP can the connection point between a single DER and the local EPS, or it can be the connection point between a group of DER systems and the local EPS. ECPs can be nested. If loads can be controllable, then they also have an ECP. The point of common coupling (PCC) is the ECP between the local EPS and the area EPS.

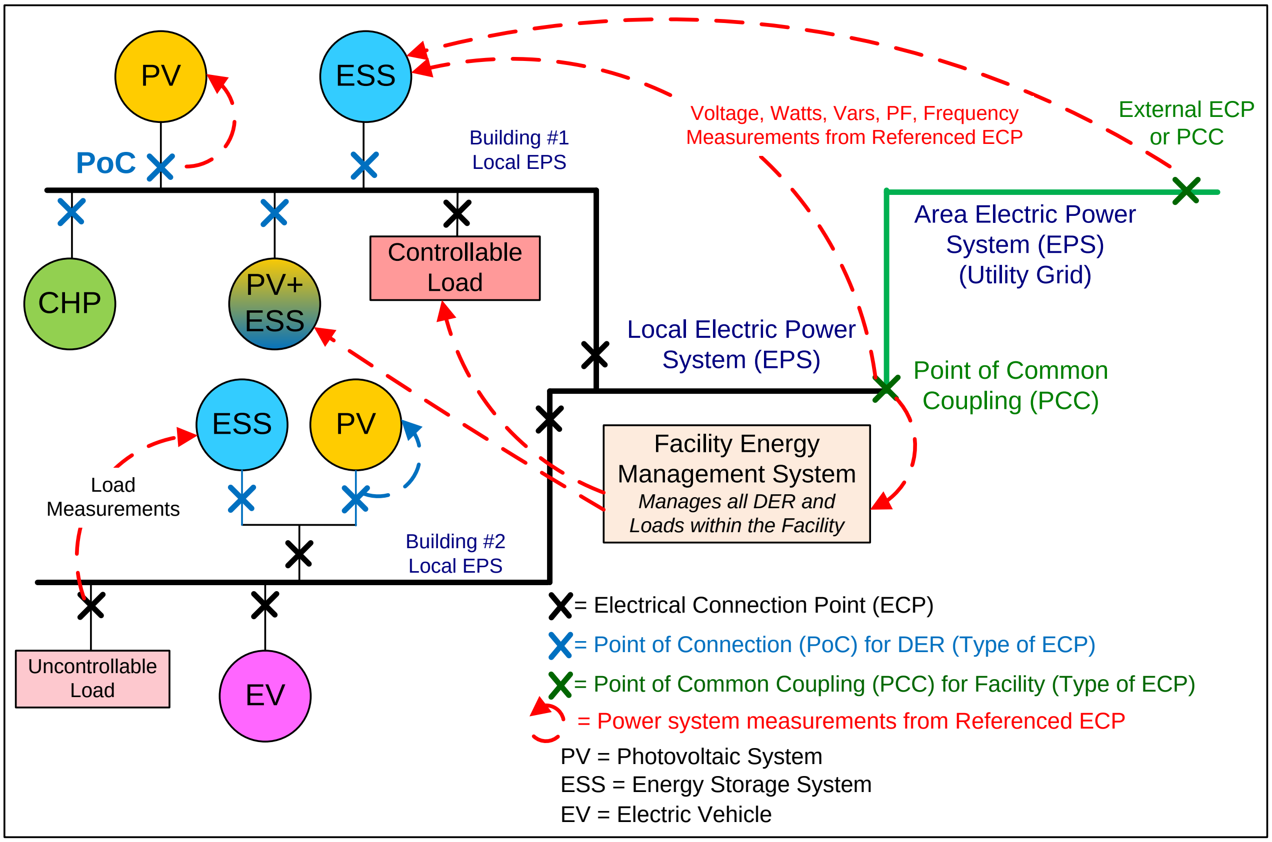

Figure 1: DER electrical connection points (ECP) and the point of common coupling (PCC)

Many Phase 3 functions may be referencing a point that is not the one where the DER system is interconnected. In particular, utilities usually expect a function to take effect at the PCC, so, for that case, the limit power output function would reference the local PCC. However other remote points could also be referenced, such as an energy storage system referencing a PV plant a few miles away at a separate facility in order to counteract PV fluctuations. Synchrophasors would also need to collect data from other remotely located synchrophasors.

Therefore many of the Phase 3 functions use the term “Referenced Point” to indicate that the identifier of the point of interest must be one of the parameters. It is assumed, of course, that these Referenced Points have been mutual agreed to, and that some means of receiving the necessary power system measurements from the Referenced Point is available to the DER system.

## 5.2 Key Monitored Information

The key monitored data that the DER shall be capable of providing shall include at a minimum the information shown in Table 4. Guidelines will be described in more detail in the Utility DER Handbooks, covering issues such as:

- Utilities will need to determine at what point this data will be required from any particular DER system, facility, or aggregator. For instance, high penetration scenarios will require this data sooner, while lower penetrations may not yet need this data right away. This data could also be used in future DRPs to determine locational benefits.
- Utilities will need to specify the retrieval rates for collecting the data for different scenarios. Data from some DER systems may be needed in “real-time” (seconds), but most will only be needed over many minutes, hours, or even days.
- Utilities will need to specify latency and accuracy requirements of information (SCADA timeframes vs. “loosely-coupled” monitoring, time skew, available data, revenue-grade, etc.)
- Utilities will need to determine which DER systems need to provide individual data, which may aggregate their data by “group”, and which may only need to provide the metered data from “smart meters”.
- Who pays for this communications is out of scope for Rule 21, but needs to be discussed in other forums – in a rate setting process.

Table 4: Utility DER data monitoring requirements – individually and/or aggregated

| ***Administrative Messaging Requirements*** | |
|---|---|
| **Information in headers** | |
| | Unique Plant or FDEMS ID |
| | Meter ID, Service Point ID, or other PoC ID |
| | Utility ID |
| | Timestamp of message and other header information |
| **Nameplate and/or “as installed” base information of DER System (for each DER System registered with utility)** | |
| | DER system manufacturer |
| | DER system model |
| | DER system software version |
| | DER system serial number |
| | DER system type |
| | Location (latitude/longitude and/or street address) |
| **Basic information of DER system or of facility or plant (FDEMS) (ratings are the installed ratings which are different from capabilities which may change or be forecast based on customer or market issues)** | |
| | Operational authority (role) |

| | |
|---|---|
| | Watt rating |
| | VA rating |
| | Var rating |
| | Current rating |
| | PF rating |
| ***Monitoring Data Sets*** | |
| **Monitored analog measurements, aggregated by the FDEMS to reflect the PoC and PCC** | |
| | Watts |
| | VArs |
| | Power Factor |
| | Hz, Frequency |
| | VA, Apparent Power |
| | A, Phase Currents |
| | PPV, Phase Voltages |
| | *{Type of data collection or aggregation, e.g. indication of whether instantaneous, average over period, max, min, first, last}* |
| **Monitored status, aggregated by the FDEMS for the PoC and PCC** | |
| | DER Connection Status |
| | PCC or PoC Connection Status |
| | Inverter status |
| | De-rated active power due to inability to meet stated rating |
| | Available active power |
| | Available vars |
| | Status of limits (flags that get raised when a specified limit is reached) |
| | Active modes (flags that get raised when a control (mode) is enabled) |
| | Ride-through status (flags on instantaneous ride-through state; does not count R-T events) |
| **Metered DER system values** | |
| | Wh, Watt-hours, lifetime (or from reset time) accumulated AC energy |
| | VAh, VA-hours, lifetime (or from reset time) accumulated |
| | VArh, VArh, lifetime (or from reset time) accumulated |
| **Notification of alarms** | |
| | Binary alarm values (flags that get raised for specific types of alarms of a specific DER) |
| | Binary alarm values (flags that get raised for specific types of facility/plant alarms) |

## 5.3 Basic Power Settings and Nameplate Values

The settings described in this section are the DER nameplate values that are fixed for the life of the product, as well as certain basic pre-set parameters that may be site or implementation specific. These would notionally be set by the manufacturer and would represent the as-built capabilities of the equipment. These settings are not expected to be modified through communications, but might be modified locally and could be read for background and assessment purposes.

The settings listed in Table 5 are defined as illustrated in Figure 2.

Table 5: Basic Power and Nameplate Settings

| **Name** | **Description** |
|---|---|
| WMax | The maximum active power that the DER can deliver to the grid, in Watts |
| VAMax | The maximum apparent power that the DER can conduct, in Volt-Amperes |
| VarMax | The maximum reactive power that the DER can produce or absorb, in Vars |
| WChaMax | The maximum active power that the DER (e.g. ESS) can absorb from the grid, in Watts. Note that WChaMax may or may not differ from WMax. |
| VAChaMax | The maximum apparent power that the DER can absorb from the grid, in Volt-Amperes. Note that VAChaMax may or may not differ from VAMax. |
| ARtg | A nameplate value, the maximum AC current level of the DER, in RMS Amps. |

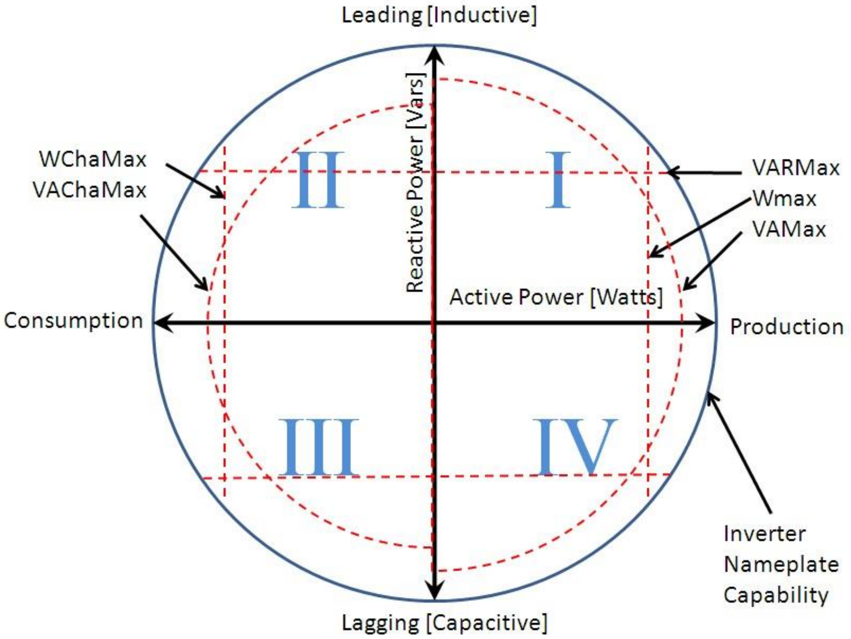

Figure 2: Basic Power Settings Illustration

It is recognized that DER units may have limitations at any time regarding their ability to produce power or perform other functions. These limitations might stem from primary generation source availability, internal malfunctions, maintenance needs, or other special conditions. In this sense,

## *5.4* Voltage Normalization Settings

For functions using voltage parameters (e.g. Volt-Var modes, Volt-Watt modes, Dynamic Grid Support), a reference voltage and an offset voltage are defined as listed in Table 6 and illustrated in Figure 3.

All inverters behind one Point of Common Coupling (PCC) have a common reference voltage, but may differ in the voltage between their own Electrical Connection Point (ECP) and the PCC due to instrumentation errors or voltage shifts within a plant. These differences can be corrected by the parameter VRefOfs that is to be applied by each inverter. This correction voltage can be set once, or infrequently, and allows for homogenous controls and setting to be used for broadcasts to many DER.

Table 6: Voltage Normalization Settings

| Name | Description |
|---|---|
| VRef | The normal operating voltage for this DER site / service connection, in Volts. |
| VRefOfs | An offset voltage that represents an adjustment for this DER, relative to VRef, in Volts. VRefOfs is defined as the voltage at the ECP, relative to the PCC. For example, if the PCC VRef is 120V, and the nominal voltage at the DER's ECP is 122V, then VRefOfs = +2V. VRefOfs may be preset or dynamically determined. |

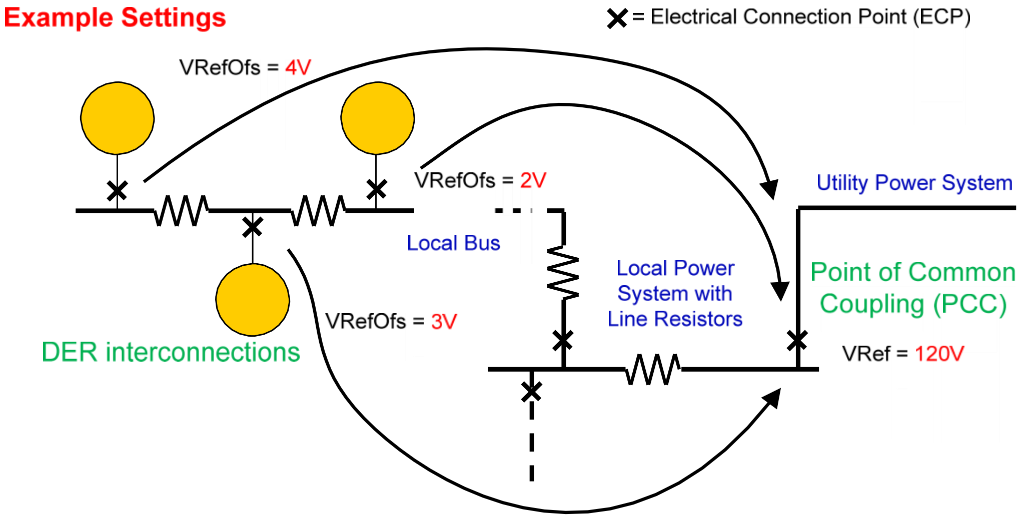

Figure 3: Offset Voltage Illustration

As will be seen in the descriptions of functions that are based on local voltage as a control variable, settings are provided in terms of the effective percent voltage, which is defined as:

$$\textit{Effective Percent Voltage} = 100^* (\textit{local measured voltage} - \textit{VRefOfs}) / (\textit{VRef})$$

## 5.5 Active Power Ramp Rate Settings

The default ramp rate of change of active power is provided by the parameter WGra. This parameter limits the rate of change of active power delivered or received due to either a change by a command or by an internal action such as a schedule change. This ramp rate (gradient) does not replace the specific ramp rates that may be directly set by the commands or schedules, but acts as the default if no specific ramp rate is specified with a command. For generating systems, WGra is defined as a percentage of WMax per second. Equivalently for the charging of energy storage systems, WChaGra is defined as a percentage of WChaMax.

Table 7: Active Power Ramp Rate Settings for generation and storage systems

| Name | Description |
|---|---|
| WGra | The default ramp rate of active power output in response to control changes. WGra is defined as a percentage of WMax per second. |

| | |
|---|---|
| WChaGra | The default ramp rate of active power input (charging) in response to control changes. WChaGra is defined as a percentage of WChaMax per second. |

Additional ramp rates are needed for emergency conditions, for soft reconnection, and other scenarios.

## 5.6 Accuracy Settings

The accuracy that the DER systems are required to meet the functional requirements at the Referenced Point is very important for determining compliance. The metrics needed to measure compliance include the following:

- Range of the measured values from the nominal value at the Referenced Point
- Time allowed for the measured values to be outside the range
- Average (mean) of the measured values

# 6. DER Cease to Energize and Return to Service Request

## 6.1 Scope of this Function

The cease to energize command causes a DER system either to galvanically disconnect from or to "cease to energize" the local and/or area EPS at the Referenced Point. The return to service command initiates the closing of the DER switch or ends the cease to energize state. A "permission to return to service" command may be used to permit the return to service but to allow the actual return to service to take place at a later time.

## 6.2 Requirements and/or Use Cases for this Function

The purpose this function is generally for emergency situations, with examples such as:

- **Emergency reduction in distributed generation.** Under certain circumstances, system voltage may rise to unacceptably high levels or certain grid assets (e.g. wires, transformers) may become overloaded. In these cases it might become desirable or even necessary to cease to energize certain DER systems from the grid.
- **Malfunctioning DER equipment.** Distributed generation or storage devices may be found to be malfunctioning – disrupting the grid due to some form of failure. In these cases, it might be desirable to cease to energize the device from the power system.
- **Grid maintenance or repair.** Utilities may wish to cease to energize DER devices from the grid during certain repairs or maintenance.
- **Concern that a DER or facility may have formed an unintentional island.** Utilities may wish to issue a cease to energize command to DER systems or facilities to ensure that an unintentional island has not inadvertently formed.

## 6.3 Description of the Cease to energize Command

The cease to energize command causes the DER or facility to either galvanically disconnect or "cease to energize". Possible points of disconnection are shown in Figure 4. The Referenced Point indicates which switch is opened for a galvanic disconnect or where the "cease to energize" function takes place. The cease to energize causes the DER or facility to go to zero active current flow and (close to zero) reactive power flow at the Referenced Point, such as at the DER's ECP or at the PCC. This function does not necessarily affect DERs if they are acting as loads.

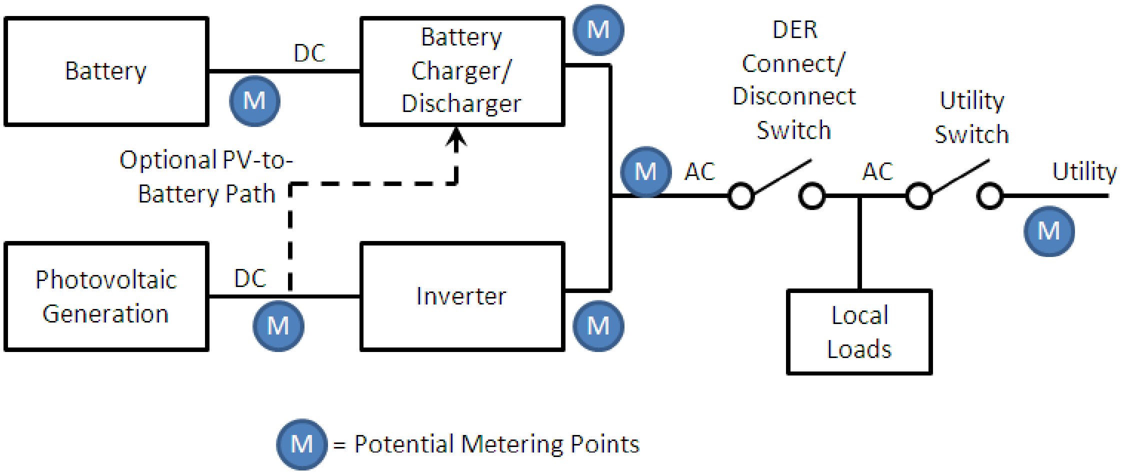

Figure 4: Example DER Diagram showing possible disconnect locations including switches

The cease to energize function consists of a "Cease to energize" command, with optionally the monitoring of the state at the Referenced Point:

- **Set Referenced Point State**: a command which either instructs the switch at the Referenced Point to open or causes a "cease to energize" state at the Referenced Point. The function may include a time window or ramping for when the action take place.
- **Monitor Referenced Point State**: a query to monitor the Referenced Point.

The function may be supported by the following information, which may be preset or exchanged as part of the command:

- **Time Window**: a time, over which the cease to energize operation is randomized. For example, if the Time Window is set to 60 seconds, then the cease to energize operation occurs at a random time between 0 and 60 seconds. This setting is provided to accommodate communication systems that might address large numbers of devices in groups.
- **Ramp Down Rate**: a ramp down rate that specifies the rate that the DER uses to decrease output to reach the cease to energize state
- **Reversion Timeout**: a time, after which a command to cease to energize expires and the device return to services. Reversion Timeout = 0 means that there is no timeout.

## 6.4 Description of the Return to service Command

The return to service command is assumed to be subordinate to any local safety switch operations, including any lock-out/tag-out system. In other words, a remote switch-connect request (or the timeout of a switch disconnect request) would NOT result in return to service of a system that was disconnected by some other means.

A "permission to return to service" may be issued to indicate that the DER may return to service when it chooses to do so. The DER may then start up its return to service process or may continue to be disconnected.

The return to service command either causes the disconnect switch at the Referenced Point to close or causes the cease-to-energize state to be discontinued:

- **Permission to Return to service**: a command indicating that return to service is permitted.
- **Set Referenced Point State**: a command which either instructs the switch at the Referenced Point to close or discontinues the “cease to energize” state at the Referenced Point. The function may include a time window or ramping for when the action take place.
- **Monitor Referenced Point State**: a query to monitor the Referenced Point.

The function may be supported by the following information, which may be preset or exchanged as part of the command:

- **Time Window**: a time, over which the return to service operation is randomized. For example, if the Time Window is set to 60 seconds, then the return to service operation occurs at a random time between 0 and 60 seconds. This setting is provided to accommodate communication systems that might address large numbers of devices in groups.
- **Ramp Up Rate**: a ramp up rate that specifies the rate that the DER uses to increase output after discontinuing the cease-to-energize state.

# 7. Limit Maximum Active Power Mode

## 7.1 Scope of this Function

This specification provides a mechanism through which the maximum active power of one DER system or an aggregation of DER systems and load within a facility can be limited at a Referenced Point.

## 7.2 Requirements/Use Cases

The context for the inclusion of this function includes a variety of needs. For example:

- **Localized (Customer Side of the Distribution Transformer) Overvoltage Conditions**. This function could be used to reduce DG output to prevent localized overvoltage conditions.
- **Localized Asset Stress.** This function could be used to limit the maximum output from DG to prevent the overloading of local assets such as transformers.
- **Feeder Overvoltage Conditions.** This function could be used across a large number of devices to prevent high-penetration DG from driving distribution system voltages too high during periods of light load.

## 7.3 Description of Function

This function establishes an upper limit on the active power that a DER system can produce or use (deliver to its local EPS) at its ECP or, in aggregate with other DER systems and loads, at the PCC, or at some other Referenced Point. The limit value may be positive if net export of active power is limited, or may be negative if net import of active power is to be greater than the limit value. This function is opposite of Peak Power Limiting, which limits the net import of active power and may require the net export of active power.

The maximum generation level function may either be percentage based, according to the nominal capability of the DER system, or may be an absolute value, particularly if referring to the maximum export at the PCC. For the percentage setting, the effect is illustrated in Figure 5.

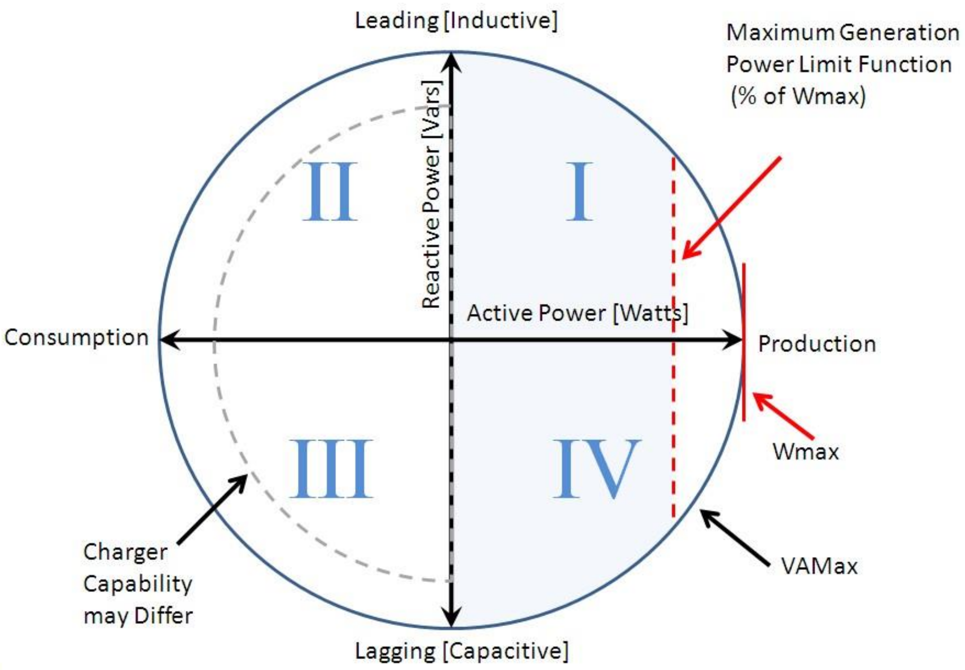

Figure 5: Example of Limit Maximum Active Power

The following information exchanges are associated with this function, either as default values or as provided at the same time as the maximum limit command:

- **Monitor Active Power at the Referenced Point:** a query to read the active power output at the Referenced Point.
- **Set Limit Active Power Level:** a command to set the maximum active power level as a percent of nominal or as a active power value. Percentage based settings allow communication to large groups of devices of differing sizes and capacities.
- **Range of Accuracy Optionally,**
- **Time Window:** a time in seconds, over which a new setting is to take effect. For example, if the Time Window" is set to 60 seconds, then the DER would delay a random time between 0 and 60 seconds prior to beginning to make the new setting effect. This setting is provided to accommodate communication systems that might address large numbers of devices in groups.
- **Reversion Timeout:** a time in seconds, after which a setting below 100% expires and the device returns to its natural "WMax, delivered" limits. Reversion Timeout = 0 means that there is no timeout.
- **Ramp Time:** a time in seconds, over which the DER linearly places the new limit into effect. For example, if a device is operating with no limit on Watts generated (i.e. 100% setting), then receives a command to reduce to 80% with a "Ramp Time" of 60 seconds, then the upper limit on allowed Watts generated is reduced linearly from 100% to 80% over a 60 second period after the command begins to take effect. (See illustration in Figure 6).

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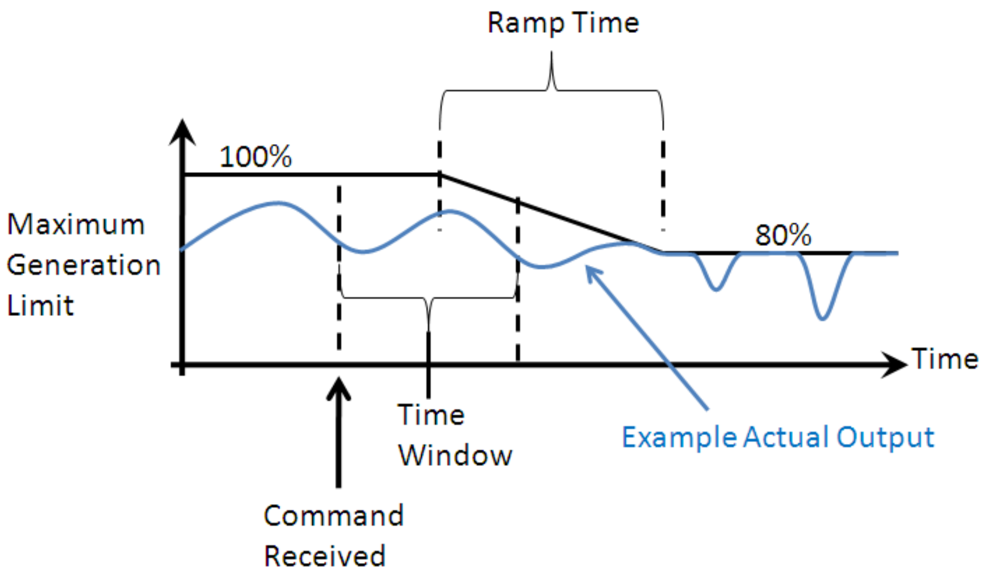


Figure 6: Example of limiting maximum active power output at a Referenced Point

# 8. Set Active Power Mode

## 8.1 Scope of this Function

This function provides a mechanism through which the active power export or import of one or more DER systems is set at the Referenced Point.

## 8.2 Requirements/Use Cases

Setting the active power export or import permits the management of active power at a Referenced Point.

## 8.3 Description of Function

This function establishes the active power that a DER system produces or uses at its ECP (OutWSet) or, in aggregate with other DER systems and loads, exports or imports at the PCC (ImptExptSet) or some other Referenced Point.

The active power export/import function may either be percentage based, according to the nominal capability of the DER system, or may be an absolute value , particularly if referring to the export or import at the PCC. The function is constrained by the capabilities of the DER systems or facility. The following parameters should be provided:

- **Monitor Active Power at the Referenced Point:** a query to read the active power output at the Referenced Point.
- **Set Maximum Generation Level:** a command to set the maximum generation level as a percent of WMax or as a active power value. Percentage based settings allow communication to large groups of devices of differing sizes and capacities.
- **Time Window:** a time in seconds, over which a new setting is to take effect. For example, if the Time Window” is set to 60 seconds, then the DER would delay a random time between 0 and 60 seconds

prior to beginning to make the new setting effect. This setting is provided to accommodate communication systems that might address large numbers of devices in groups.

- **Reversion Timeout:** a time in seconds, after which a setting below 100% expires and the device returns to its natural "WMax, delivered" limits. Reversion Timeout = 0 means that there is no timeout.
- **Ramp Time:** a time in seconds, over which the DER linearly places the new limit into effect. For example, if a device is operating with no limit on Watts generated (i.e. 100% setting), then receives a command to reduce to 80% with a "Ramp Time" of 60 seconds, then the upper limit on allowed Watts generated is reduced linearly from 100% to 80% over a 60 second period after the command begins to take effect. (See illustration in Figure 6).

# 9. Frequency-Watt Mode

## 9.1 Scope of this Function

This function establishes curves that define the changes in watt output based on frequency deviations from nominal, as a means for countering those frequency deviations. The watt output may reflect rapid frequency changes or may be configured only to respond to longer term frequency deviations.

## 9.2 Requirements/Use Cases

Possible use cases include:

- **Short-Term (Transient) Frequency Deviations.** Under certain circumstances, system frequency may dip suddenly. Some discussion of this type of event may be found in reports from PNNL's Grid Friendly Appliance project. Autonomous responses to such events are desirable because response must be fast to be of benefit.
- **Long-Term Frequency Deviations or Oscillations.** Particularly in smaller systems or during islanded conditions, frequency deviations may be longer in duration and indicative of system generation shortfalls or excesses relative to load.

## 9.3 Frequency-Watt Function for Emergency Situations

These functions address the issue that high frequency often is a sign of too much power in the grid, and vice versa. One method for countering the over-power problem is to reduce power in response to rising frequency (and vice versa if storage is available). Adding hysteresis provides additional flexibility for determining the active power as frequency returns toward nominal.

Table 8 shows the Function 1 settings for the active power reduction by frequency.

The parameters for frequency are relative to nominal grid frequency (ECPNomHz). The parameter HzStr establishes the frequency above nominal at which power reduction will commence. If the delta grid frequency is equal or higher than this frequency, the actual active power will be frozen, shown as $P_M$. If the grid frequency continues to increase, the power will be reduced by following the gradient parameter (WGra), defined as percent of $P_M$ per Hertz. This reduction in output power continues until either the power level is zero or some other limit (e.g. a 1547 turn off limit) is reached.

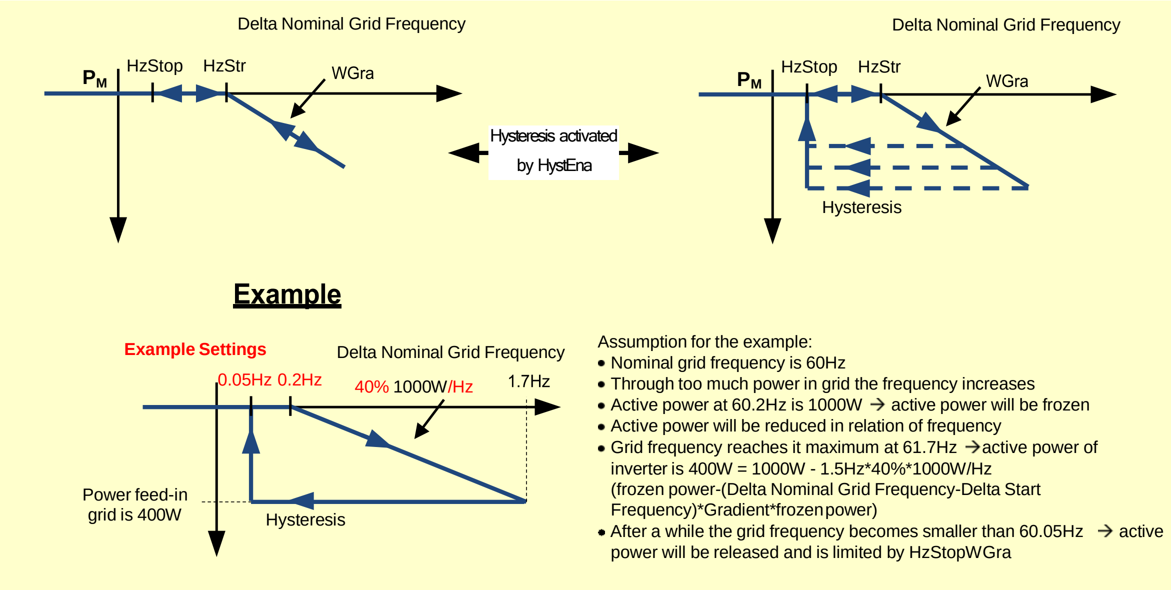
The parameter HystEna can be configured to activate or deactivate hysteresis. When hysteresis is activated, active power is kept reduced until the delta grid frequency reaches the delta stop frequency, HzStop.

Whether or not hysteresis is active, the maximum allowed output power will be unfrozen when the delta grid frequency becomes smaller than or equal to the parameter HzStop.

In order that the increase in power is not abrupt after releasing the snap shot value (frozen power) a time gradient is defined. The parameter HzStopWGra can bet set in Pmax/minute. Default is 10% Pmax/minute.

Table 8: Frequency-Watt Function 1 Settings

| **Name** | **Description** | **Example Settings** |
|---|---|---|
| WGra | The slope of the reduction in maximum allowed Watt output as a function of frequency | 40% Pref/Hz |
| HzStr | The frequency deviation from nominal frequency (ECPNomHz) at which a snapshot of the instantaneous power output is taken as a maximum power output reference level (Pref) and above which reduction in power | 0.2 Hz |
| HzStop | The frequency deviation from nominal frequency (ECPNomHz) at which curtailed power output may return to normal and the snapshot value is released | 0.05 Hz |
| HystEna | A boolean indicating whether or not hysteresis is enabled | On |
| HzStopWGra | The maximum time rate of change at which power output returns to normal after having been curtailed by an over | 10% Pmax/minute |



Assumption for the example:

- Nominal grid frequency is 60Hz
- Through too much power in grid the frequency increases
- Active power at 60.2Hz is 1000W → active power will be frozen
- Active power will be reduced in relation of frequency
- Grid frequency reaches it maximum at 61.7Hz →active power of inverter is 400W = 1000W - 1.5Hz*40%*1000W/Hz (frozen power-(Delta Nominal Grid Frequency-Delta Start Frequency)*Gradient*frozen power)
- After a while the grid frequency becomes smaller than 60.05Hz → active power will be released and is limited by HzStopWGra

Figure 7: Frequency-Watt Function 1 Visualization

## 9.4 Frequency-Watt Function for Smoothing Frequency

This function provides a configurable curve-shape method for establishing the desired Frequency-Watt behavior in the end device. The general approach follows that of the previously defined Volt-Watt function.

As with the Volt-Var modes, multiple Frequency-Watt Function 2 modes may be configured into an inverter. For example, the desired frequency-watt curve-settings might be different on- peak vs. off-peak, or different when islanded vs. grid connected. A simple mode change broadcast could move the inverters from one pre-configured frequency-watt mode to another.

The basic idea is illustrated in Figure 8.

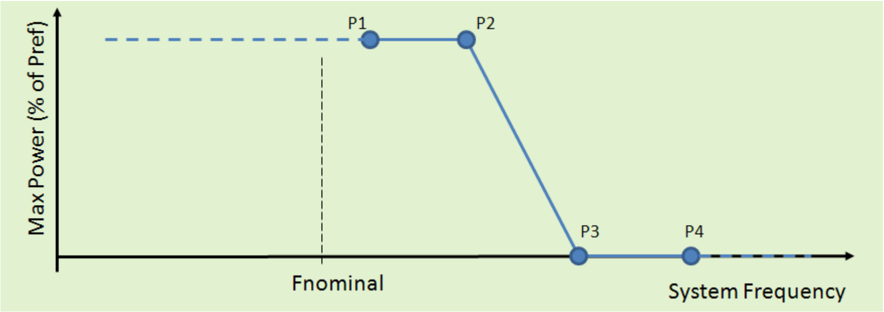


Figure 8: Example of a Basic Frequency-Watt Mode Configuration

The desired frequency-watt behavior is established by writing a variable-length array of frequency-watt pairs. Each pair in the array establishes a point on the desired curve such as those labeled as P1-P4. The curve is assumed to extend horizontally to the left below the lowest point and to the right above the highest point in the array. The horizontal X-axis values are defined in terms of actual frequency (Hz). The vertical Y-axis values are defined in terms of a percentage of a reference power level (Pref) which is, by default, the maximum Watt capability of the system. WMax (defined in prior work), is configurable and may differ from the nameplate value. As will be explained later in this document, these Y-axis values are signed, ranging from +100% to -100%, with positive values indicating active power produced (delivered to the grid) and negative values indicating power absorbed.

**Optional Setting of a SnapShot Power Reference (Pref) Value**

In some cases, it may be desirable to limit and reduce power output relative to the instantaneous output power at the moment when frequency deviates to a certain point. To enable this capability, each frequency-watt mode configuration may optionally include the following parameters.

- **Snapshot_Enable**: A Boolean, which when true, instructs the inverter that the Pref value (the vertical axis reference) is to be set to a snapshot of the instantaneous output power at a certain frequency point. When Snapshot is enabled, no reduction in output power occurs prior to reaching the Pref_Capture_Frequency
- **Pref_Capture_Frequency**: The frequency setting, in hertz, at which the Pref value is established at the instantaneous output of the system at that moment. This parameter is only valid if Snapshot_Enable is true.
- **Pref_Release_Frequency**: The frequency setting, in hertz, at which the Pref value is released, and system output power is no longer limited by this function. This parameter is only valid if Snapshot_Enable is true.

**Optional Use of Hysteresis**

Hysteresis can be enabled for this frequency-watt function in the same way as with the Volt-Watt function defined previously. Rather than the configuration array containing only points incrementing from left to right (low frequency to high frequency), as indicated in Figure 11-2, hysteresis is enabled by additional points in the configuration array which progress back to the left. Figure 9 illustrates this concept.

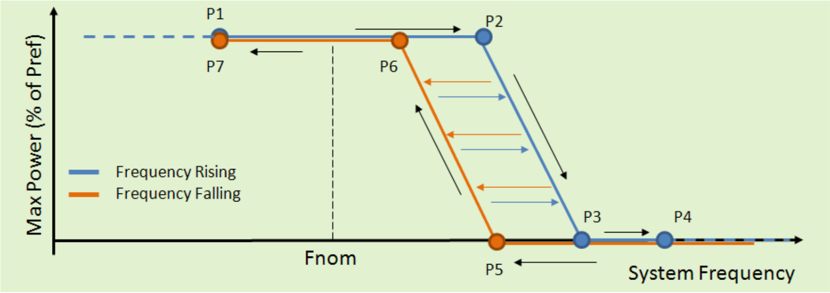


Figure 9: Example Array Settings with Hysteresis

In this case, the points in the configuration array can be thought-of as the coordinates for an X-Y plotter. The pen goes down on the paper at the first point, then steps through the array to the last point, tracing out the resulting curve. As with any configuration (including those without hysteresis), inverters must inspect the configuration when received and verify its validity before accepting it. The hysteresis provides a sort of dead-band, inside which the maximum power limit does not change as frequency varies. For example, if frequency rises until the max power output is being reduced (somewhere between points P2 and P3), but then the frequency begins to fall, the maximum power setting would follow the light orange arrows horizontally back to the left, until the lower bound is reached on the line between points P5 and P6.

The return hysteresis curve does not have to follow the same shape as the rising curve. Figure 10 illustrates an example of such a case.

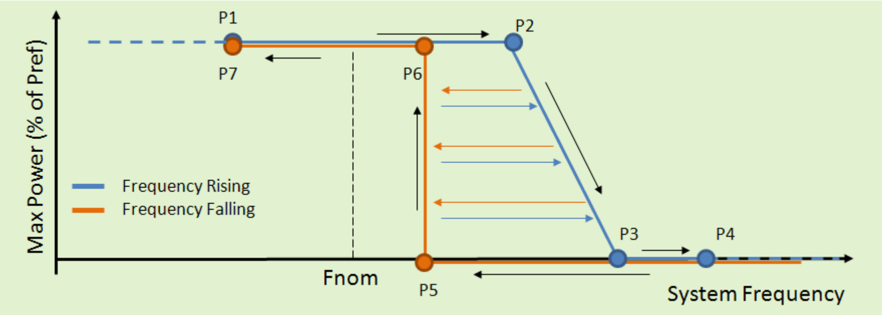


Figure 10: Example of an Asymmetrical Hysteresis Configuration

### Controlling Ramp Time

It may be desirable to limit the time-rate at which the maximum power limit established by these functions can rise or fall. To enable this capability, each frequency-watt mode configuration will include the following parameters, in addition to the array.

- **Ramp_Time_Increasing** and **Ramp_Time_Decreasing**: The maximum rates at which the maximum power limit established by this function can rise (defined as moving away from zero power) or fall (defined as moving toward zero power) , in units of %WMax/second.

### Supporting Two-Way Power Flows

Some systems, such as energy storage systems, may involve both the production and the absorption of Watts. To support these systems, a separate control function is defined, which is identical to that described above, except the vertical axis is defined as maximum watts absorbed rather than maximum watts delivered. This allows for energy storage systems to back-off on charging when grid frequency drops, in the same way that photovoltaic systems back-off on delivering power when grid frequency rises. Figure 11 illustrates an example setting.

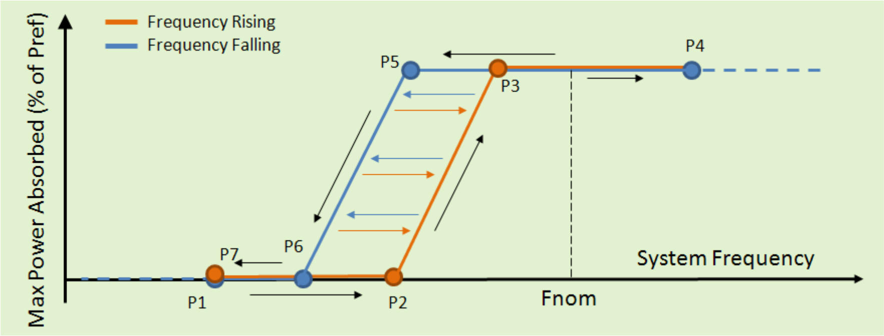


Figure 11: Example Array Configuration for Absorbed Watts vs. Frequency

A further characteristic of systems capable of two-way power flows is that the maximum power curtailment need not stop at 0%. It may pass through zero, changing signs, and indicating that power must flow in the opposite direction (unless prevented from doing so by some other hard limitation) as illustrated in Figure 12.

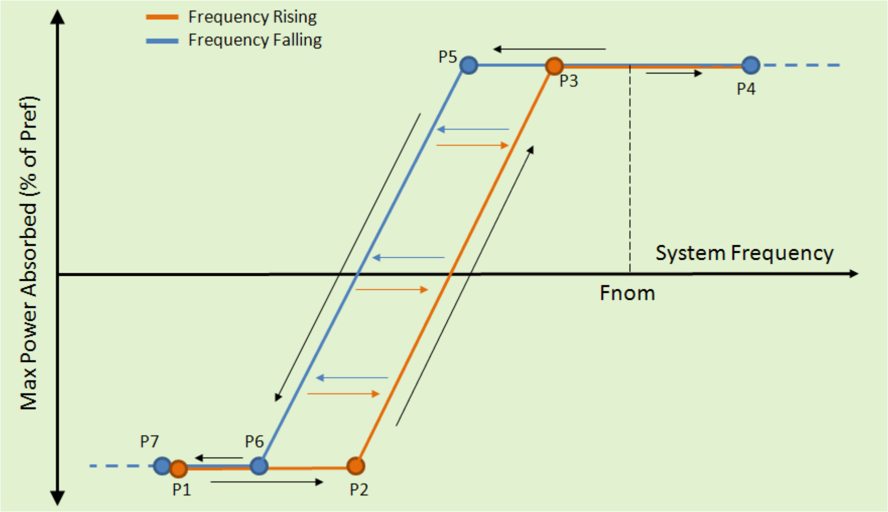


Figure 12: Example Configuration for Reversing Sign on $P_{ABSORBED}$ Limit

For example, an energy storage system may be in the process of charging, absorbing power from the grid. If the grid frequency then falls below normal, the maximum absorbed power level may begin to be curtailed. Once it has been curtailed to zero, if the frequency keeps falling, the system could be configured to produce watts, delivering power to the grid. Likewise, a energy storage system could curtail discharging if the grid frequency rises too high, and begin charging if frequency continues to rise further. These array configurations would utilize the signed nature of the array Y-values, as mentioned above.

### 9.4.1 Configuration Data

The resulting configuration data for this function, as described, is summarized in Figure 28.

Table 9: Summary Configuration Data for each Frequency-Watt Function (Per Mode)

| Parameters for Frequency-Watt Function 1 | Description |
|---|---|
| WGra | The slope of the reduction in maximum allowed Watt output as a function of frequency (%WMax/sec) |

| | |
|---|---|
| HzStr | The frequency deviation from nominal frequency (ECPNomHz) at which a snapshot of the instantaneous power output is taken as a maximum power output reference level (Pref) and above which reduction in power output occurs (Hz) |
| HzStop | The frequency deviation from nominal frequency (ECPNomHz) at which curtailed power output may return to normal and the snapshot value is released (Hz) |
| HystEna | A boolean indicating whether or not hysteresis is enabled |
| HzStopWGra | The maximum time rate of change at which power output returns to normal after having been curtailed by an over frequency event (Hz) |
| **Frequency-Watt Function 2** | Note: The following parameter set exists once for each "Frequency-Watt Produced" mode, and once for each "Frequency-Watt Absorbed mode" |
| Configuration Array | The variable length array of Frequency-Watt pairs that traces out the desired behavior. (%PRef vs. Hz) |
| Snapshot_Enable | A boolean determining whether snapshot mode is active |
| Pref_Capture_Freq | The frequency at which the power reference point is to be captured if in snapshop mode (Hz) |
| Pref_Release_Freq | The frequency at which the power reference point is to be released if in snapshop mode (Hz) |
| Ramp_Time_Inc | The maximum time rate of increase in the max power limit associated with this mode configuration (%WMax/Second) |
| Ramp_Time_Dec | The maximum time rate of decrease in the max power limit associated with this mode configuration (%WMax/sec) |
| Time_Window | This is a window of time over which the inverter randomly delays before beginning execution of the command. For example, an inverter given a new Volt-Watt configuration and a Time-Window of 60 seconds would wait a random time between 0 and 60 seconds before beginning the change to the new setting. The purpose of this parameter is to avoid large numbers of devices from simultaneously changing state if addressed in groups. (in seconds) |
| Ramp_Time | This setting, which exists for most functions, is replaced by the separate Ramp_Tme_Inc and Ramp_Time_Dec settings for this function. |
| Time-Out Window | This is a time after which the command expires. A setting of zero means to never expire. After expiration, the Volt-Watt curve would no longer be in effect. (in seconds) |

### 9.4.2 Relative Prioritization of Modes

Multiple modes which may act to limit Watt production, such as the Volt-Watt and Frequency-Watt functions, may both be simultaneously active. In that situation, the one that indicates the lower max-power level (closest to zero) at any point in time should be the one that establishes the limit at that time.

# 10. Volt-Watt Mode

## 10.1 Scope of this Function

This function modifies watts based on voltage, using curves to establish the associations.

## 10.2 Requirements/Use Cases

A number of purposes for the volt-watt function have been identified, for instance:

- **During High/Low Voltage Ride-Through**, the volt-watt function can be activated autonomously to modify watt output in the high voltage ranges, potentially decreasing output until reaching a “cease-to-energize” state.
- **High penetration of DER systems at the distribution level, driving feeder voltage too high.** Some utilities described circumstances where high PV output and low load is causing feeder voltage to go too high at certain times. Existing distribution controls are not able to prevent the occurrence.
- **Localized High Service Voltage.** Several utilities described circumstances where a large number of customers served by the same distribution transformer have PV systems, causing local service voltage that is too high. The result is certain PV inverters that do not turn on at all.

## 10.3 Description of Function

The Volt-Watt function utilizes a “configurable-curve”. This mechanism allows the inverter to be configured using an array of points, where the points define a piece-wise linear “curve” that establishes an upper limit on Watt output as a function of the local voltage. Figure 13 illustrates the concept.

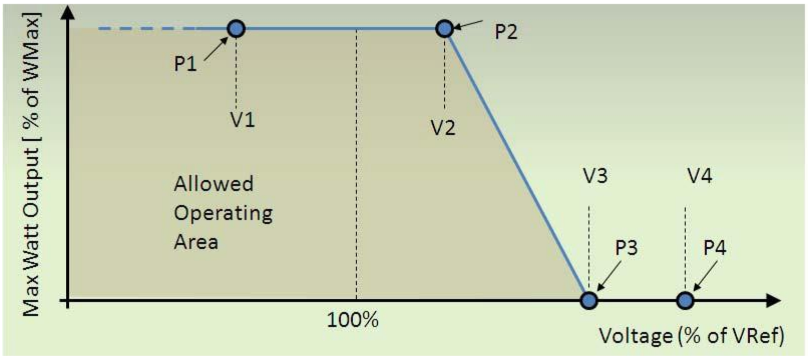


Figure 13: Example Configuration Curve for Maximum Watts vs. Voltage

The exact curve shape shown in Figure 13 is only an example. The array of points could be chosen so as to produce whatever behavior is desired. By definition of this function, the curve extends horizontally below the lowest voltage point and above the highest voltage point until such level that some other operational limit is reached. This means that in this example, point 1 and point 4 could be deleted, leaving only two configuration points, with no change in the resulting function.

In this configuration, the voltages are to be represented in the form of “Percent of VRef”, consistent with the voltage axis on the previously defined Volt-Var curves. “VRef” is a single global setting for the inverter that represents the nominal voltage at the PCC or some other point between the DER’s ECP and the PCC. See the “Configuration Curve Axis Definitions” section below for further explanation.

In addition to this curve configuration, it is proposed that the Volt-Watt configuration also include a time window, ramp time, time-out window, a filter time constant and a gradient limit, as defined in Table 10.

### 10.3.1 Defining “Percent Voltage”, the Array X-Values

As defined previously in the “Device Limits Settings” document form this initiative’s work, each DER will locally compute an “Effective Percent Voltage” based on its real-time local voltage measurement, nominal voltage setting, and offset voltage setting, as:

***Effective Percent Voltage = 100% * (local measured voltage-VRefOfs) / (VRef)***

The inverter shall compare this “Effective Percent Voltage” Value to the voltages (X-Values) in the curve, such that the X-Values of the curve points shall be calculated as follows:

*Percent Voltage (X-Value of Curve) = (Voltage at the Curve Point / VRef) * 100%*

Such that a “Percent Voltage” value of 100% represents the desired behavior when the voltage is exactly at the systems nominal or reference value.

This calculation permits the same configuration curves to be used across many different DER without adjusting for local conditions at each DER. For example, a utility might create a general “normal operation” Volt-Var curve that is to be used across many different DER. This works, even though the actual nominal voltage might be 240V at some DER and 480V at others. Each DER is configured with a VRef, and VRefOfs such that the same Volt-Var curve works for all.

### 10.3.2 Application to ESS (Two-Way Power Flows)

The limits for Watts-absorbed by ESSs are managed by a separate setting than that used for Watts-produced, although the method and parameters of the “Absorbed Volt-Watt” function would be identical to those for the Produced Volt-Watt function, except that a typical curve setting might look as illustrated in Figure 14.

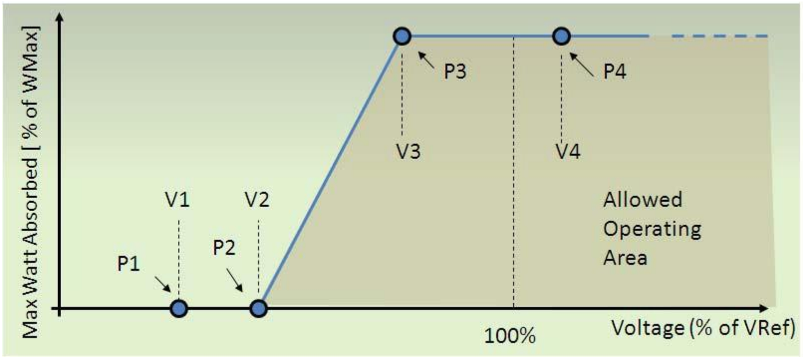


Figure 14: Example Configuration Curve for Maximum Watts Absorbed vs. Voltage

There may be a “Watts-Produced versus Voltage” mode and a “Watts-Absorbed versus Voltage” mode effective at the same time, each limiting the power flow in only one direction.

### 10.3.3 Limiting the Rate of Change of the Function

This function ultimately results in an upper limit on the Watts produced by the inverter, and likewise a limit on Watts absorbed for energy storage systems. Two mechanisms are proposed for limiting the rate of change of these limits. These may be configured such that they are used individually, together, or not at all.

### 10.3.4 Using Modes for Handling of Multiple Volt-Watt Configurations

Just as with the Volt-Var modes defined in Phase 1, it is proposed that inverters may accept and store multiple Volt-Watt curve configurations, each constituting a Volt-Watt “Mode”. In this way, an inverter may be commanded to change from one Watts-Voltage Mode to another by simply setting the desired pre-configured mode to “active”. Different inverters may have specific tailored curve shapes for a given mode, but all may be addressed in a single broadcast or multicast command to change the Volt-Watt mode.

There are multiple scenarios in which different Volt-Watt modes may be desired. For example, a DER that is sometimes connected near the sourcing substation, and sometimes at the end of the line due to distribution switching, might be best managed with different settings in each of the two conditions. “Mode” settings may help prepare smart inverters for integration with advanced distribution automation systems. Another example may be intentional islanding, where different settings for the inverter are desired when operating as part of an island.

This “Mode” concept is facilitated by adding to the list of configuration parameters listed in Table 10, a “Mode number” (unique ID for the mode) and a single global field for the “Currently Active Watt Produced-Voltage Mode”.

### 10.3.5 Scheduling Volt-Watt Modes

Just as with the Volt-Var modes defined in Phase 1, it is proposed that the Volt-Watt modes be schedulable. The schedules will essentially define which Volt-Watt mode is in effect at a given time.

### 10.3.6 Resulting Block Diagram

The combination of a setting for maximum Watts-Produced vs. Voltage and another for maximum Watts-Absorbed vs. Voltage results in a functional block diagram as in Figure 15. Note that for either function, several mode configurations might be stored in the inverter, and separate mode selection switches exist for each.

The diagram presently illustrated both a “steady-state filter” on the voltage input, and rate of change limitations on the effective operating bounds (Max Watts-Produced, and Max Watts- Absorbed). The configuration data depicted in Table 10 indicates that each rate-of-change limiter would have separate rising and falling limits, as shown.

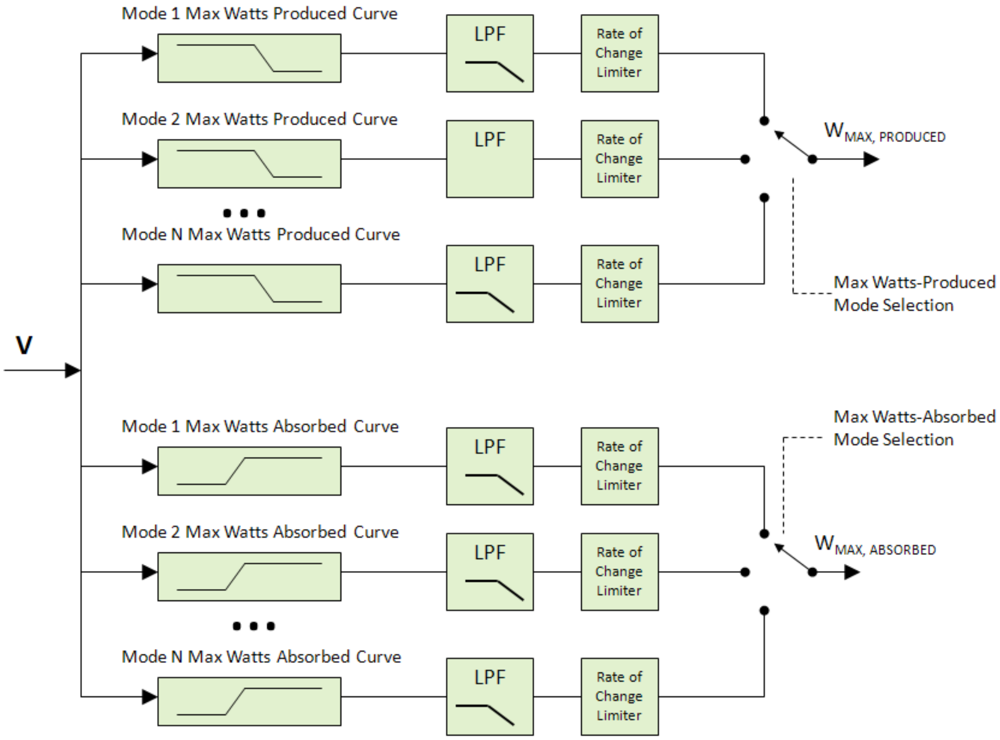


Figure 15: Overall Functional Block Diagram

### 10.3.7 Resulting Configuration Data

The resulting configuration data for this function, as described, is summarized in Table 10-1. Note that this data set is replicated for each Watts-Delivered and Watts-Absorbed mode that is defined.

Table 10: Summary Configuration Data for one Volt-Watt Mode

| Parameter | Description |
|---|---|
| Enable/Disable | This enables / disables this Volt-Watt Mode |
| Number of Array Points | The number of points in the Volt-Watt Curve Array (N points) |
| Array Voltage Values | A length=N array of “percent of VRef” values |
| Array Wattage Values | A length=N array of “Percent of WMax values |
| Randomization Time Window | Delay before a new command or newly activated mode begins to take effect |
| Mode Transition Ramp Time | Rate of change limit for new commands as they take effect. This ramp time only manages the rate at which Watt output may transition to a new level when a configuration change is made (by communication or by schedule). It does not affect the rate of change of Watt output in response to voltage variations during normal run time. |
| Time Out | Duration that a new command remains in effect |
| Maximum Watt Capability (WMax) | Configured Value. Defined in Phase 1 work |
| VRef | Reference Voltage. Defined in Phase 1 work |
| VRefOfs | Reference Voltage Offset. Defined in Phase 1 work |
| Fall_Limit | The maximum rate at which the Max Watt limit may be decreased in response to changes in the local voltage. This is represented in terms of % of WMax per second. |
| Rise_Limit | The maximum rate at which Max Watt limit may be increased in response to changes in the local voltage. This is represented in terms of % of WMax per second. |
| Low Pass Filter Time | Equal to three time-constants (3 ) of the first order low-pass filter in seconds (the approximate time to settle to 95% of a step change). |

### 10.3.8 Interaction of this Function with the Intelligent Volt-Var Function

The Volt-Var modes that were described in Phase 1 of this project were designed in such a way that watts take precedence over Vars. The vertical axis of any Volt-Var curve can be thought of as the “requested” Var level, with the understanding that an inverter that is producing its full Watt capacity at any point in time may have no Vars to offer.

The interaction between the Volt-Var function and the present Watt-Volt function is direct and intentional. The vertical axis of the Volt-Var function’s configuration curve was defined as “percent of available Vars”, meaning that watts production always takes precedence over Vars, regardless of voltage. This agreement came from focus group discussion that included the consideration of the interests of the PV owner, the preference for clean watts generation in general, and the recognition that in almost all cases, there is a good margin between the inverter rating and the peak array output, meaning that significant Var production capability usually exists.

When this definition of the Volt-Var function is coupled with a Watt-Volt function, one gains the ability to back off on watts as voltage rises, forcing more Var capability to be available, and in effect enabling the Volt-Var function to be active and produce Vars even in situations when the array output is capable of driving the full rating of the inverter.

As an example, consider an inverter with the two functions shown in Figure 10-5 (top = Volt- Var function, Bottom = Volt-Watt function), both active simultaneously.

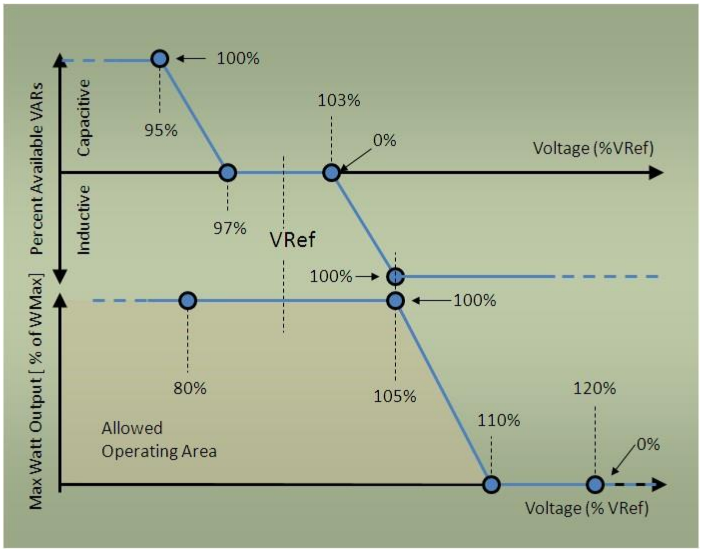


Figure 16: Example Settings for Volt-Var and Volt-Watt Modes

# 11. Dynamic Reactive Current Support Mode

## 11.1 Scope

In the Dynamic Reactive Current mode, the DER provides reactive current support in response to dynamic variations in voltage. This function is distinct from the steady-state Volt-Var function in that the controlling parameter is the change in voltage rather than the voltage level itself. In other words, the power system voltage may be above normal, resulting in a general need for inductive Vars, but if it is also falling rapidly, this function could produce capacitive reactive current to help counteract the dropping of the voltage.

## 11.2 Requirements/Use Cases

This is a type of dynamic system stabilization function. Such functions create an effect that is in some ways similar to momentum or inertia, in that it resists rapid change in the controlling parameter.

Power quality, such as flicker, may be improved by the implementation of functions of this type and when implemented in fast-responding solid-state inverters, these functions may provide other (slower) grid equipment with time to respond.

## 11.3 Description of Function

It is proposed to provide support for a behavior as illustrated in Figure 17. This function provides dynamic reactive current support in response to a sudden rise or fall in the voltage at the Point of Common Coupling (PCC).

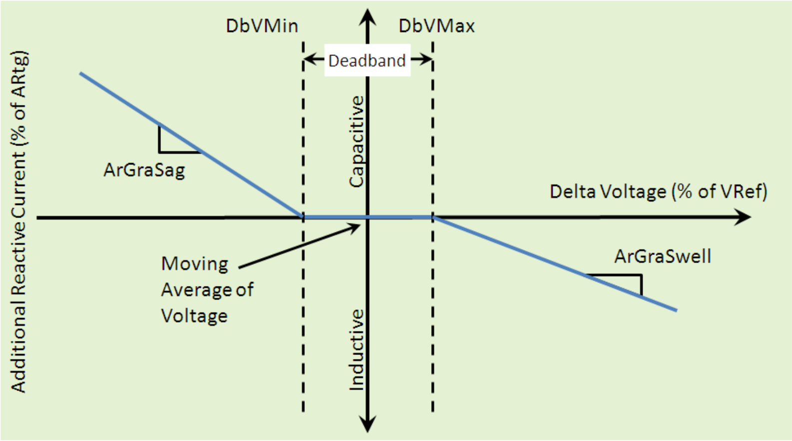


Figure 17: Dynamic Reactive Current Support Function, Basic Concept

This function identifies “Delta Voltage” as the difference between the present voltage and the moving average of voltage, VAverage (a sliding linear calculation), over a preceding window of time specified by FilterTms. The calculation of Delta Voltage (Delta Voltage = Present Voltage – Moving Average Voltage, expressed as a percentage of VRef) is illustrated at time = “Present” in Figure 18.

The “present voltage” in this context refers to the present $AC_{RMS}$ voltage, which requires a certain period to calculate. For example, some inverters might calculate voltage every half-cycle of the AC waveform. It is outside the scope of this specification to define the method or timing of the $AC_{RMS}$ measurement.

Parameters DbVMin and DbVMax allow the optional creation of a dead band inside which zero dynamic current is generated. The separate ArGraSag and ArGraSwell parameters make it possible to independently define the rate that the magnitude of additional reactive current increases as delta-voltage increases or decreases, as illustrated.

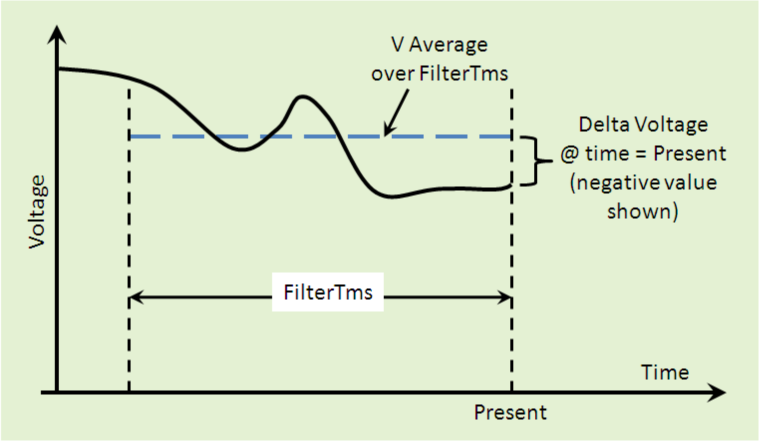


Figure 18: Delta-Voltage Calculation

### 11.3.1 Event-Based Behavior

This function includes an option to manage how the dynamic reactive current support function is managed, as indicated in Figure 19 and described below.

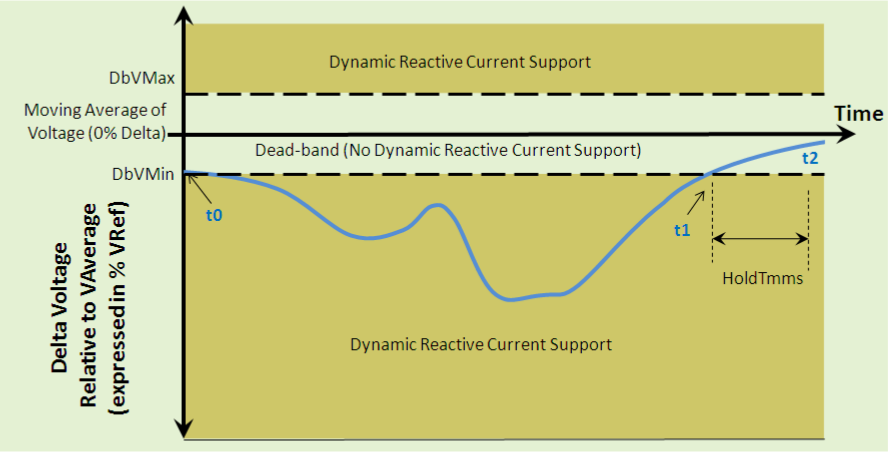


Figure 19: Activation Zones for Reactive Current Support

Activation of this behavior allows for a voltage sag or swell to be thought of as an “event”. The event begins when the present voltage moves above the moving average voltage by DbVMax or below by DbVMin, as shown by the blue line and labeled as t0.

In the example shown, reactive current support continues until a time HoldTmms after the voltage returns above DbVMin as shown. In this example, this occurs at time t1, and this event continues to be considered active until time t2 (which is t1 + HoldTmms).

When this behavior is activated, the moving average voltage (VAverage) and any reactive current levels that might exist due to other functions (such as the static Volt-Var function) are frozen at t0 when the “event” begins and are not free to change again until t2 when the event ends. The reactive current level specified by this function continues to vary throughout the event and be added to any frozen reactive current.

### 11.3.2 Alternative Gradient Shape

This function includes the option of an alternative behavior to that shown in Figure 20. ArGraMod selects between the behavior of Figure 16-1 (gradients trend toward zero at the deadband edges) and that of Figure 16-4 (gradients trend toward zero at the center). In this alternative mode of behavior, the additional reactive current support begins with a step change when the “event” begins (at DbVMin for example), but then follows a gradient through the center until the event expires, HoldTmms after the voltage returns above the DbVMin level.

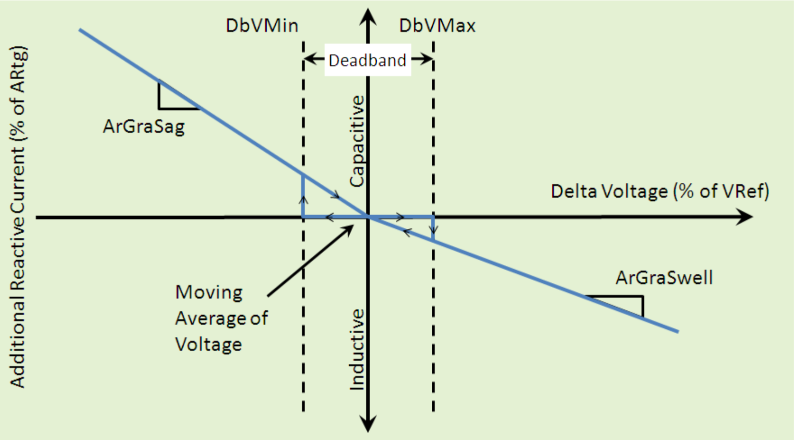


Figure 20: Alternative Gradient Behavior, Selected by ArGraMod

### 11.3.3 Blocking Zones

This function also allows for the optional definition of a blocking zone, inside which additional reactive current support is not provided. This zone is defined by the three parameters BlkZnTmms, BlkZnV, and HysBlkZnV. It is understood that all inverters will have some self- imposed limit as to the depth and duration of sags which can be supported, but these settings allow for specific values to be set, as required by certain country grid codes.

As illustrated in Figure 21, at t0, the voltage at the ECP falls to the level indicated by the BlkZnV setting and dynamic reactive current support stops. Current support does not resume until the voltage rises above BlkZnV + HysBlkZnV as shown at t1. BlkZnTmms provides a time, in milliseconds, before which dynamic reactive current support continues, regardless of how low voltage may sag. BlkZnTmms is measured from the beginning of any sag "event" as described previously.

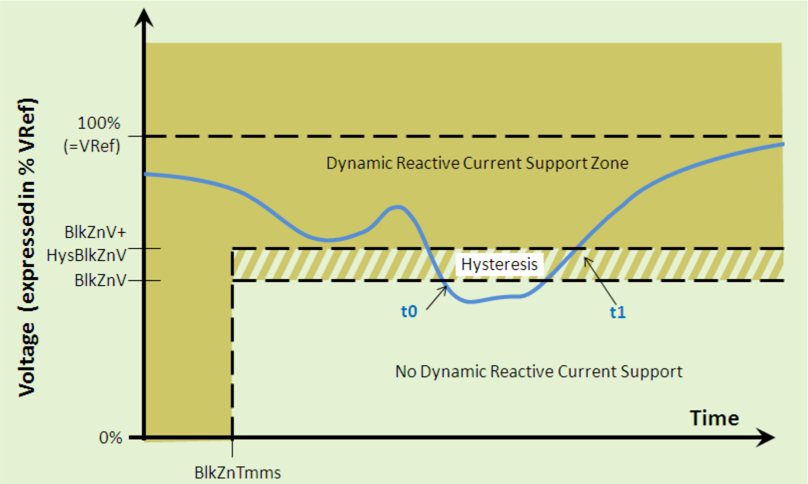


Figure 21: Settings to Define a Blocking Zone

### 11.3.4 Relationship to the Static Volt-Var Function

As indicated in Figure 16-1, the reactive current level indicated by this dynamic stabilization function is defined as "additional" Current. This means that it is added to the reactive current that might exist due to a static Volt-Var function or fixed power factor setting that is also currently active.

For example, a static volt-var configuration may involve a curve that, at the present operating voltage, results in Var generation of +1000[Vars]. At the same time, this function may be detecting a rising voltage level, and may be configured to produce a reactive current amounting to -300[Vars] in response. In this case, the total Var output would be +700[Vars].

Units may also be configured so that the Var level indicated by this dynamic Volt-Var function are the only Vars, by not activating other Var controls, such as the static Volt-Var modes or non- unity power factor settings.

### 11.3.5 Dynamic Reactive Current Support Priority Relative to Watts

Under certain operating conditions, the production of the additional reactive current specified by this function could imply a reduction in real-power levels based on the inverter's limits. Such a reduction may or may not be beneficial in terms of providing optimal dynamic support to the grid.

To handle this possibility, an optional setting called “DynamicReactiveCurrentMode” is defined, with associated behaviors as identified in Table 11: Dynamic Reactive Current Mode ControlTable 11. Implementation and utilization of this Boolean is optional. If it is not used or supported, the default behavior is that active power levels (Watts) are curtailed as needed to support this function.

Table 11: Dynamic Reactive Current Mode Control

| Setting | Implication | Present Condition | Behavior of this Function |
|---|---|---|---|
| DynamicReactive CurrentMode = 0 (default) | Reactive current is preferred over Watts for grid | Inverter is Delivering Active Power, Voltage Sags | Dynamic reactive current takes priority over Watts |
| | | Inverter is Delivering Active Power, Voltage | Dynamic reactive current takes priority over Watts |
| | | Inverter is Absorbing Active Power, Voltage | Dynamic reactive current takes priority over Watts |
| | | Inverter is Absorbing Active Power, Voltage | Dynamic reactive current takes priority over Watts |
| DynamicReactive CurrentMode = 1 | Watts are preferred over reactive current for grid | Inverter is Delivering Active Power, Voltage Sags | Watts take priority over dynamic reactive current |
| | | Inverter is Delivering Active Power, Voltage | Dynamic reactive current takes priority over Watts |
| | | Inverter is Absorbing Active Power, Voltage | Dynamic reactive current takes priority over Watts |
| | | Inverter is Absorbing Active Power, Voltage | Watts take priority over dynamic reactive |

### 11.3.6 Settings to Manage this Function

As shown in the previous figures, the settings used to configure this function are:

Table 12: Settings for Dynamic Reactive Current Mode

| Name | Description |
|---|---|
| Enable/Disable Dynamic Reactive Current Support Function | This is a parameter that indicates whether the dynamic reactive current support function is active or inactive. |
| DbVMin | This is a voltage deviation relative to Vaverage, expressed in terms of % of Vref (for example -10%Vref). For negative voltage deviations (voltage below the moving average) that are smaller in amplitude than this amount, no additional dynamic reactive current is produced. |
| DbVMax | This is a voltage deviation relative to Vaverage, expressed in terms of % of Vref (for example +10%Vref). For positive voltage deviations (voltage above the moving average) that are smaller in amplitude than this amount, no additional dynamic reactive current is produced. Together, DbVMin and DbVMax allow for the creation of a dead-band, inside of which the system does not generate additional reactive current support. |

| Name | Description |
|---|---|
| ArGraSag | This is a gradient, expressed in unit-less terms of %/%, to establish the ratio by which Capacitive % Var production is increased as %Delta-Voltage decreases below DbVMin. Note that the % Delta-Voltage may be calculated relative to Moving Average of Voltage + DbVMin (as shown in Figure 16-1) or relative to Moving Average of Voltage (as shown in Figure 16-4), according to the ArGraMod setting. |
| ArGraSwell | This is a gradient, expressed in unit-less terms of %/%, to establish the ratio by which Inductive % Var production is increased as %Delta-Voltage increases above DbVMax. Note that the % Delta-Voltage may be calculated relative to Moving Average of Voltage +DbVMax (as shown in Figure 16-1) or relative to Moving Average of Voltage (as shown in Figure 16-4), according to the ArGraMod setting. |
| FilterTms | This is the time, expressed in seconds, over which the moving linear average of voltage is calculated to determine the Delta-Voltage. |
| **Additional Settings (Optional)** | |
| ArGraMod | This is a select setting that identifies whether the dynamic reactive current support acts as shown in Figure 16-1 or Figure 16-4. (0 = Undefined, 1 = Basic Behavior (Figure 16-1), 2 = Alternative Behavior (Figure 16-4). |
| BlkZnV | This setting is a voltage limit, expressed in terms of % of Vref, used to define a lower voltage boundary, below which dynamic reactive current support is not active. |
| HysBlkZnV | This setting defines a hysteresis added to BlkZnV in order to create a hysteresis range, as shown in Figure 16-5, and is expressed in terms of % of VRef. |
| BlkZnTmms | This setting defines a time (in milliseconds), before which reactive current support remains active regardless of how deep the voltage sag. |
| Enable/Disable Event-Based Behavior | This is a Boolean that selects whether or not the event-based behavior is enabled. |
| Dynamic Reactive Current Mode | This is a Boolean that selects whether or not Watts should be curtailed in order to produce the reactive current required by this function. |
| HoldTmms | This setting defines a time (in milliseconds) that the delta-voltage must return into or across the dead-band (defined by DbVMin and DbVMax) before the dynamic reactive current support ends, frozen parameters are unfrozen, and a new event can begin. |

# 12. Scheduling Power Values and Modes

## 12.1 Scope of this Function

This function addresses scheduling of real and reactive power, as well as the enabling/disabling of the different types and variations of DER modes.

## 12.2 Requirements/Use Cases

Larger DER systems and large aggregations of small DER systems have significant influence on the distribution system and have local volt-var characteristics that may vary throughout the day. As a result, a single function or operational mode such as a specific volt-var curve may not be suitable at all times. Yet sending many control commands every few hours to many different DER systems may impact bandwidth-limited communications systems or may not be received in a timely manner, leading to inadequate DER system responses. However, if schedules can be established that the DER systems can follow autonomously, then these communication impacts can be minimized.

Schedules establish what behavior is expected during specified time periods. A schedule consists of an array of time periods of arbitrary length, with each time period associated with a value or mode.

Schedules use relative time, so that increasing time values are the delta seconds from the initial time value. The actual start date/time replaces the initial time value when the schedule is activated. A ramp rate sets the rate at which the function or mode in one time period moves to the function or mode in the subsequent time period, while the ramp type indicates how the ramp is to be understood. A stop time indicates when the schedule is deactivated.

Schedules can be used to allow even more autonomous control of the behavior of DER equipment. They may be sent ahead of time, and then activated at the appropriate time.

## 12.3 Description of Function

The relations between schedule controller, schedules and entity controlled by the schedule are shown in

Figure 22. The schedule controller monitors state and priority of its associated schedules and informs the scheduled entity about the reference to the active schedule. The scheduled entity can then receive the scheduled value from the active schedule.

- Schedule controllers: One or more schedule coordinators may be available at the ECP. Each schedule controller can control multiple schedules so long as they are not running at the same time. The schedule controller indicates which schedule is currently ready-to-run or running. For one schedule controller, only one schedule can be running.
- Schedules: Each schedule must have a non-zero identifier that is a unique schedule identity within the ECP. A schedule consists of time periods of arbitrary length that reference delta time from the initial entry.
- Scheduled entities: Each entry in a schedule references a specific value, a mode, or a function. Configuration parameters indicate the units and other characteristics of the entries.
  - Values are direct settings, such as maximum watt output. These are absolute values or a percentage, to be used primarily where specific values are needed.
  - Modes are the identities of the mode type (e.g. volt-var, frequency-watt) and the specific set of pre-established parameters (e.g. volt-var curve #2, frequency-watt curve #5).

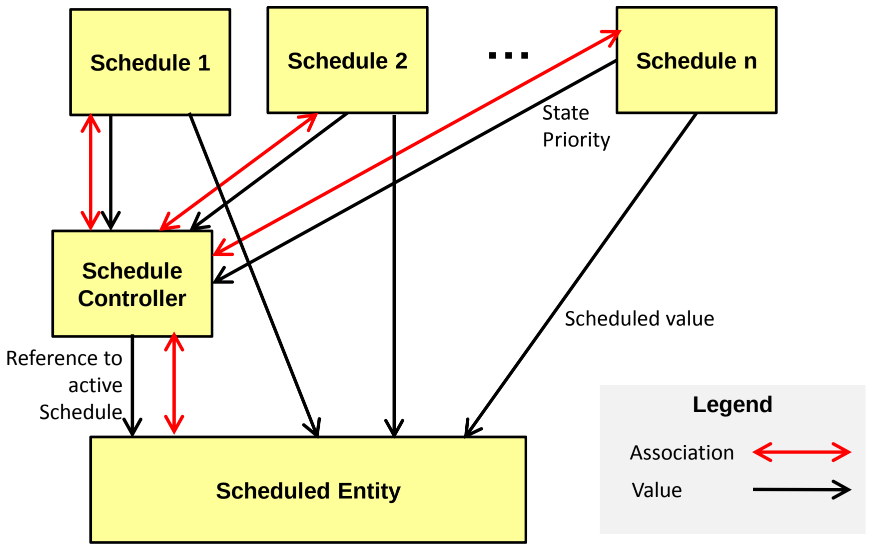


Figure 22: Relation between schedule controller, schedules and entity controlled

Different schedules may be combined over a given period of time, including with different priorities, thereby providing richer ways to utilize the ESS without requiring manual intervention.  For example, a power scheduler may provide one schedule which directs the ESS to charge the batteries during nighttime hours when energy is cheap, and provide a subsequent schedule which directs the ESS to operate in Fixed Power Factor mode during the day. An illustration of priority management is shown in Figure 23.

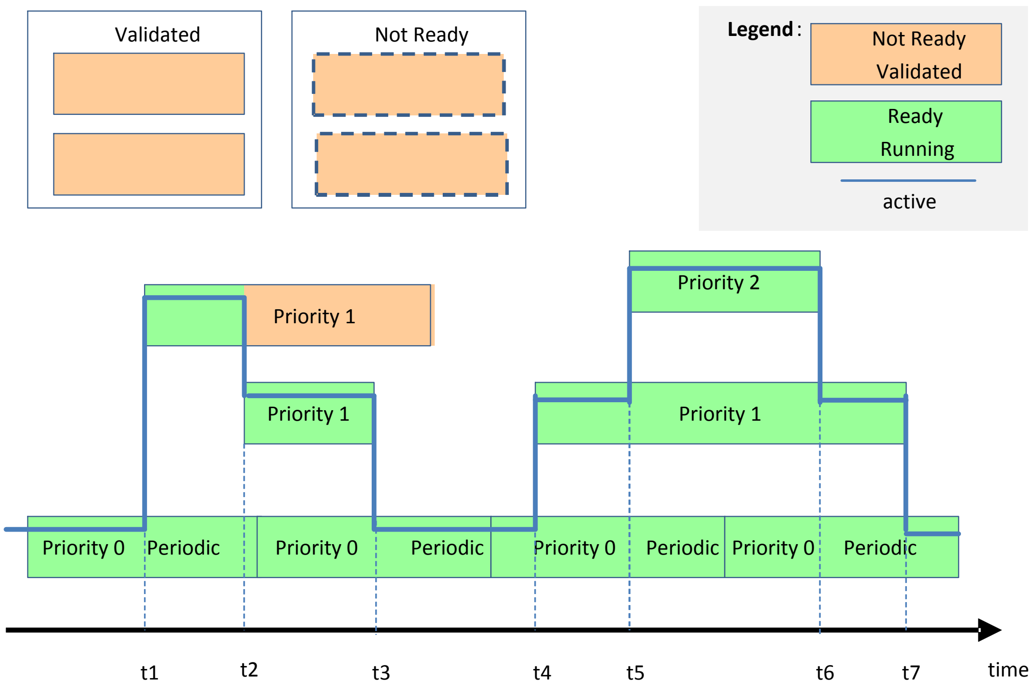


Figure 23: Handling priorities of schedules

The settings for scheduling include those in Table 13.

Table 13: Settings for Scheduling

| **Name** | **Description** |
|---|---|
| **FSCHxx** (the xx refers to the schedule number (index) | Select which schedule to edit |
| **FSCHxx.ValASG** (with FSCH.ClcIntvTyp set to seconds) | Set the Time Offset (X-Value) for each schedule point. Time Offsets must increase with each point. Time Offsets represent relative seconds from each repetition of the schedule. |
| **FSCHxx.ValASG** (set for power system values, such as W or Vars) | Set the Y-value for each schedule point for power system values (watts, vars, PF, etc.) |
| **FSCHxx.ING** (set to the operating mode identity) | Set the Y-value for enabling or disabling operating modes (VV, FW, VW, etc.) at each schedule point |
| **FSCHxx.NumEntr** | Set the number of points used for the schedule.  Set this value to zero to disable the schedule (there are other ways to enable and disable schedules). |
| **FSCHxx.SchdPrio** | Set the priority for the schedule. |
| **FSCHxx.ValMV** (for power system values) or **FSCH.ValINS** (for operating modes) | Set the meaning of the Y-values of the schedule. |
| **FSCHxx.StrTm** | Set the start time for the selected schedule |
| **FSCHxx.IntvPer** | Set the repeat interval for the selected schedule |
| **FSCHxx.ClcIntvTyp** | Set the repeat interval units for the selected schedule |
| **FSCHxx.Enable** | Enable the Schedule by changing its state to “ready”. |

# 13. DER Functions "Also Important" to DER Integrators and Other Third Parties

## 13.1 Overview of Additional DER Functions

The list of DER functions selected as part of the Phase 3 document was developed in response to utility assessments of their relative importance to utilities. However, other stakeholders, such as aggregators, integrators, manufacturers, and consultants, also expressed their opinions on the relative importance of certain DER functions in the Phase 3 survey. Although there was significant agreement on which of the functions should be rated of high importance, a few were deemed higher in importance by the other stakeholders than by utilities. Although there was no consensus on exactly which ones are the most important, those "also important" functions are listed here:

1. **Active Power Smoothing mode:** This function provides settings by which a DER may dynamically absorb or produce additional watts in response to a rise or fall in the power level of a Referenced Point.
2. **Dynamic Volt-Watt mode**: This function involves the dynamic absorption or production of active power in order to counteract fast variations in the voltage at the Referenced Point.
3. **Watt-Power Factor mode**: This function shifts the power factor based on active power level. The power factor is not fixed but changes with the power level. It might be slightly capacitive at very low output power levels and becoming slightly inductive at high power levels.
4. **Active Power Following**: This function involves the variable dispatch of energy in order to maintain the DER's active power to track the active power level of the Referenced Point. In the case of load following, the output of the DER power output rises as the consumption of the reference load rises. In the case of generation following, the power output counteracts the output of the reference generation to maintain a total steady value. The DER may apply a percentage of the Referenced Point active power level to its active power output, thus compensating only a part of that active power.
5. **Frequency-Watt Smoothing mode**: This function rapidly modifies active power to counteract and smooth minor frequency deviations. The frequency-watt settings define the percentage of active power to modify for different degrees of frequency deviations on a second or even sub-second basis.
6. **Participate in AGC**: Support frequency regulation by automatic generation control (AGC) commands. The DER system (or aggregations of DER systems, particularly energy storage systems) implements modification of active power based on AGC "reg-up" and "reg-down" signals on a multi-second basis.
7. **Imitate capacitor bank triggers:** Provide reactive power through autonomous responses to weather, current, or time-of-day. Similar to capacitor banks on distribution circuits, the DER system implements temperature-var curves that define the reactive power for different ambient temperatures, similar to use of feeder capacitors for improving the voltage profile. Curves could also be defined for current-var and for time-of-day-var.
8. **Short Circuit Current Limit**: DER must have short circuit limits. DER should limit their short circuit current to no more than 1.2 p.u. This is useful for utilities in order to perform short circuit impact studies.
9. **Provide black start capabilities**: The DER system operates as a microgrid (possibly just itself with no load) and supports additional loads being added, so long as they are within its generation capabilities.

10. **Provide "spinning" or operational reserve as bid into market**: The DER system provides emergency active power upon command at short notice (seconds or minutes), either through increasing generation or discharging storage devices. This function would be in response to market bids for providing this reserve.
11. **Reactive Power Support during non-generating times**: Support the grid with reactive power during non-generating times. DERs support the grid with reactive power (VARs) when there is no primary energy (i.e. solar irradiance). This can be used by utilities to reduce the stress in the system in areas with high motor load (A/C) during peak times.
12. **Flow Reservation**: Energy Storage System requests permission to either charge or discharge a defined amount of energy (kWh) starting at a defined time and completing by a defined time at a rate not exceeding a defined charge or discharge power level. The utility or other authorized entity responds with an authorized energy transfer, start time, and maximum power level. The utility can update the response periodically to modulate the power flow during transfer, but cannot change from discharging to charging, or the reverse, without a new flow reservation request by the storage unit.
13. **FDEMS or Aggregator provides expected schedules:** The FDEMS or Aggregator provides schedules of expected generation and storage reflecting customer requirements, maintenance, local weather forecasts, etc.
14. **FDEMS or Aggregator provides forecasts of available energy or ancillary services**: The FDEMS or Aggregator provides scheduled, planned, and/or forecast information for available energy and ancillary services over the next hours, days, weeks, etc., for input into planning applications. Separate DER generation from load behind the PCC.
15. **FDEMS or Aggregator provides micro-locational weather forecasts**: The FDEMS or Aggregator provides micro-locational weather forecasts, such as: ambient temperature, wet bulb temperature, cloud cover level, humidity, dew point, micro-location diffuse insolation, micro-location direct normal insolation, daylight duration (time elapsed between sunrise and sunset), micro-location total horizontal insolation, micro-location horizontal wind direction, micro-location horizontal wind speed, micro-location vertical wind direction, vertical wind speed, micro-location wind gust speed, barometric pressure, rainfall, micro-location density of snowfall, micro-location temperature of snowfall, micro-location snow cover, micro-location snowfall, water equivalent of snowfall.
16. **Initiate Periodic Tests**: Test DER functionality, performance, software patching and updates Initial DER software installations and later updates are tested before deployment for functionality and for meeting regulatory and utility requirements, including safety. After deployment, testing validates the DER systems are operating correctly, safely, and securely.
17. **DC Fault Test during start-up**: DER tests its primary energy mover (DC solar PV modules) for fault conditions. This feature will try to alarm plant operators, owners, public that the DC side has a potential short that could lead to a fire hazard.
18. **Provide low cost energy:** Utility, aggregator, or FDEMS determines which DER systems are to generate how much energy over what time period in order to minimize energy costs. Some DER systems, such as PV systems, would provide low cost energy autonomously, while storage systems would need to be managed.
19. **Provide low emissions energy**: Utility, REP, or FDEMS determines which non-renewable DER systems are to generate how much energy in order to minimize emissions. Renewable DER systems would operate autonomously.

20. **Provide renewable energy**: Utility, Aggregator, or FDEMS selects which non-renewable DER systems are to generate how much energy in order to maximize the use of renewable energy. Renewable DER systems would operate autonomously.

21. **Respond to active power pricing signals**: Manage active power output based on demand response (DR) pricing signals The DER system receives a demand response (DR) pricing signal from a utility or aggregator for a time period in the future and determines what active power to output at that time.

22. **Respond to ancillary services pricing signals:** Manage selected ancillary services based on demand response (DR) pricing signals. The DER system receives a DR pricing signal from a utility or retail energy provider (REP) for a time period in the future and determines what ancillary services to provide at that time.

## 13.2 Active Power Smoothing Mode

### 13.2.1 Scope of this Mode

The Active Power Smoothing Function compensates for intermittent renewables and transient loads by a smoothing function for loads or generation. This function involves the dynamic dispatch of energy in order to compensate for variations in the power level a reference signal. With proper configuration, this function may be used to compensate for either variable load or variable generation.

### 13.2.2 Requirements/Use Cases

This function was identified as a requirement by several utilities working together in EPRI's storage research program (P94). These utilities have developed a specification for a large scale Lithium Transportable Energy Storage System (Li-TESS) which includes a requirement for a Load/Generation Smoothing function.

### 13.2.3 Description of the Function

This proposal describes a method by which distributed energy resources (DER) may perform a load/generation smoothing function as described in the following subsections.

#### *13.2.3.1 Active Power Smoothing*

This function provides settings by which a DER may dynamically absorb or produce additional Watts in response to a rise or fall in the power level of a reference point of load or generation. This function utilizes the same basic concepts and settings as the "Dynamic Var Support Function" described separately.

The Watt levels indicated by this function are additive – meaning that they are in addition to whatever Watt level the DER might otherwise be producing. The dynamic nature of this function (being driven by the change (dW/dt) in load or generation level as opposed to its absolute level makes it well suited for working in conjunction with other functions.

As illustrated in the left pane of Figure 24, this function allows the setting of a "Smoothing Gradient" which is a unit-less quantity (Watts produced per Watt-Delta). This is a signed quantity. The example in Figure 24 shows a negative slope. A value of -1.0 would absorb one additional Watt (or produce one less Watt) for each Delta Watt (Present Wattage – Moving Average) of the reference device. Negative settings would be a natural fit for smoothing variable generation, where the DER would dynamically reduce power output (or absorb more) when the reference generation increased.

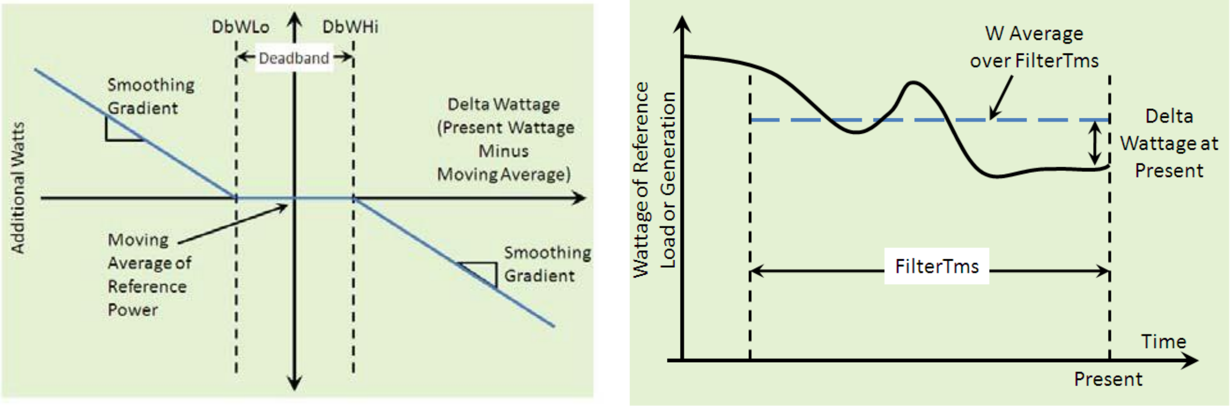


Figure 24: Smoothing Function Behavior

Likewise, a gradient setting of +1.0 would generate one additional Watt (or absorb one less Watt) for each Delta Watt (Present Wattage – Moving Average) of the reference device. Positive settings would be a natural fit for smoothing variable load, where the DER would dynamically increase power output (or absorb less) when the reference load increased.

As illustrated in the right frame of Figure 24, The Delta Wattage is to be computed as Present Wattage – Moving Average, where the Moving Average is calculated as a sliding linear average over the previous "FilterTms" period. FilterTms is configurable.

#### 13.2.3.2 Limitations of the Function

As with all functions, DER systems will operate within self-imposed limits and will protect their own components. These limits are acknowledged to vary, depending on many factors (e.g. state of maintenance, damage, temperature). In addition, it is acknowledged that the load/generation following and active power smoothing functions are limited by present device limit settings, such as WMax.

There are also practical limits to a DER system's ability to provide load/generation following. For example, an energy storage system cannot necessarily follow load or generation indefinitely, and may at some point reach its upper or lower SOC limits. Methods to handle this could include scheduling of the load/generation following modes so that regular charge/discharge commands are used at other times.

#### 13.2.3.3 Settings to Manage this Function

The following settings are defined to manage this function:

Table 14: Active Power Smoothing Function Settings

| **Setting Name** | **Description** |
|---|---|
| Enable/Disable Active Power Smoothing | This parameter indicates whether the function is active or inactive. |
| Smoothing Gradient | This is a signed quantity that establishes the ratio of smoothing Watts to the present delta-watts of the reference load or generation. Positive values are for following load (increased reference load results in a dynamic increase in DER output), and negative values are for following generation (increased reference generation results in a dynamic decrease in DER output). |
| FilterTms | This is a configurable setting that establishes the linear averaging time of the reference power (in Seconds). |
| DbWLo and DbWHi | These are optional settings, in Watts, that allow the creation of a dead-band inside which power smoothing does not occur. |
| Time Window | This is a window of time over which the inverter randomly delays before beginning execution of the command. For example, an inverter given a new smoothing configuration (or function activation) and a Time-Window of 60 seconds would wait a random time between 0 and 60 seconds before beginning to put the new settings into effect. The purpose of this parameter is to avoid large numbers of devices from simultaneously changing state if addressed in |
| Ramp Time | This is a fixed time in seconds, over which the inverter settings (Watts in this case) are to transition from their pre-setting level to their post-setting level. The purpose of this parameter is to prevent sudden changes in output as a result of the receipt of a new command or mode activation. Note: this setting does not impact the rate of change of Watt output during run-time as a result of power changes at the reference point. |
| Time-Out Window | This is a time after which the setting expires. A value of zero means to never expire. After expiration, the Power Smoothing settings would no longer be in effect. |

## 13.3 Dynamic Volt-Watt Function

### 13.3.1 Scope of this Function

The Dynamic Volt-Watt Function provides a mechanism through which inverters, such as those associated with energy storage systems, can be configured to dynamically provide a voltage stabilizing function. This function involves the dynamic absorption or production of active power (Watts) in order to resist fast variations in the local voltage at the ECP.

### 13.3.2 Requirements/Use Cases

Use cases have been identified (TBD).

### 13.3.3 Description of Function

This function describes the dynamic volt-watt function by which a DER may dynamically absorb or produce additional Watts in response to a rise or fall in the voltage level at the ECP. This function utilizes the same basic concepts and settings as the “Power Smoothing Function” described separately, except in this case the controlling parameter is the local voltage at the ECP rather than the power level of a remote reference point.

The Watt levels indicated by this function are additive – meaning that they are in addition to whatever Watt level the DER might otherwise be producing. The dynamic nature of this function (being driven by the change (dV/dt) in local voltage level as opposed to its absolute level makes it well suited for working in conjunction with other functions.

As illustrated in the left pane of Figure 25, this function allows the setting of a “Dynamic Watt Gradient” which determines how aggressively additional Watts are produced relative to the amplitude of voltage deviation. This is a signed, unit-less quantity, expressed as a %/%, or more specifically, as Watts (%WMax) / Volts (%VRef). The example shows a negative slope. A value of -1.0 would absorb one additional %WMax (or produce 1% less) for each 1% VRef increase in Delta Voltage (Present Voltage – Moving Average). Negative settings would be a natural fit for compensating for variable voltages caused by intermittent generation.

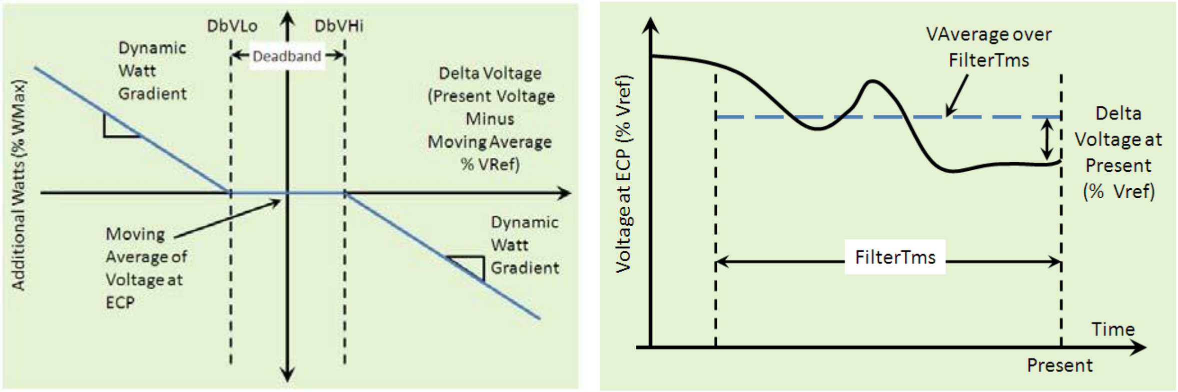


Figure 25: Dynamic Volt-Watt Function Behavior

As illustrated in the right frame, The Delta Voltage is to be computed as Present Voltage – Moving Average, and expressed as a percent of VRef, where the Moving Average is calculated as a sliding linear average over the previous “**FilterTms**” period. **FilterTms** is configurable.

#### *13.3.3.1 Limitations of the Function*

As with all functions, DER will operate within self-imposed limits and will protect their own components. These limits are acknowledged to vary, depending on many factors (e.g. state of maintenance, damage, temperature). In addition, it is acknowledged that the dynamic Volt-Watt function is limited by present device limit settings, such as WMax, and physical limitations such as a PV-only system that has no additional Watts to offer.

#### *13.3.3.2 Settings to Manage this Function*

The following settings are defined to manage this function:

Table 15: Dynamic Volt-Watt Function Settings

| Setting Name | Description |
|---|---|
| Enable/Disable the Dynamic Volt-Watt Function | This parameter indicates whether the function is active or inactive. |
| Dynamic Watt Gradient | This is a signed unit-less quantity that establishes the ratio of dynamic Watts (expressed in terms of % WMax) to the present delta-voltage of the reference ECP (expressed as % VRef). |
| FilterTms | This is a configurable setting that establishes the linear averaging time of the ECP voltage (in Seconds). |
| DbVLo and DbVHi | These are optional settings, expressed in %VRef, that allow the creation of a dead-band inside which the dynamic volt-watt function does not produce any additional Watts.<br>For example, setting DbVLo = 10 and DbVHi = 10 results in a dead-band that is 20% of VRef wide. |
| Time-Out Window | This is a time after which the setting expires. A value of zero means to never expire. After expiration, the Dynamic Volt-Watt settings would no longer be in effect. |
|  | Note that this function does not have a "Time Window" or "Ramp Time" parameter because the nature of the function starts out with no action upon activation. |

## 13.4 Watt-Power-factor Function

### 13.4.1 Scope of this Function

This function modifies PF based on watts.

### 13.4.2 Requirements/Use Cases

TBD.

### 13.4.3 Description of Function

As illustrated in Figure 26, this function will use the curve method used in other functions. The curve will be defined by writing an array of X,Y point pairs which create a piece-wise linear "curve". The X-values of the array (the controlling parameter) will be the present active power output, expressed as a percentage of maximum nameplate active power output (Wmax). The Y- values of the array (controlled parameter) will be the power factor, expressed as a signed value greater than 0 and up to 1.

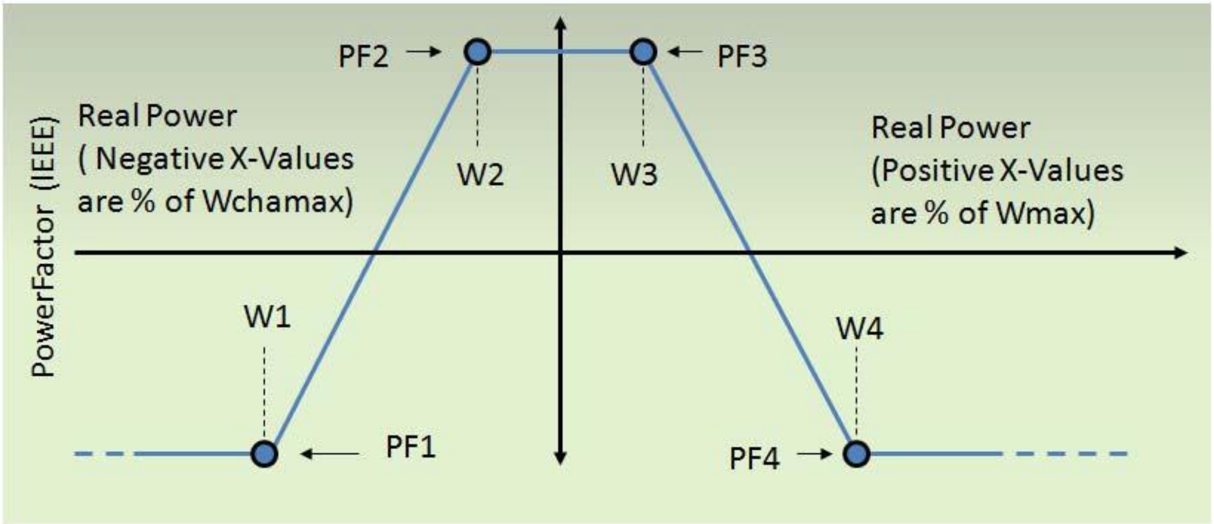


Figure 26: Example Watt – Power Factor Configuration

As illustrated, the X-values for this configuration may be signed, with negative percentage values relating to Watts received from the grid, and being percentages of the maximum charging rate, **WChaMax** and positive percentage values relating to Watts delivered to the grid, and being percentages of the maximum active power output Wmax. For devices that only produce power (to the grid), configurations may be used that only include positive X-values.

Like other functions, this function will include settings for:

- **Time_window**: a time window over which a random delay will be applied prior to activating this function after the command is received or scheduled to take effect.
- **Ramp_time**: a time over which this function gradually takes effect, once the time-window is past
- **Time_out**: a time after which this function expires.

This function is mutually exclusive with the Volt-Var and other static Var curves.

## 13.5 Active Power Following Mode

### 13.5.1 Scope of this Function

This function involves the variable dispatch of energy in order to maintain the DER's active power to track the active power level of the Referenced Point. In the case of load following, the output of the DER power output rises as the consumption of the reference load rises. In the case of generation following, the power output counteracts the output of the reference generation to maintain a total steady value. The DER may apply a percentage of the Referenced Point active power level to its active power output, thus compensating only a part of that active power.

### *13.5.2* Load Following

Load following uses the DER to generate in order to follow the power consumption of a reference load. Figure 27 illustrates the concept.

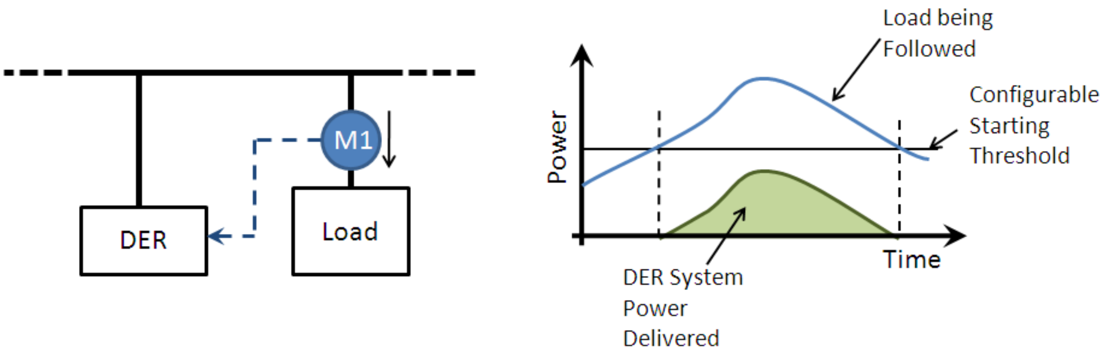


Figure 27: Example Load Following Arrangement and Waveform

As shown in the waveform to the right, this function allows for the use of a “Configurable Starting Threshold”. The DER then produces a power output that is proportional to the level of power consumed by the reference load that is above this threshold.

As indicated in the diagram to the left, this function requires that the DER has access to an indicator of the power level consumed by the reference load. The polarity of this data/signal is such that a positive value indicates power absorbed by the load.

### 13.5.3 Generation Following

Generation following is handled by the same mechanism, with the direction of power flows reversed. Generation following uses the DER to absorb power in order to follow the output of a reference generation device. Figure 28 illustrates the concept.

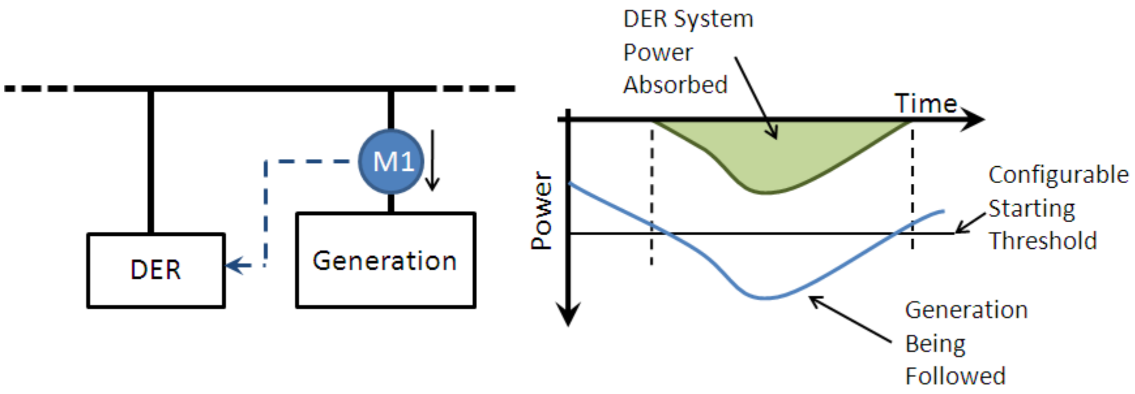


Figure 28: Example Generation Following Arrangement and Waveform

As shown in the waveform to the right, this function uses the same “Configurable Starting Threshold”, but it is now set as a negative quantity to be consistent with the polarity of the signals. The DER then absorbs power at a level that is equal to the level of power output from the reference generator that is below this threshold.

As indicated in the diagram to the left, this function requires that the DER has access to an indicator of the power level produced by the reference generator. The polarity of this data/signal is such that a negative value indicates power produced by the generator.

### *13.5.4* Allowing for Proportional Load/Generation Following

The illustrations in Figure 27 and Figure 28 show the DER following 100% of the load/generation once its magnitude exceeds the configurable threshold. This function, however, allows the “following” to be set to any proportional level by way of a percentage setting. This allows for the possibility that several DER are used collectively to follow a given load.

### *13.5.5* Settings to Manage this Function

The following settings are defined to manage this function:

Table 16: Peak Power Limiting Function Settings

| **Setting Name** | **Description** |
|---|---|
| Enable/Disable Active Power Following Mode | Enable Active Power Following mode |
| Referenced Point | Set the Active Power Following Mode Referenced Point |
| Referenced Point Active Power Level | This is the power measurement in Watts which the DER is using as the reference for load/generation following. From the perspective of this function, this quantity is read-only. As discussed previously, it is the responsibility of the DER manufacturer and user to configure and establish how the DER acquires this measurement. |
| Active Power percentage | Set the Active Power Following percentage as percent of the external active power level |
| Active Power threshold | Set threshold for starting Active Power Following |
| Active Power Following percentage | This is a configurable setting that controls the ratio by which the DER follows the load once the magnitude of the load exceeds the threshold. This setting is a unit-less percentage value.<br>As an example, consider a DER that is following load, with a present load level of 200KW, a threshold setting of 80kW and a following ratio setting of 25%. The amount of the load above the threshold is 120kW, and 25% of this is 30kW. So the output power of the DER would be 30kW. |
| Ramp Time | This is a fixed time in seconds, over which the inverter settings (Watts in this case) are to transition from their pre-setting level to their post-setting level. The purpose of this parameter is to prevent sudden changes in output as a result of the receipt of a new command. Note: this setting does not impact the rate of change of Watt output during run-time as a result of power changes at the reference point. |
| Time-Out Window | This is a time after which the setting expires. A value of zero means to never expire. After expiration, the Peak-Power Limit settings would no longer be in effect. |

## 13.6 Price or Temperature Driven Functions

### 13.6.1 Scope of this Function

These functions are intended to provide a flexible mechanism through which price or temperature may act as the controlling variable for a curve-based control function, such volt-var or frequency-watt.

### 13.6.2 Requirements/Use Cases

None captured.

### 13.6.3 Description of Function

This function is proposed to work by using a configurable array, just as with the volt-var or other array-based functions. As with the other curve-based functions, the settings would allow for a variable number of points and for hysteresis if desired.

An enumerated setting will be used to identify the X-variable (controlling parameter) of the array, whether price or temperature. The specific format and scaling of the X-variable will be implicit in the enumeration.

Likewise, the Y-variable (controlled variable) of the array will be identified by a separate enumeration, with format and scaling implicit in the enumeration. For example, the Y-values could be percentages of some maximum value, or an absolute value. If the output (Y-value) chosen is a percentage, it may require a reference value to be initialized before the curve should be enabled.

## 13.7 Peak Power Limiting Function

### 13.7.1 Scope of this Function

This proposal is for a Peak Power Limiting Function in which DER systems, particularly ESS, may be configured to provide a peak-power limiting function. This function involves the variable dispatch of energy in order to prevent the power level at some point of reference from exceeding a given threshold.

### 13.7.2 Requirements/Use Cases

Several energy storage system use cases have identified the requirement for this capability. For example:

- Large-scale energy storage units are strategically placed on distribution systems and designed to limit the power load on particular distribution system assets such as transformers. Such placement could be used to extend the useful life of products, or to defer investments in equipment upgrades.
- Small pad-mount energy storage systems could limit overloads on distribution transformers caused either by excess generation or load.

### 13.7.3 Description of Function

This proposal describes a method by which distributed energy resources (DER) may perform peak load limiting, as illustrated in Figure 29.

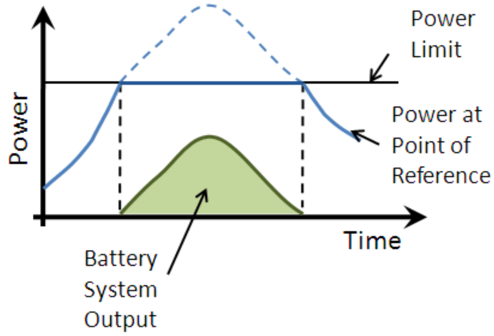


Figure 29: Example Peak Power Limiting Waveform

In this illustration, the solid blue line represents the power measurement at the selected point of reference for the function. As discussed below, this point could be physically located anywhere. Without support from the peak-power limiting function, this hypothetical power measurement would have followed the blue dashed line.

The horizontal black line represents a peak-power limit setting established at the DER by the utility or other asset owner.

The green shaded area represents the power output of the DER. This output follows the part of the blue curve that would have been above the desired power limit. The result is that the power level at the point of reference is limited to (or near to) the power limit setting.

### 13.7.3.1 *Limitations of the Function*

As with all functions, DER will operate within self-imposed limits and will protect their own components. These limits are acknowledged to vary, depending on many factors (e.g. state of maintenance, damage, temperature). In addition, it is acknowledged that the peak-limiting function is limited by present device limit settings, such as WMax.

There are also practical limits to a DER system's ability to provide peak-power limiting. Two common examples are the limitation of the power level that the DER can produce and the limitation on the total energy stored. As illustrated in Figure 30, these could result in failure to hold the power level at the reference point to the desired limit for the desired duration.

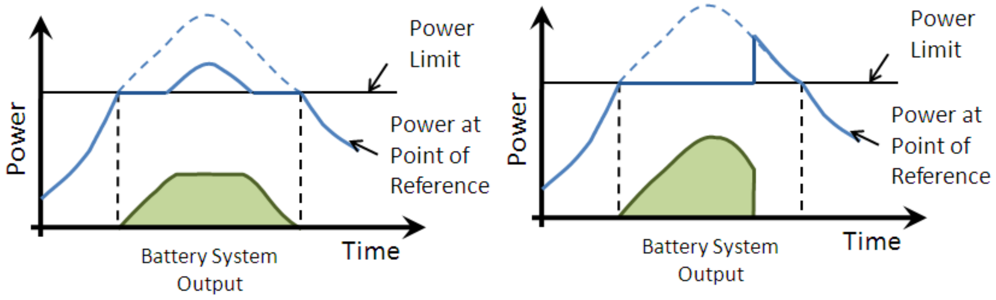


Figure 30: Examples of Practical Limitations – Watt Limit (left) and Battery Capacity Limit (right)

### 13.7.3.2 *Point of Reference for Power Limiting*

Several possibilities might exist for how a DER unit might receive the measurement data indicative of the power flow at the point of reference for the peak power limiting function. Figure 31 illustrates two such possibilities.

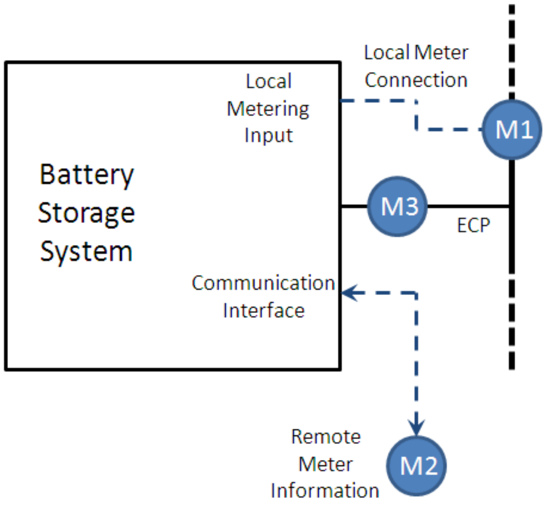


Figure 31: Example Points of Reference for Power Limiting

In this illustration, measurement M1 represents the option of an internal or local measurement that is connected to the DER unit via a local port or analog connection of some kind. M2 represents a remote measurement that could be a great distance from the DER, and providing readings via a communication interface (could be the same interface through which the DER is connected to the utility or another interface). Note that both M1 and M2 indicate the total power flow somewhere on the utility system, not the power flow of the DER itself. This function assumes that increases in the power output of the DER (M3) serve to decrease the power flow at the point of reference (M1 or M2).

It is outside the scope of this specification to dictate to the DER how the measurement data from the point of reference is to be acquired. The idea is that when a peak-power limiting function is supported and enabled, the manufacturer will have built into the product the knowledge of the proper source for the reference data and the user will have set-up and configured the product properly. Examples include:

- A product might include a local measurement that is used for peak limiting.
- A product might use a local communication port to interface with a nearby reference measurement for peak limiting.
- A product might use a local analog input to represent the reference measurement.
- A product might be designed to receive (pulled or pushed) reference measurement from a remote system via the standard communication interface.

#### 13.7.3.3 *Settings to Manage this Function*

The following settings are defined to manage this function:

Table 17: Peak Power Limiting Function Settings

| Setting Name | Description |
|---|---|
| Enable/Disable Peak Power Limit Mode | This is a Boolean that makes the peak power limiting mode active or inactive. |
| Peak Power Limit | This is the target power level limit, expressed in Watts. |

| Setting Name | Description |
|---|---|
| Reference Point Power Level | This is the power measurement in Watts which the DER is using as the reference for peak power limiting. From the perspective of this function, this quantity is read-only. As discussed previously, it is the responsibility of the DER manufacturer and user to configure and establish how the DER acquires this measurement. |
| Time Window | This is a window of time over which the inverter randomly delays before beginning execution of the command. For example, an inverter given a new Peak Power Limit configuration and a Time-Window of 60 seconds would wait a random time between 0 and 60 seconds before beginning to put the new settings into affect. The purpose of this parameter is to avoid large numbers of devices from simultaneously changing state if addressed in groups. |
| Ramp Time | This is a fixed time in seconds, over which the inverter settings (Watts in this case) are to transition from their pre-setting level to their post-setting level. The purpose of this parameter is to prevent sudden changes in output as a result of the receipt of a new command. Note: this setting does not impact the rate of change of Watt output during run-time as a result of power changes at the reference point. |
| Time-Out Window | This is a time after which the setting expires. A value of zero means to never expire. After expiration, the Peak-Power Limit settings would no longer be in effect. |

## 13.8 Price-Based Active Power Function

### 13.8.1 Scope of this Function

This function provides a mechanism through which ESSs may be informed of the price of energy so that they may manage charging and discharging accordingly. The ESS responds to this pricing signal according to preferences that set by the ESS owner/operator.

### 13.8.2 Requirements/Use Cases

In addition to direct settings for charging and discharging storage, utilities and storage system providers indicated a requirement for a mode in which the ESS manages its own charging and discharging. The idea for this function is that the storage system is provided with a signal indicative of the price (or value) of energy. The storage system then manages its own decisions about when to charge and discharge, and at what levels.

This kind of autonomous approach allows that the storage system might be taking into account a range of owner preferences and settings, such as considerations of battery life expectancy, anticipation of bad weather /outage, and predictions regarding real-time energy price swings. It enables battery system providers to develop innovative learning algorithms and predictive algorithms to optimize asset value for the owner rather than leaving these algorithms to another entity that may not understand the battery system's capabilities and limitations as well.

### 13.8.3 Description of Function

#### *13.8.3.1 General ESS Settings*

The price-based charge/discharge function will utilize the same general ESS settings identified in the direct charge/discharge function (i.e. only one set of these settings will exist in the unit). This includes Maximum

Intermittency Ramp Rate, Minimum Reserve for Storage, Maximum Storage Charge Rate, and Maximum Storage Discharge Rate.

#### 13.8.3.2 Price-Based Charge Discharge Mode

This function provides the ESS with energy price information. It is acknowledged that in some scenarios this price information could actually be an arbitrary "relative price indicator" or "energy value indicator", according to the arrangement between the entity generating the signal and the storage system owner.

This function be supported by the following information:

- **Activate Price-Based Charge/Discharge Management Mode:** a Boolean that activates the price-based charge/discharge mode (e.g. the storage system is managing based on the price signal, possibly incorporating its history, and forward-looking schedules, if provided. 1 = Price- Based C/D Mode is Active, 0 = Not active.
- **Set Price:** a setting of the price (or abstract energy value). The scaling of this value will be determined by the particular communication protocol mapping.
- **Present Price:** a query to read the present price setting.
- **Randomization Time Window:** a time in seconds, over which the DER randomly delays prior to beginning to put a new price setting into effect. The purpose of this setting is to allow multiple systems to be managed using a single broadcast or multicast message, while avoiding simultaneous responses from each device.
- **Reversion Timeout:** a time in seconds, after which a new price signal is no longer valid. A DER will return to its default behavior (typically an idle state). Reversion Timeout = 0 means that there is no timeout.
- **Ramp Time:** a time in seconds, over which the DER linearly varies its charge or discharge levels in response to a price change. The purpose of this setting is to avoid sudden or abrupt changes in energy input/output at step changes in price.

#### 13.8.3.3 Price Schedules

In addition to an immediate price setting (i.e. the price now), a schedule can be used to provide ESSs with a forward-looking view of price. The use of schedules would allow the "Price" parameter defined in the setting above to be scheduled relative to time. Schedules will allow for daily, weekly, or seasonal recurrence (looping).

For some products, price-based management might not be possible without a forward-looking schedule. These might support a fixed rate structure such as Time-Of-Use, but not Real Time Pricing. Other products could include adaptive/learning algorithms that monitor the history of the price information they have received and manage based on that history.

This function will utilize the existing scheduling mechanisms that exist in most communication protocols, so no attempt will be made here to establish a new scheduling mechanism. At transition points in price schedules, the "Ramp Time" and "Randomization Time Window" settings apply, in order to prevent abrupt transitions.

## 13.9 Coordinated Charge/Discharge Management Function

### 13.9.1 Scope of this Function

This function identifies a set of quantities that can be used to enable the management of ESS to be coordinated with the local needs of the storage users in terms of target charge level and schedule. This function enables the separately-described direct charge/discharge function to be handled more intelligently, ensuring that the storage system achieves a target state of charge by a specified time.

The primary use of this function is to manage the charging of Electric Vehicles (EVs) by determining the most cost-effective charging rates and charging time-of-day while ensuring the EV is charged to the user's required state of charge by the time the user needs the EV. However any ESS that is expected to meet local user requirements while still actively participating in grid activities can utilize this function. For instance, this function could also be useful with a Community Energy Storage (CES) unit that may need to be fully charged by the time that a severe storm is forecast to arrive in the service area.

### 13.9.2 Requirements/Use Cases

The separately defined "direct charge/discharge" function only allows a controlling entity to directly manage the power flow of a storage system as bounded by being fully charged or discharged to a minimum reserve level. In such a case, it is assumed by the controlling entity that it is acceptable to terminate a session with the storage system depleted to its minimum reserve level and that any recharging will be a self-directed activity conducted by the storage system after it is released.

This could be a problem if the storage system must achieve a target state of charge by a specified time and there is not enough time to complete unrestricted charging from the minimum reserve level beginning at the time of release by the controlling entity. The storage system could either be left with insufficient charge to perform needed tasks or it might abruptly disengage early from the controlling entity and revert to charging to meet its own requirements. This coordinated charge/discharge management is intended to help avoid such circumstances.

### 13.9.3 Description of Function

#### *13.9.3.1 Parameters from the Direct Charge/Discharge Function*

This coordinated charge/discharge function builds on the direct charge/discharge function. The command structure is unchanged from that of the direct charge/discharge function. The following parameters described in the Charge/Discharge function are also used in relation to this function:

- Minimum Reserve for Storage
- Set Maximum Storage Charge Rate (WChaMax)
- Set Maximum Storage Discharge Rate (WMax)
- Randomization Time Window
- Reversion Timeout
- Ramp Time
- Read Charge/Discharge Rate
- Set Charge/Discharge Rate
- Activate Direct Charge/Discharge Management Mode

### 13.9.3.2 *Time-based Charging Model*

The charging model for this function is based on the ESS being authorized by the controlling entity to engage in unrestricted charging at up to 100% of its maximum charging rate (WMaxStoCh). The model is shown in Figure 32 and parameters are defined below. Not all of the parameters are shown in the figure. The figure shows a representative charging profile of power versus time. The area under the curve, shown in green, is the total energy remaining to be transferred to the system from the grid at a specific time of reference. It is not just the energy stored in the system and it includes losses.

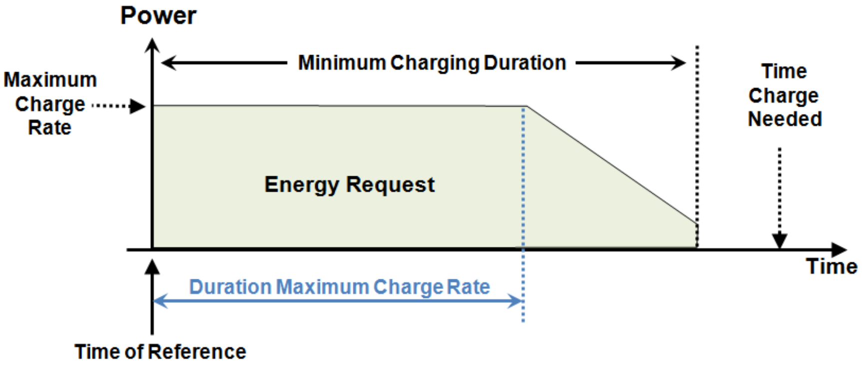


Figure 32: Storage System Model: Time-Base

## *13.9.4* Duration at Maximum Charging and Discharging Rates

To support this function, the reference charging and discharging power limit curves for a storage system are set forth, as illustrated in Figure 33. The discharging power limit is shown in blue on top and the charging power limit is shown in red on the bottom. The defined maximums represent levels that can be sustained across a broad range of SOC. The example profile shown identifies a certain SOC below which the DER can no longer sustain discharging at the Maximum Discharge Rate, and the discharge rate slows. Likewise, it identifies a certain SOC, above which the DER can no longer sustain charging at the Maximum Charge Rate. Such limitations are possible in practice, and while not passed across the communication interface, would be known to the storage system and reflected in the duration parameters that it reports.

These parameters are typically known to the DER by design, but may not be known by other entities that manage the DER. The shaded blue area represents the present energy in the storage system that is available for production at the Maximum Discharge Rate. Likewise, the shaded red area represents the capacity of the DER to store additional energy at the Maximum Charge Rate. As illustrated, this reference profile recognizes that more energy might be available for either charge or discharge, but not at the maximum charge/discharge rates.

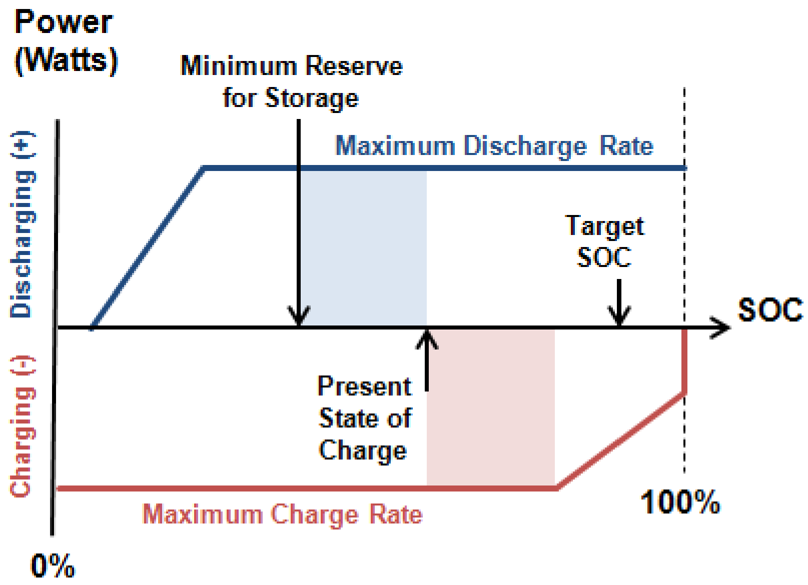


Figure 33: Storage System Model: SOC-Base

This function results in the following parameters in an ESS. In the event that coordinated charge/discharge management is needed (e.g. there is a local need for a certain target charge at a certain time) these parameters are relevant.

Table 18: Parameters for Coordinated Battery Management

| Name | Description |
|---|---|
| Target State of Charge (read or write) | This parameter represents the target state of charge that the system is expected to achieve, as a percentage of the usable capacity.<br>This quantity may be:<br>Read-from the ESS, as in cases where the target state of charge is determined locally, such as when an electric vehicle is set locally to require a certain charge by a certain time.<br>Written-to the ESS, as in cases where the target state of charge is determined by a remote managing entity, such as when a utility is informing community energy storage systems to be prepared with a certain storage level by the time that a storm is expected in the area. |
| Time Charge Needed (read or write) | This parameter represents the time by which the storage system must reach the target SOC. This quantity may be read-from, or written-to the ESS as described in the examples given in the “Target State of Charge” parameter description.<br>Setting the value to that of a distant date would prevent any conflict which could cause the ESS to disengage and revert to charging at the Maximum Charge Rate. |
| Energy Request (read only) | This parameter represents the amount of energy (Watt-hours) that must be transferred from the grid to the charger to move the SOC from the value at the specific time of reference to the target SOC. This quantity is calculated by the ESS and must be updated as the SOC changes during charging or discharging. As possible, the calculation shall account for changes in usable capacity based on temperature, cell equalization, age, and other factors, charger efficiency, and parasitic loads (such as cooling systems). |

| Name | Description |
|---|---|
| Minimum Charging Duration<br>(read only) | This parameter represents the minimum duration (seconds) to move from the SOC at the time of reference to the target SOC. This assumes that the ESS is able to charge at 100% of the Maximum Charge Rate (WMaxStoCh). This parameter is calculated by the ESS and must be updated as the SOC changes during charging or discharging. The calculation shall take into account all charging profile characteristics, such as a decrease in charging rate as 100% SOC is reached.. |
| Time of Reference (read only) | This parameter identifies the time that the SOC is measured or computed by the storage system and is the basis for the Energy Request, Minimum Charging Duration, and other parameters. This parameter may be useful to a controlling entity to correct for any delays between measurement of SOC by the storage system and use of the calculated parameters by the controlling entity to aid in managing the charging and discharging of the ESS. |
| Duration at Maximum Charge Rate<br>(read only) | This parameter identifies the duration that energy can be stored at the Maximum Charge Rate. This duration is calculated by the storage system based on the available capacity to absorb energy to the SOC above which the maximum charging rate can no longer be sustained. This calculation shall account for losses.<br>In the event that "Time Charge Needed" is reached before reaching the SOC limit for Maximum Charge Rate, then this duration parameter is determined by the "Time Charge Needed". In effect, the energy that can be stored from the grid is the product of the Duration at Maximum Charge Rate and the Maximum Charge Rate. |
| Duration Maximum Discharge Rate<br>(read only) | This parameter identifies the duration that energy can be delivered at the Maximum Discharge Rate. This duration is calculated by the storage system based on the available capacity to discharge to the "Minimum Reserve for Storage" or the SOC below which the maximum discharging rate can no longer be sustained (whichever is greater). This calculation shall account for losses.<br>In effect, the energy that can be delivered to the grid is the product of the<br>Duration at Maximum Discharge Rate and the Maximum Discharge Rate.<br>This discharge duration may be further limited by a target-charge requirement, if there is not sufficient time to discharge for this duration and then successfully recharge to the target SOC by Time Charge Needed.<br>The storage system uses Energy Request, Minimum Charging Duration, and Time Charge Needed as part of the computation of this parameter. |

The Duration at Maximum Charge Rate and the Duration at Maximum Discharge Rate are key parameters that the controlling entity can use to plan storage DER management. The charging model constraints are embedded in the calculation of these two parameters. At any time of reference these parameters can be recalculated and read by a controlling entity. In this way, the controlling entity may know from the Duration at Maximum Discharge Rate how much energy is available to the grid from the storage system at the Maximum Discharge Rate.

The slack time in this example charging solution is provided by the difference between the Time Charge Needed less the Minimum Charging Duration and the Time of Reference. The slack time can be used as an additional way of planning use of the storage system.

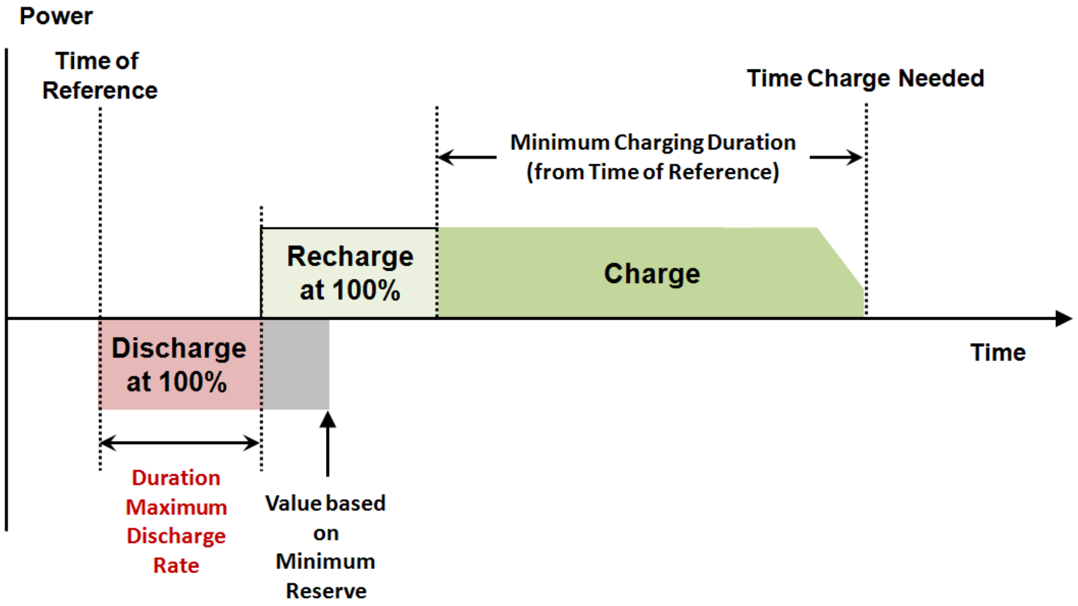


Figure 34: Example of Using the Duration at Maximum Discharge Rate

The **Target State of Charge** and **Time Charge Needed** parameters could result in a DER overriding other settings or modes affecting charging and discharging. This is true regardless of whether these parameters are set remotely or determined locally. This depends on the design and purpose of the DER, as to how it prioritizes achieving the target SOC at the specified time over following a power set-point. This DER default behavior may be selectable as part of an enrollment process for a specific application.

For example, an electric vehicle may prioritize its need to achieve a target SOC by its scheduled departure time. If a utility requests a fixed Charge Rate that would result in the vehicle being fully charged at 11:00 but the owner of the vehicle locally requested a full charge by 8:00, the electric vehicle would revert to charging at its maximum rate at the latest time needed to achieve that objective. The utility would know this could happen when remaining duration until the Time Charge Needed approaches the Minimum Charging Duration – so there would be no surprise.

This could also occur if the storage asset is completely managed remotely by the utility; for instance if the utility programmed a schedule in the inverter to discharge at a fixed rate for four hours, but during the second hour an operator changed the Target State of Charge such that it would require a reversion to charging at max charging rate after one more hour of discharging, the inverter would switch to charging at maximum rate in one hour.

As shown in these examples, a reversion by a storage DER to charging at maximum rate could occur if there becomes a conflict between continuing operation at the current power setpoint and the ability to achieve the Target SOC in the time remaining until the Time Charge Needed.

However, the reversion behavior can be defeated by setting the Time Charge Needed to a distant time (e.g. one year out, exact method to be defined by the protocol mapping), or whatever which eliminates any conflict.