California Energy Commission

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California Public Utilities Commission

Recommendations for Requirements for SIWG Phase 3 Functions

Draft!

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1. Scope, Background, and Recommendations

1.1 Scope of this Document

This document covers the Smart Inverter Working Group (SIWG) Phase 3 Distributed Energy Resource (DER) functions that were rated as highest priority by the California IOUs. The DER systems included in this effort are inverter-based generators, including energy storage systems (ESS) for both discharging and charging. Explicitly excluded are controllable loads other than those associated with ESS. It is understood that Rule 21 does not cover "loads" and that the charging cycle of ESS could be seen as a load, but ESS capabilities and functions must be discussed as a whole, included both charging/discharging. The issue of what Rule and what procedure will be used to address ESS will therefore be left up to the CPUC.

Some of those functions consist of variations of a base function, but are different enough to be described in its own section. The Phase 3 list of functions includes:

- Monitor DER Status and Output: Provide status and measurements on current energy and ancillary services (Section 3)
- Command DER to Connect or Disconnect: Support direct command to disconnect or reconnect (Section 4)
- Limit Maximum Real Power: Limit maximum real power output at an ECP or the PCC upon a direct command from the utility (Section 5)
- Set Real Power: Set actual real power output at the ECP or export/import level at the PCC or at some virtual point (Section 6)
  - Set Energy Storage charge and discharge rates: a variation of the set real power function (Section 7)
  - Load and generation following: a variation of the set real power function (Section 8)
  - Real power smoothing: a variation on load and generation following (Section 9)
  - Set Storage Ramp Rate: Apply ramp rates to the charging and discharging of energy storage systems (similar to Phase 1 Set Ramp Rates)
- Frequency-Watt: Counteract frequency excursions beyond normal limits by decreasing or increasing real power (Section 10)
  - Storage Frequency-Watt: Vary active power to counter frequency changes (Section 10)
- Voltage-Watt: Modify real power output autonomously in response to local voltage variations (Section 11)
  - Dynamic Volt-Watt provides a voltage stabilizing function (Section 12)
- Dynamic Reactive Current Support: Counteract voltage excursions beyond normal limits by providing dynamic current support (Section 13)
- Scheduling settings and modes (Section 14)
  - Schedule Storage: Set or schedule the storage of energy for later delivery, indicating time to start charging and discharging (e.g. charging an Electric Vehicle), charging and discharging rate and/or "EV charge-by" time.

- Schedule output at PCC: Schedule actual or maximum real power output at specific times
- Schedule DER Functions: Schedule real power and ancillary service outputs
- FDEMS or Aggregator provides generation and storage schedules: Provide schedules to utilities or others

• DER Functions Seen as "Also Important" to DER Integrators and Other Third Parties (Section 15)

The DER functions seen as having some importance by aggregators, integrators, manufacturers, and consultants, but not included in the "utility high importance list" are listed in Section 15. Additional functions already described in the EPRI document are included in Section 16.

1.2 Use of Parameters to Help Describe 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 provide one means for clearly and explicitly describing the functions.

However, these parameters can also be used for external parties to interact with the DER functions – local or remote communications can be used to read or set these parameters. 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.

1.3 Use of EPRI Report as Input for SIWG Phase 3 Functions

The EPRI report *"Common Functions for Smart Inverters"*, Version 3, 3002002233, 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."[1]

1.4 Recommendations for How to Include Which Phase 3 Functions in Rule 21

It is expected that only a few, if any, of these Phase 3 functions will be mandated to be implemented by all inverter-based DER systems in Rule 21, but it is also expected that Rule 21 will require that if they are optionally implemented, then they shall be implemented according to the requirements in this document and any referenced material, such as the updated IEEE 1547 rev.

The Mandatory or Optional recommendations for DER system capabilities to perform each Phase 3 functions are categorized in Table 1:

1. *"Capability" is mandated and enabled by default, with details in Rule 21, in the Phase 3 document, or in IEEE 1547 revision*
2. *"Capability" is mandated but not enabled by default. It may be enabled after contractual (financial) agreements are made*
3. *"Capability" is optional for being supported by all DER systems, but IF implemented, THEN it should be compliant with the Phase 3 document*

Table 1: Mandatory and Optional DER Capabilities

SIWG Phase 3 DER Functions	Capability is mandated and enabled by default	Capability is mandated but not enabled by default	Capability is optional, but IF implemented, THEN it should be compliant with the Phase 3 document
Monitor DER Status and Output: (Section 3)		Yes	
Command DER to Connect or Disconnect: (Section 4)		Yes	
Limit Maximum Real Power: (Section 5)			Yes
Set Real Power: (Section 6)		Yes	
Set Energy Storage charge and discharge rates: (Section 7)		Yes (for ESS)	

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

SIWG Phase 3 DER Functions	Capability is mandated and enabled by default	Capability is mandated but not enabled by default	Capability is optional, but IF implemented, THEN it should be compliant with the Phase 3 document
Load and generation following: (Section 8)			Yes
Real power smoothing: (Section 9)			Yes
Set Storage Ramp Rates:			Yes (for ESS)
Frequency-Watt: (Section 10)		Yes	
Storage Frequency-Watt: (Section 10)		Yes (for ESS)	
Voltage-Watt: (Section 11)		Yes	
Dynamic Volt-Watt (Section 12)			Yes
Dynamic Reactive Current Support: (Section 13)		Yes	
Scheduling settings and modes (Section 14)			Yes

2. Basic Device Settings and Limits

2.1 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 2 are defined as illustrated in Figure 1.

Table 2: Basic Power and Nameplate Settings

Name	Description
WMax	The maximum real 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 real 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.

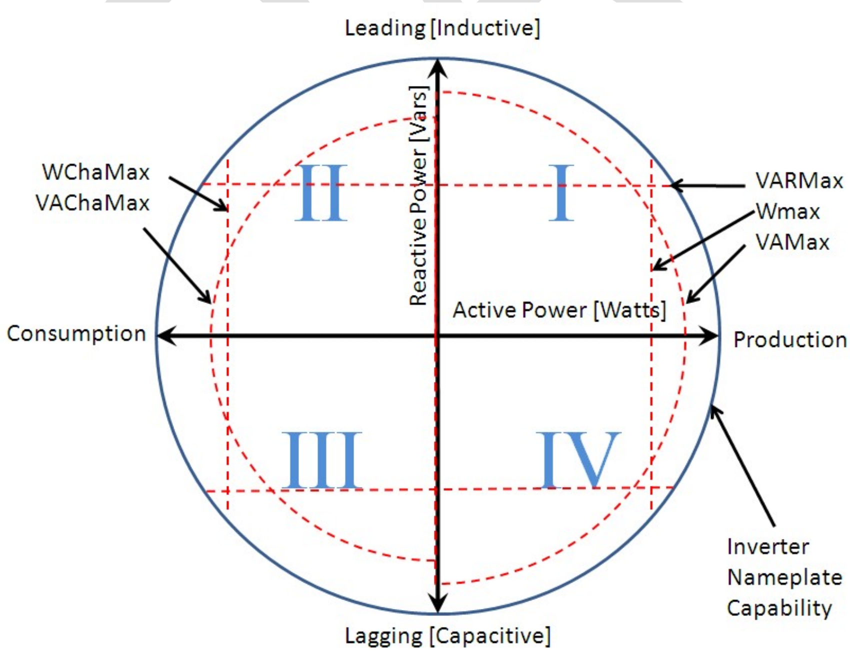

Figure 1: Basic Power Settings Illustration

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,

2.2 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 3 and illustrated in .

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 3: 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 dynamically determined.

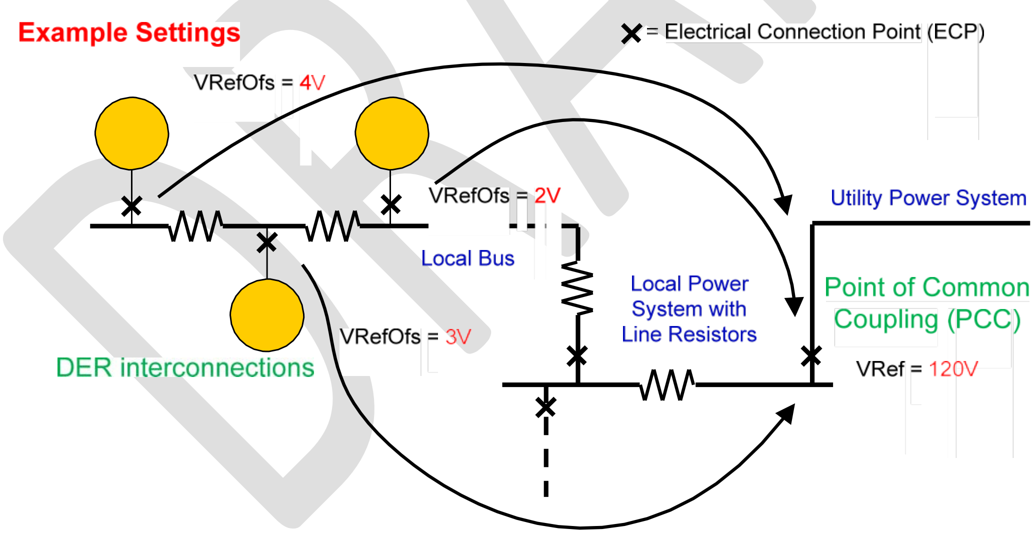

Figure 2: Offset Voltage Illustration

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:

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

2.3 Real 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 real 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. WGra is defined as a percentage of WMax per second.

Table 4: Real Power Ramp Rate Setting

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

3. Monitor DER Status and Output through Communications

Many functions require or are enhanced through the use of communications to monitor the status and output of the DER system either periodically, on significant change of a value, or upon request. The SIWG Phase 2 has defined the basic communication requirements, the default protocol, and most of the operational requirements, while Phase 3 is identifying additional mode parameters for the Phase 3 functions.

3.1 Monitoring Data Items

In the EPRI document, the data items in Table 5 are identified as (optionally) important to effective operations. These may be useful for the Phase 2 effort that is defining the communication requirements.

Table 5: Data Status and Output from DER Systems

Status Point	Description
Primary Information	
Connected time	Total time (since commissioning) that the DER has been connected to the power system
Operating time	Total time (since commissioning) that the DER has been operating
Connect/disconnect switch status	Whether or not the device is currently connected at its ECP
PV present	Yes this DER site includes PV / No it does not
Storage present	Yes this site includes storage / No it does not
Var capability present	Yes this DER can provide reactive power /No it cannot
Current Operating Mode	Identity of mode or function that the PV/Storage is in, including “owner mode” (details according to the specific protocol used, for example, an enumeration with range reserved for vendor proprietary modes)
Detailed Information	

Status Point	Description
Inverter status	Inverter is switched on (operating), off (not able to operate), or in stand-by mode (capable of operating but currently not operating)
DC Current level available for operation	Indicates whether or not there is sufficient DC current to allow operation. – Value, not yes/no
DC Voltage	See battery charge/discharge functions
Local/Remote control mode	Inverter is under local control or can be remotely controlled
Real power setpoint	Value of the real power setpoint
Reactive power setpoint	Value of the output reactive power setpoint
Power factor setpoint	Value of the power factor setpoint as angle
Nominal frequency setpoint	Value of the frequency setpoint
Type of connection point	An enumeration – detailed by the particular protocol mapping. To include: unknown, DER to local load, DER to local EPS, local EPS with load to area EPS, local EPS w/o load to area EPS, other
Type of circuit phases	An enumeration – detailed by the particular protocol mapping. To include: unknown, single phase, 3-phase, delta, wye, wye-grounded,
Energy/Power Measurements	
Inverter active power output	Present real power output level (Watts). This is an instantaneous (minimal averaging) reading.
Inverter reactive output	Present reactive power output level (Vars, leading or lagging). This is a signed quantity.
Power Factor	Power factor at the connection point
Present line frequency	The present frequency of the power system
Active power at the ECP	Active power at the PCC
Reactive power at the ECP	Reactive power at the PCC
Phase to ground voltages	Voltage values per phase
Voltage angles	Angle measurements of each phase
Power factor	Power factor value, plus high and low limits
Real energy generated	Real energy supplied to grid (Watt-hours)
Real energy received	Real energy received (demanded) from grid (Watt-hours)
Reactive energy supplied	Reactive energy supplied to grid (Var-hours)
Reactive energy received	Reactive energy received (demanded) from grid (Var-hours)
Energy storage Status (If Storage is Included in System)	
Capacity rating	The useable capacity of the battery, maximum charge minus minimum charge from a technology capability perspective (Watt-hours)
State of charge	Currently available energy, as a percent of the capacity rating (percentage)
Storage reserve	A percentage of the capacity rating that is reserved for ancillary purposes. For example, a battery system might be charged and discharged daily, but be configured to always reserve 30% of capacity for customer backup in the event of an outage.
Available energy	State of charge minus storage reserve (Watt-hours) See storage settings section for definition of “storage reserve”

Status Point	Description
Maximum battery charge rate	The maximum rate of energy transfer into the storage device. (Watts) This establishes the reference for the charge percentage settings in function
Maximum battery discharge rate	The maximum rate of energy transfer out of the storage device (Watts) This establishes the reference for the discharge percentage settings in function
Internal battery voltage	Internal battery voltage
DC inverter power input	Used for determining efficiency of inverter
Nameplate and Configuration Settings Information	
Manufacturer name	Text string
Model	Text string
Serial number	Text string
Inverter nameplate power rating	The continuous power output capability of the inverter (Watts)
Inverter nameplate VA rating	The continuous Volt-Amp capability of the inverter (VA)
Inverter nameplate Var rating	Maximum continuous Var capability of the inverter (Var)
Time resolution	Time resolution and precision
Source of time synchronization	Text string

3.2 Roles and Operating States Data

There are multiple ways that an electric utility may control a grid connected DER system, while different utilities have different operating procedures and contractual arrangements. Therefore the operating model must be flexible enough to include these differences, while still maintaining interoperability. One method for providing this flexibility is to establish different roles for the various users and to provide parameters that can be used to link these roles to different “rights and permissions”. In addition, the DER will include different operational states that these “rights and permissions” can affect, and can (optionally) use Areas of Responsibility (AoR) to constrain roles to certain times of day or the week or to impose other sorts of constraints.

Figure 3 provides a generic overview of Role-Based Access Control (RBAC), with a list of generic roles, the basic permissions that can be assigned, and the generic operational rights.

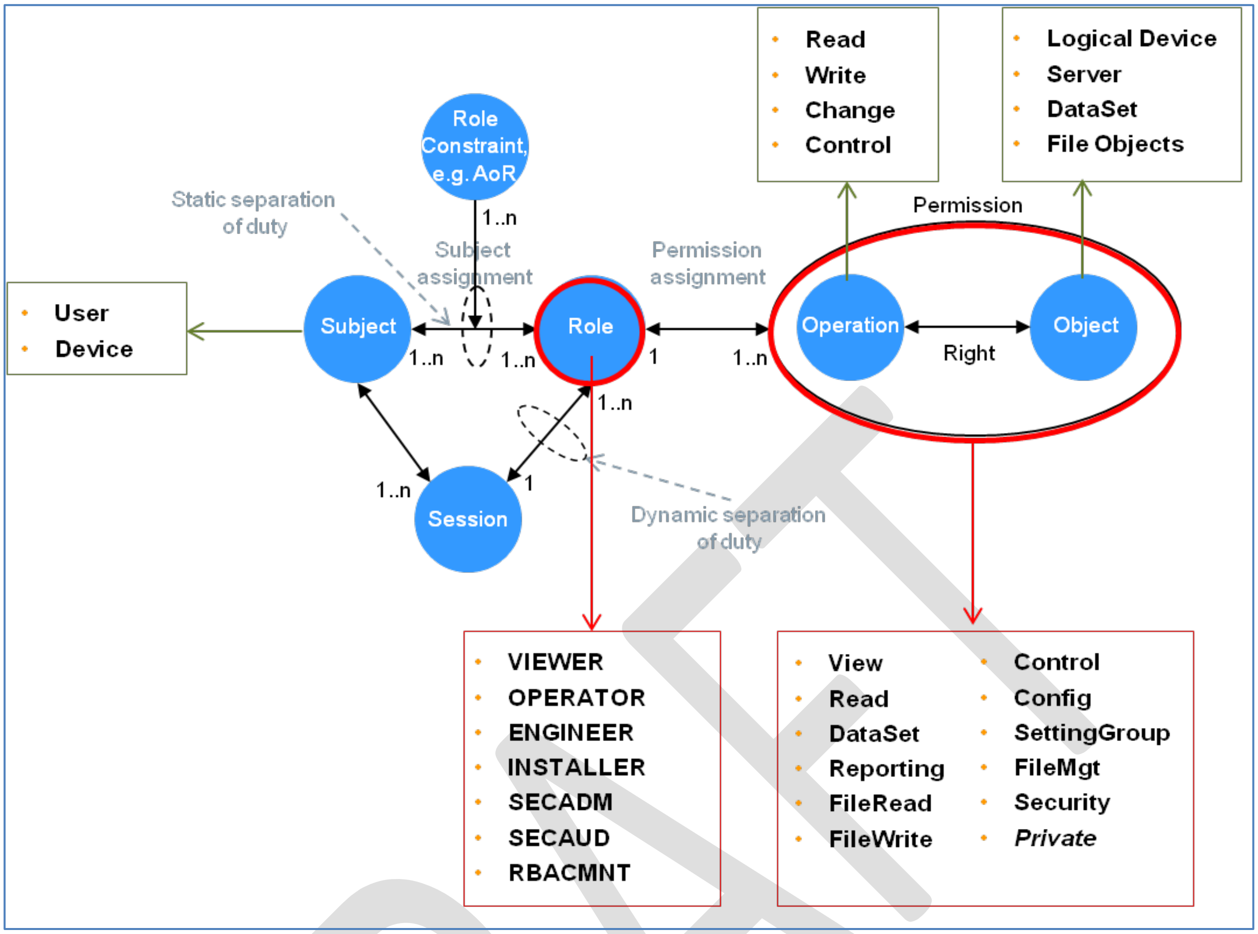

Figure 3: Role-based Access Control and Operational States

For DER user interactions, the following roles are recommended, with additional roles permitted. Although different mechanisms may be used to assign users to roles, at a minimum login credentials shall be used during the assignment:

- Utility DER operator
- Utility DER scheduler
- On-site DER operator
- Facility DER operator
- DER maintenance personnel
- DER vendor
- Guest viewer

The DER or subsystems of the DER shall support the following recommended operational states, with additional operational states permitted:

- Normal operations (both utility and facility control are permitted)
- Facility-only operations (only facility operations are permitted)
- Under maintenance or test

- Offline (i.e. not in the other 3 operational states such as turned off or unavailable)

Default assignments of permissions to roles are shown in Table 6. In order for different implementations to assign different permissions to different roles, each of these assigned permissions should be visible (able to be monitored and/or visible locally), and should be either preset upon installation and/or modifiable through communications. Assigned permissions-to-roles will be one of four: Mandatory-Yes (M), Mandatory-No (MN), Recommended-Yes (R), Recommended-No (RN or blank).

Table 6: DER Default Assignment of Permissions to Roles

Permissions \ Role	Utility DER Operator	Facility DER Operator	Maintenance Personnel	DER Vendor	Guest Viewer
In any operational state					
• Set DER to normal operations		M			
• Set DER to facility-only operations		M			
• Set DER to maintenance/test		M	R		
• Set DER to offline		M	R	R	
• View roles and permissions	R	M	R	R	
• Modify roles and permissions		M		R	
When DER (or subsystem) is in Normal Operations					
• Monitor facility-level DER information		M	R	R	
• Monitor DER status, modes, and measurements	R	M	R	R	R
• Monitor operational logs	R	M	R	R	
• Monitor security logs		M			
• Monitor historical data (if available)	R	M			
• Monitor configuration information		M	R	R	
• Update parameters of functional modes	R	M			
• Enable functional modes	R	M			
• Disable functional modes	R	M			
• Issue disconnect command from grid	M	M	R		
• Issue connect command to grid		M			
• Issue operational control command	R	M			
• Send schedule	R	R			
• Enable schedule	R	R			
• Disable schedule	R	R			
• Add item to operational log	R	R	R		
When DER (or subsystem) is in Facility-Only Operations					
• Monitor facility-level DER information		M	R	R	
• Monitor DER status, modes, and measurements	R	M	R	R	R
• Monitor operational logs		M	R	R	

Permissions / Role	Utility DER Operator	Facility DER Operator	Maintenance Personnel	DER Vendor	Guest Viewer
• Monitor security logs		M	R		
• Monitor historical data (if available)		M	R		
• Update parameters of functional modes		M			
• Enable functional modes		M			
• Disable functional modes		M			
• Issue disconnect command from grid	M	M	R		
• Issue connect command to grid		M			
• Issue operational control command		M			
• Send schedule		R			
• Enable schedule		R			
• Disable schedule		R			
• Add item to operational log		R	R		
When DER (or subsystem) is in Maintenance/Test					
• Execute diagnostic tests			R	R	
• Monitor DER status, modes, and measurements			R	R	
• Issue test commands			R	R	
When DER (or subsystem) is Offline					
• Patch or update DER software			R	R	
• Update security measures			R	R	
• Modify configurations			R	R	

3.3 Event Logging and Reporting

3.3.1 Scope

This specification identifies a mechanism for DER systems to log and report a set of events using a standardized coding.

3.3.2 Requirements/Use Cases

A common method for event logging and reporting is a high priority requirement. Having at least a beginning set of uniform event codes and (through protocol mappings) a common way to log and report these events was considered a requirement.

3.3.3 Description of Function

All event log entries will contain (at least) the following 5 fields:

- **Date and Time Stamp:** The accuracy of this timestamp will be determined by the frequency of time synchronization and the innate precision in keeping time of the PV system, and is therefore outside the scope of this specification. Zeros can be used to pad any timestamp if the accuracy does not match the format.

- **Data Reference**: the reference to the data item that triggered the event log entry. For instance, if it is a voltage-related event, the Data reference will be to that data object. If it is a PV Mode event, the Data Reference will be to the PV Mode data object.
- **Value**: Value field of the Data reference field that is triggering the event, including commands, state changes of monitored values, quality code changes, mode setting, etc. For instance, the request to go into a specific PV mode will be logged with the Value containing the PV mode identity.
- **Event Code**: 4-part code to uniquely identify the type of event – see Table 24-1.
- **Optional Text Field**: Text of supporting information. This text will not be standardized, but can be used to provide additional details about the event.

To enable the filtering of events so that different users can select different types of events to retrieve, event "codes" are established. These event codes are based on the IEC 61968-9 (CIM for distribution) event codes, with additions as necessary to address inverter events. The Event Code standard contains many codes, with only a small fraction relevant to PV/Storage systems. The more important ones (including additional ones) are shown in Table 7 below, but different implementations may choose different sets of event types, including vendor-specific and/or implementation-specific event types.

The codes are built from 4 levels: Domain, Part, Type, and Attribute. In this Specification, four existing domains are used:

- Communications (for communication-related events)
- Grid power (for power system events)
- Device asset (for time and asset-related events)
- Security (for security-related events)

And two new domains are defined:

- PV system (for PV inverter events, as well as other PV events)
- Storage system (for storage inverter events, as well as other storage events)

In the table below, a Storage system, if separate from a PV System, would have the same event codes except for changing "PV System" to "Storage System" with a D# code of 22 instead of 21.

Various communication protocols (e.g. DNP3) approach event logging and reporting in different ways. This specification will employ those existing mechanisms, with details being identified in the protocol mapping documents.

Ideally, users will have the ability to filter requests for events from the logs by Domain, Part, Type and Attribute, so that only those events of interest may be collected. Also, it is envisioned that the communication protocols will provide for reading only new events, or those not previously reported.

Additional event log interactions could include:

- Notification if event log is almost full or completely full without having been retrieved

- Notification of an event log error

Table 7: Standard Event Codes

Domain	D#	Part	P#	Type	T#	Attribute	A#	Description
Comms	01	Messaging	19	Status	17	Success	244	Request received successfully. Value field identifies the request as a "demand response"
Comms	01	Messaging	19	Status	17	Success	244	Command received successfully. Value field identifies the command as a "Direct command"
Comms	01	Messaging	19	Status	17	Acknowledged	3	Response – acknowledgment sent
Comms	01	Messaging	19	Alarm	1	Message failed	156	Response – alarm invalid message. Value field contains type of error.
Comms	01	Network interface	23	Alarm	1	Comm. failed	32	Alarm communications error. Value field contains type of error.
PV System	21	Inverter	51	Command	6	Success	244	Action taken successfully (details are provided in Mode and Command events)
PV System	21	Inverter	51	Command	6	Failed	85	Requested action failed. Value field contains type of error.
PV System	21	Inverter	51	Command	6	Deviation	65	Action taken is a deviation from the requested action. Data Reference and Value fields contain indication of this deviation
PV System	21	Mode	22	Status	17	PV Mode	302	Inverter is in one of the PV modes, as indicated in the Value field
PV System	21	Inverter	51	Command	6	PC Command	303	Inverter responded to one of the PC commands, as indicated in the Value field
PV System	21	Inverter	51	Status	17	Limit exceeded	139	Inverter status changed due to internal control threshold exceeded. Data Reference and Value fields provide details
PV System	21	Schedule	52	Schedule change	31	Success	244	Action was successfully taken in response to the scheduled requirement
PV System	21	Schedule	52	Schedule change	31	Failed	85	Action failed in response to the scheduled requirement. Value field indicates the type of error
PV System	21	Power	26	Status	17	Power out	185	Inverter power turned off
PV System	21	Power	26	Status	17	Power on	216	Inverter power turned on
PV System	21	Power	26	Alarm	1	Power out	185	Power tripped off due to internal situation
PV System	21	Power	26	Alarm	1	DC Voltage	301	Inadequate DC bus voltage, Value field provide measured value
PV System	21	Power	26	End alarm	9	DC Voltage	301	DC bus voltage within limits. Value field provide measured value
PV System	21	Temperature	35	Alarm	1	Limit exceeded	139	Temperature limit exceeded. Value field contains type of error.
PV System	21	Temperature	35	End alarm	9	Limit exceeded	139	Returned within temperature limit. Value field contains type of error.
Grid Power	6	ECP Switch	31	Status	17	Connected	42	Switch at the ECP between inverter and the grid is connected
Grid Power	6	ECP Switch	31	Status	17	Disconnected	68	Switch at the ECP between inverter and the grid is connected
Grid Power	6	Voltage	38	Alarm	1	Limit exceeded	139	Voltage limit exceeded. Value field contains voltage measurement.

Domain	D#	Part	P#	Type	T#	Attribute	A#	Description
Grid Power	6	Voltage	38	End alarm	9	Limit exceeded	139	Returned within voltage limit. Value field contains voltage measurement.
Grid Power	6	Voltage	38	Alarm	1	Limit exceeded	139	Voltage distortion limit exceeded. Value field contains voltage distortion.
Grid Power	6	Voltage	38	End alarm	9	Limit exceeded	139	Returned within voltage distortion limit. Value field contains voltage distortion.
Grid Power	6	Current	6	Alarm	1	Limit exceeded	139	Current limit exceeded. Value field contains current measurement.
Grid Power	6	Current	6	End alarm	9	Limit exceeded	139	Returned within current limit. Value field contains current measurement.
Grid Power	6	Power quality	28	Alarm	1	Limit exceeded	139	Harmonic limit exceeded. Value field contains harmonic measurement.
Grid Power	6	Power quality	28	End alarm	9	Limit exceeded	139	Returned within harmonic limit. Value field contains harmonic measurement.
Grid Power	6	Other 1547 parameters?		Alarm	1	Limit exceeded	139	?? limit exceeded
Grid Power	6	Other 1547 parameters?		End alarm	9	Limit exceeded	139	Returned within ?? limit
Device asset	2	Logs	17	Status	17	Almost full	8	Log is almost full. Value contains percentage full.
Device asset	2	Logs	17	Alarm	1	Full	304	Log full: new events to overwrite unread events
Device asset	2	Time	36	Alarm	1	Clock failed	29	Clock failure. Value contains error information.
Device asset	2	Time	36	Alarm	1	Synch failed	252	Synchronization failed. Value contains error information
Device asset	2	Time	36	Setting	16	Synchronized	254	Synchronized. Value contains delta between new time and old time
Device asset	2	Time	36	Setting	16	Daylight adjust	254	Daylight time or Standard time adjustment. Value indicates Daylight of Standard
Device asset	2	Firmware	11	Alarm	1	Data error	52	Data error detected in firmware. Value indicates type of error

4. Connect/Disconnect Command

4.1 Scope of this Function

This function permits a utility, a facility energy management system, aggregator, or any other party to cause a DER system to connect to or to galvanically disconnect from the local and/or area EPS at its ECP.

4.2 Requirements and/or Use Cases for this Function

The purpose this function is generally for emergency situations, 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 disconnect 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 disconnect the device from the power system.
- **Grid Maintenance or Repair.** Utilities may wish to disconnect DER devices from the grid during certain repairs or maintenance.

4.3 Description of Function

This function is not the same as setting the power output to zero (cease to energize). It specifically refers to the operation of a switch device that would completely isolate the DER from the grid.

This function is not related to intentional islanding, and refers to the management of a switch that separates at the DER, leaving customers connected to the grid. In reference to the example diagram in Figure 4, this function relates to the operation of the "DER Connect/Disconnect Switch," not the "Utility Switch."

This function is assumed to be subordinate to any local safety switch operations, including a 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 reconnection of a system that was disconnected by some other means.

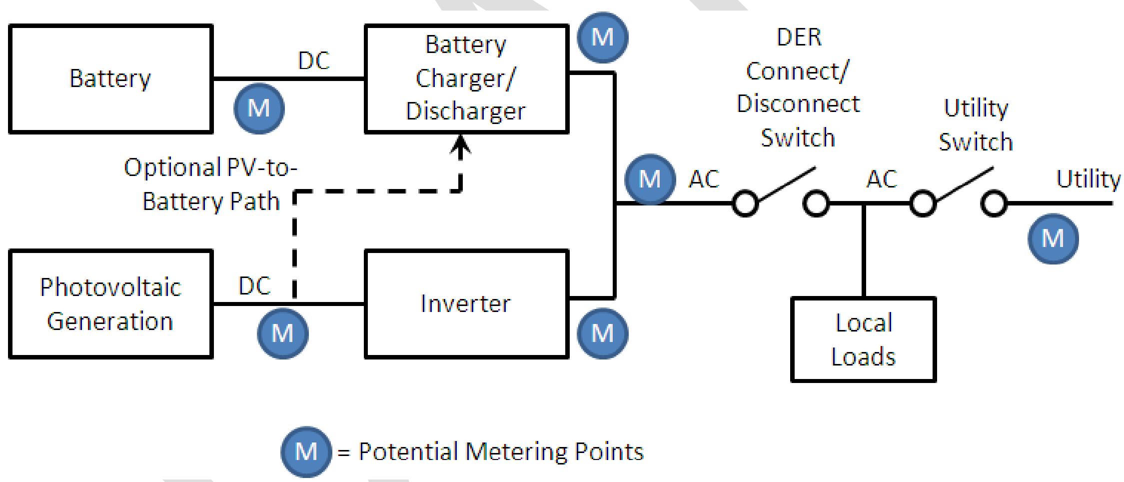

Figure 4: Example DER Diagram

This function consists of a simple "Connect" or "Disconnect" command, with optionally the monitoring of the state:

- **Set Switch State**: a command which instructs the DER interconnection switch to either open or close.
- **Monitor Switch State**: a query to read the present DER interconnection switch state (opened or closed).

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 switch operation is randomized. For example, if the Time Window" is set to 60 seconds, then the switch 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.
- **Reversion Timeout**: a time, after which a command to disconnect expires and the device reconnects. Reversion Timeout = 0 means that there is no timeout.

5. Limit Maximum Generation and Charging

5.1 Scope of this Function

This specification provides a mechanism through which the maximum generation level of one DER system or an aggregation of DER systems and load within a facility can be limited.

5.2 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.

5.3 Description of Function

5.3.1 Device Ratings

This function operates as a control, to establish an upper limit on the real power that a DER system can produce (deliver to the grid) at its ECP or, in aggregate with other DER systems and loads, at the PCC. The description herein references the basic device settings set forth in the Device Limits section of this document.

5.3.2 Maximum Generation Level Function

The maximum generation level function may either be percentage based, according to the "WMax" 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.

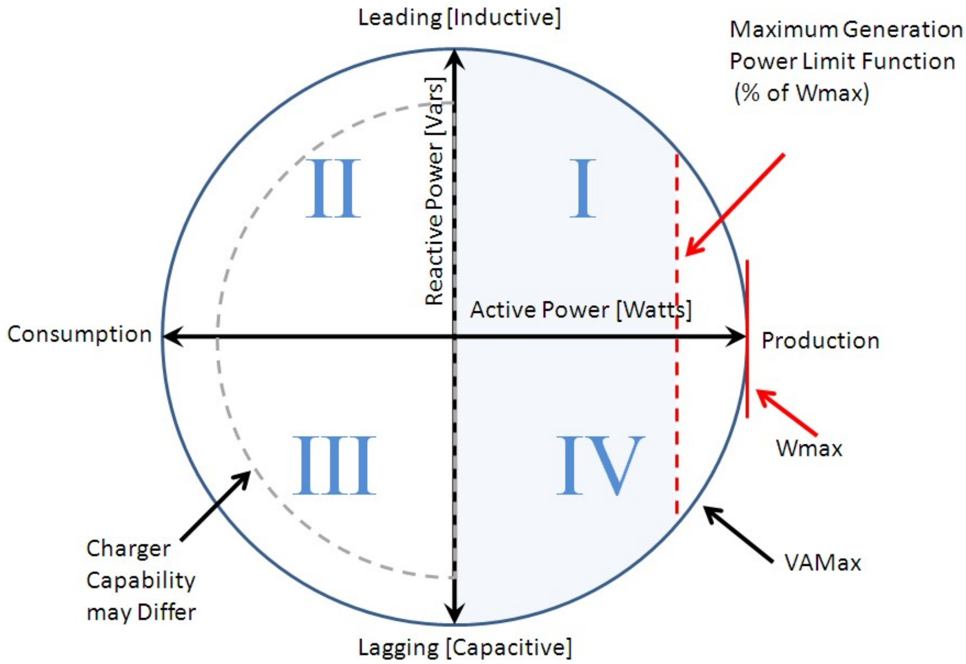

Figure 5: Example Maximum Generation Settings

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 Maximum Generation Level Setting:** a query to read the present setting as a percent of WMax of a DER system or as an absolute value at the PCC.
- **Set Maximum Generation Level:** a command to set the maximum generation level as a percent of WMax. 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).

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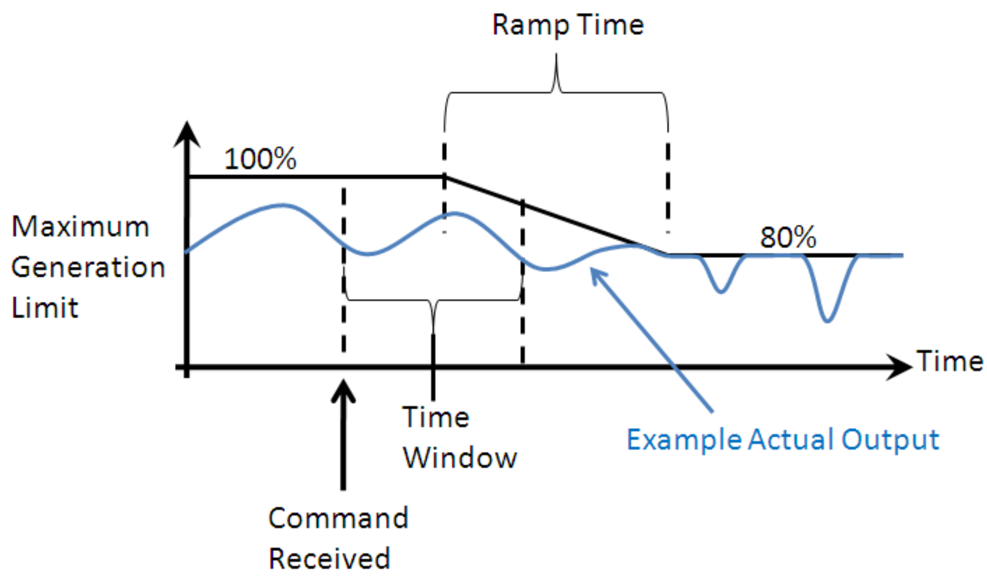

Figure 6: Example of limiting maximum generation

6. Set Real Power Output of DER

6.1 Scope of this Function

This specification provides a mechanism through which the generation level of one DER system is set at its ECP, or the total export or import level at the PCC is set for an aggregation of DER systems and load within a facility, constrained by the capabilities of the DER system or facility.

6.2 Requirements/Use Cases

Setting the output of a DER system or of a facility at its PCC permits direct control of DER generation and/or total facility demand.

6.3 Description of Function

6.3.1 Device Ratings

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

6.3.2 Real Power Output Function

The real power output function may either be percentage based, according to the "WMax" capability of the DER system, or may be an absolute value , particularly if referring to the export or import at the PCC.

7. Set Charge/Discharge Rates of ESS

7.1 Scope of this Function

This function permits the charging and discharging rates of ESS to be directly set. In addition, ramp rates can be set so that abrupt changes in charging or discharging can be avoided.

7.2 Requirements/Use Cases

This basic charge/discharge function permits ESSs to be directly managed, by issuing charge and discharge rate commands. These commands may be issued by:

- A utility that has authority to directly control an ESS
- A facility energy management system with authority to manage ESSs within the facility
- An Aggregator with authority to manage specified ESSs
- An ESS controller responding to pricing signals or other signals

7.3 Description of Function

7.3.1 General Storage System Settings

The charge/discharge function is supported by these storage-related settings:

- **Maximum Storage Charge Rate (WMaxStoCh):** The maximum power rate at which the storage unit may be charged, in Watts.
- **Maximum Storage Discharge Rate (WMaxStoDis):** The maximum power rate at which the storage unit may be discharged, in Watts.
- **Maximum Ramp Rate:** A setting for the maximum rate at which the real output power level may ramp up or down at a certain point of reference, such as the ESS's ECP or the PCC. This setting may be used to manage the effects of intermittency of local generation (e.g. variable PV) or as a means to avoid abrupt charging or discharging changes. This maximum rate must be within the maximum storage charge and discharge rates.
- **Minimum Reserve for Storage:** The minimum level to which the storage system may be discharged. This setting is expressed as a percentage of the total usable storage. For example, a setting of 50% indicates that half of the usable storage is to be reserved. This setting is <u>not</u> intended as a replacement for manufacturer-defined limits on minimum battery State Of Charge (SOC). It is intended for maintaining a minimum level of usable charge as a reservation for customer backup or other ancillary uses.

7.3.2 Direct Charge Discharge Request

A direct request is issued to the ESS to set the storage charge or discharge rate to a given value. The values will be provided as a percentage (or absolute value?), in terms of the WMaxStoDis (for discharging) and WMaxStoCh (for charging) ratings of the storage unit. It is recognized that the maximum charging rate and the maximum discharging rate may differ, such that a setting of 50% charging might result in a different power magnitude than a setting of 50% discharging. It is also understood that this is a "request" and that the actual ability of the ESS to charge or discharge will be affected by many factors, including present battery charge level, temperature, etc.

It is proposed that this function be supported by the following information exchanges:

- **Monitor Charge / Discharge Rate:** a query to read the present charge or discharge rate settings.
- **Activate Direct Charge / Discharge Management Mode:** Activate the direct charge/discharge mode (e.g. the storage system is following either direct charge/discharge requests or a schedule for the same) 1 = Direct C/D Mode is Active, 0 = Not active.
- **Set Charge / Discharge Rate:** a request to set the charge/discharge rate. This setting is provided as a percentage between +100% (discharging) and -100% (charging) or may be a specific value.
- **Randomization Time Window:** a time in seconds, over which the DER randomly delays prior to beginning to put a new charge or discharge rate setting into effect. The use of this setting is the same as with the Connect/Disconnect and other previously defined functions, although the value used for each may differ.
- **Reversion Timeout:** a time in seconds, after which a DER will return to its default charge or discharge setting (typically an idle state). Reversion Timeout = 0 means that there is no timeout.
- **Ramp Time:** a time in seconds, over which the DER linearly places the new charge or discharge setting into effect. The use of this setting is the same as with the Maximum Generation Level Function previously defined, although the value used may differ.

7.3.3 Charge/Discharge Schedules

In addition to direct (immediate) setting, a schedule may be used to manage the charging and discharging. These schedules will allow the "Charge/Discharge Rate" parameter defined in the direct function above to be scheduled relative to time. Schedules will allow for daily, weekly, or seasonal recurrence (looping).

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 charge/discharge schedules, the "Ramp Time" and "Randomization Time Window" settings apply, in order to prevent abrupt transitions.

8. Load and Generation Following Function by DER and/or ESS

8.1 Scope of this Function

This function involves the variable dispatch of energy in order to maintain the power level that tracks the level of a reference signal. 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 absorbed by the ESS increases as the output of the reference generation increases.

8.2 Requirements/Use Cases

Several ESS use cases have identified the requirement for this capability. For example:

- An ESS plant is used to counter fluctuations of a nearby PV plant to minimize changes in total energy output.
- A DER system follows the load in a facility and maintains a constant power level at the PCC.

8.3 Description of Function

This proposal describes a method by which distributed energy resources (DER) may perform the functions described in the following subsections:

8.3.1 Load Following

Load following uses the DER to generate in order to follow the power consumption of a reference load. Figure 7 illustrates the concept.

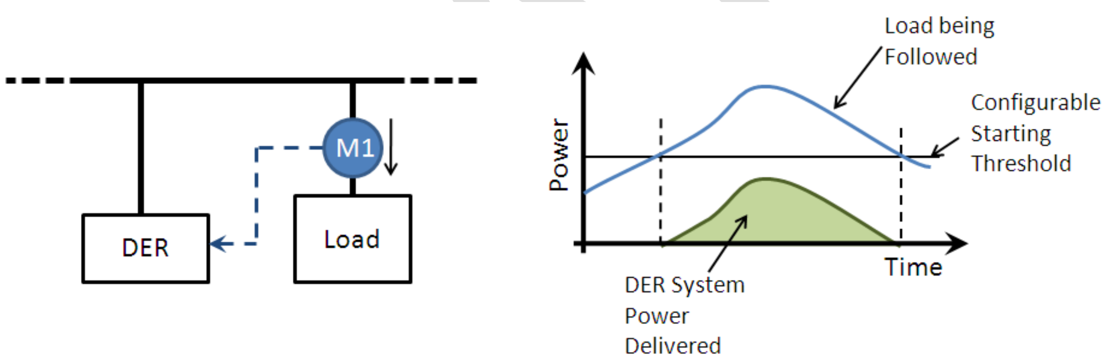

Figure 7: Example Load Following Arrangement and Waveform

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.

8.3.2 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 8 illustrates the concept.

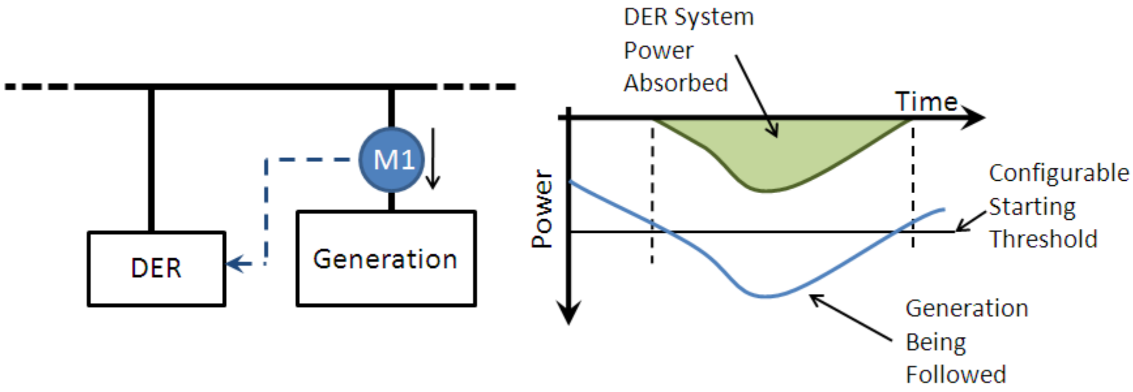

Figure 8: Example Generation Following Arrangement and Waveform

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.

8.3.3 Allowing for Proportional Load/Generation Following

The illustrations in Figure 7 and Figure 8 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.

8.3.4 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 load/generation following function is 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, a energy storage system cannot follow load or generation indefinitely, and must at some point recharge or discharge in order to continue. One way to handle this is to have other charge / discharge functions active in the background while the load/generation function is also enabled (i.e. they are not mutually exclusive). In this way, the background task could be actively managing the discharging or recharging of the storage device when the load/generation following function is idle due to the starting threshold.

Another method to handle this could include scheduling of the load/generation following modes so that regular charge/discharge commands are used at other times.

8.3.5 Point of Reference for Load/Generation Following

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 load/generation following function is supported and enabled, the manufacturer will have built into the product the knowledge of the proper source(s) 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 load/generation following.
- A product might use a local communication port to interface with a nearby reference measurement for load/generation following.
- 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.

8.3.6 Settings to Manage this Function

The following settings are defined to manage this function:

Table 8: Peak Power Limiting Function Settings

Setting Name	Description
Enable/Disable Load/Generation Following Mode	This parameter indicates whether the mode active or inactive.
Starting Watt Threshold	This is a configurable threshold, below which load/generation following does not occur. Expressed in Watts. The Starting Watt Threshold may be set to zero.
Load/Generation Following Ratio	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. 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.
Reference Point 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.
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.

9. Real Power Smoothing Function

9.1 Scope of this Function

The Real 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.

9.2 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.

9.3 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.

9.3.1 Real 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 9, 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 9 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.

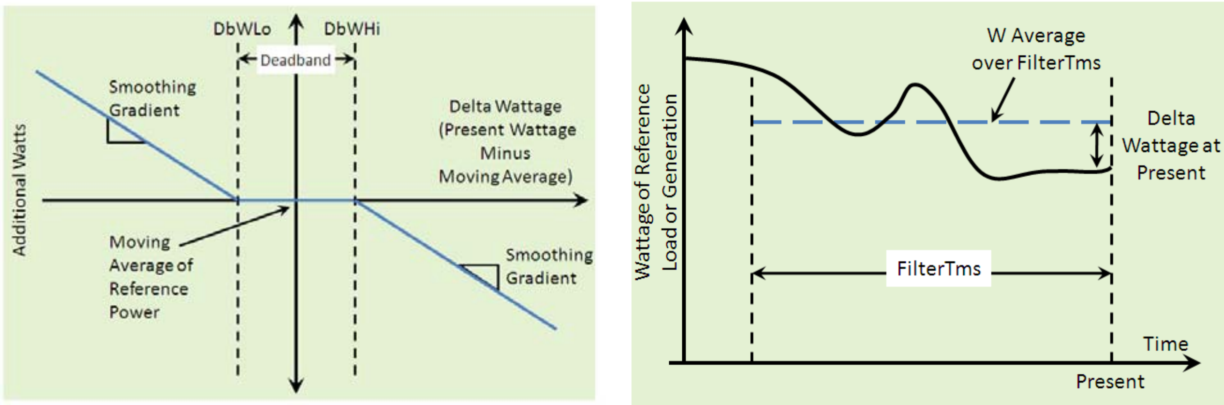

Figure 9: Smoothing Function Behavior

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 9, 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.

9.3.2 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 load/generation following and real 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, a energy storage system cannot follow load or generation indefinitely, and must at some point recharge or discharge in order to continue. Methods to handle this could include scheduling of the load/generation following modes so that regular charge/discharge commands are used at other times.

9.3.3 Settings to Manage this Function

The following settings are defined to manage this function:

Table 9: Real Power Smoothing Function Settings

Setting Name	Description
Enable/Disable Real Power Smoothing	This parameter indicates whether the function is active or inactive.

Setting Name	Description
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.

10. Frequency-Watt Function

10.1 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.

10.2 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.

10.3 Description of Function

10.3.1 Frequency-Watt Function 1

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 10 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 10: 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

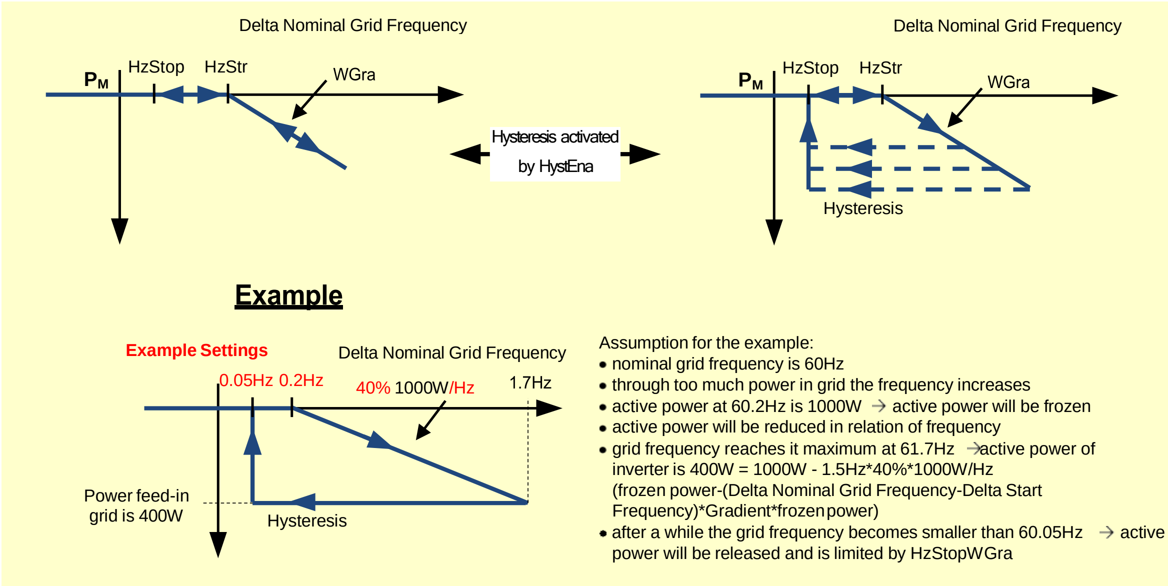

Figure 10: Frequency-Watt Function 1 Visualization

10.3.2 Frequency-Watt Function 2

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 11.

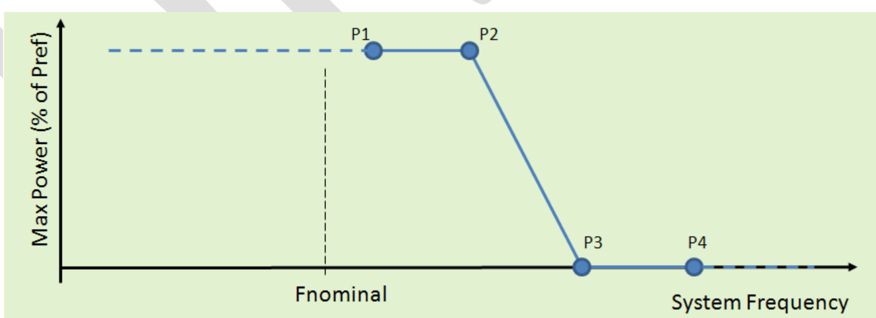

Figure 11: Example of a Basic Frequency-Watt Mode Configuration

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 real 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 12 illustrates this concept.

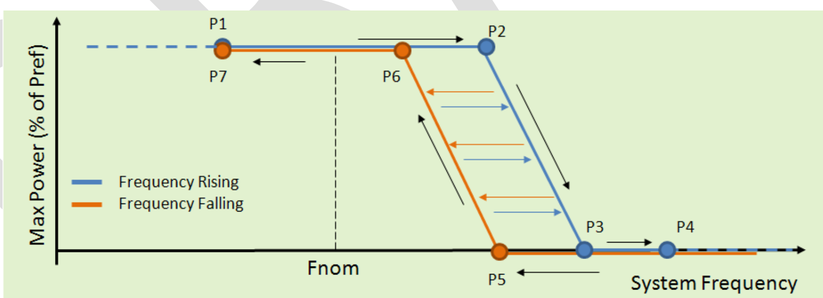

Figure 12: Example Array Settings with Hysteresis

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 13 illustrates an example of such a case.

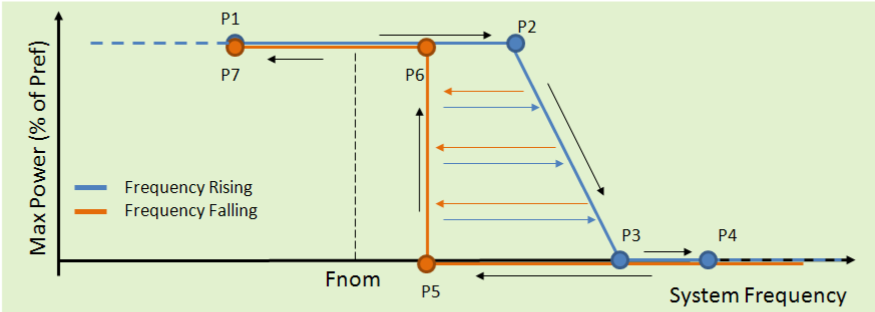

Figure 13: Example of an Asymmetrical Hysteresis Configuration

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 14 illustrates an example setting.

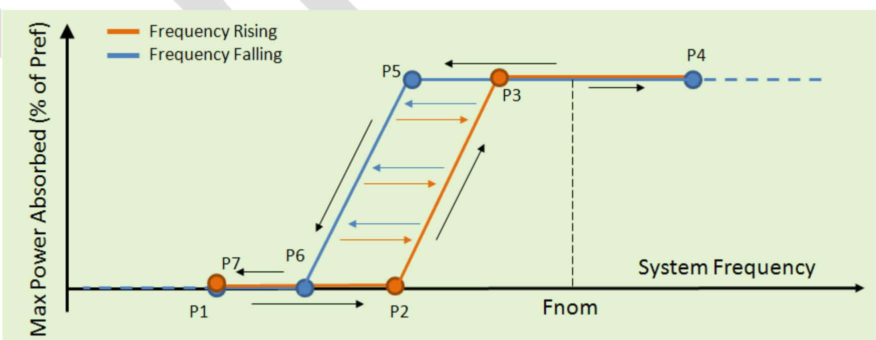

Figure 14: Example Array Configuration for Absorbed Watts vs. Frequency

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 15.

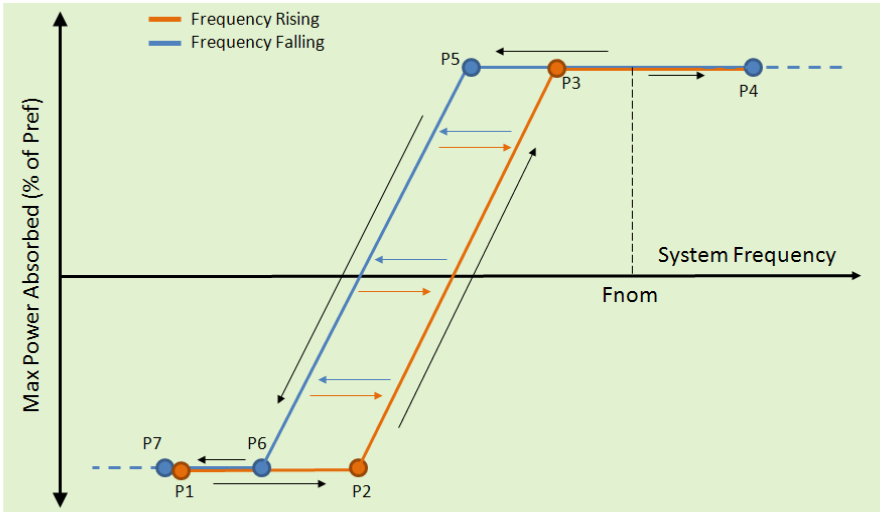

Figure 15: Example Configuration for Reversing Sign on $P_{ABSORBED}$ Limit

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.

10.3.3 Configuration Data

The resulting configuration data for this function, as described, is summarized in Figure 8.

Table 11: 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)

10.3.4 Relative Prioritization of Modes

Multiple modes which may act to limit Watt production are being defined by the Smart Inverter Communication Initiative, including the recent additions of the Volt-Watt and Frequency-Watt functions. The overall body of work will identify relative priorities for all overlapping functions.

In regards to Volt-Watt and Frequency-Watt functions, both of which may be simultaneously active, the one that indicates the lower max-power level (closest to zero) at any point in time is the one that establishes the limit at that time.

11. Volt-Watt Function

11.1 Scope of this Function

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

11.2 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.

11.3 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 16 illustrates the concept.

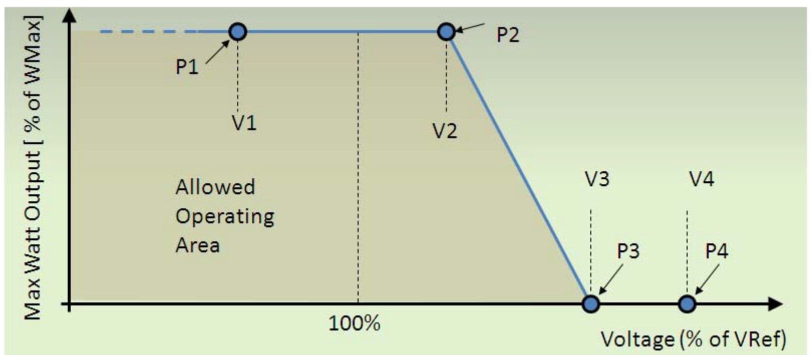

Figure 16: Example Configuration Curve for Maximum Watts vs. Voltage

The exact curve shape shown in Figure 16 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 12.

11.3.1 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.

11.3.2 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 17.

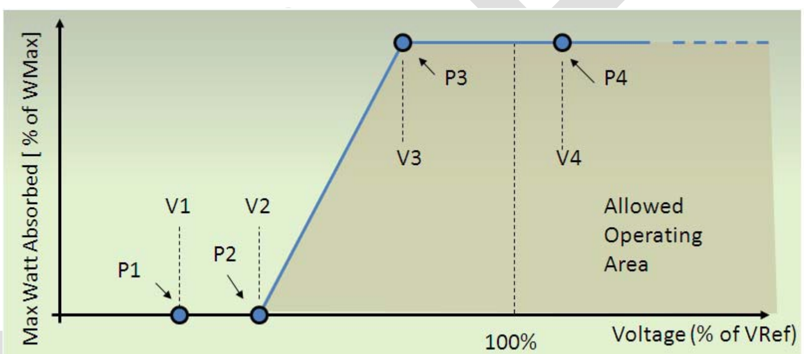

Figure 17: Example Configuration Curve for Maximum Watts Absorbed vs. Voltage

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.

11.3.3 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.

11.3.4 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 12, a "Mode number" (unique ID for the mode) and a single global field for the "Currently Active Watt Produced-Voltage Mode".

11.3.5 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.

11.3.6 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 18. 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 12 indicates that each rate-of-change limiter would have separate rising and falling limits, as shown.

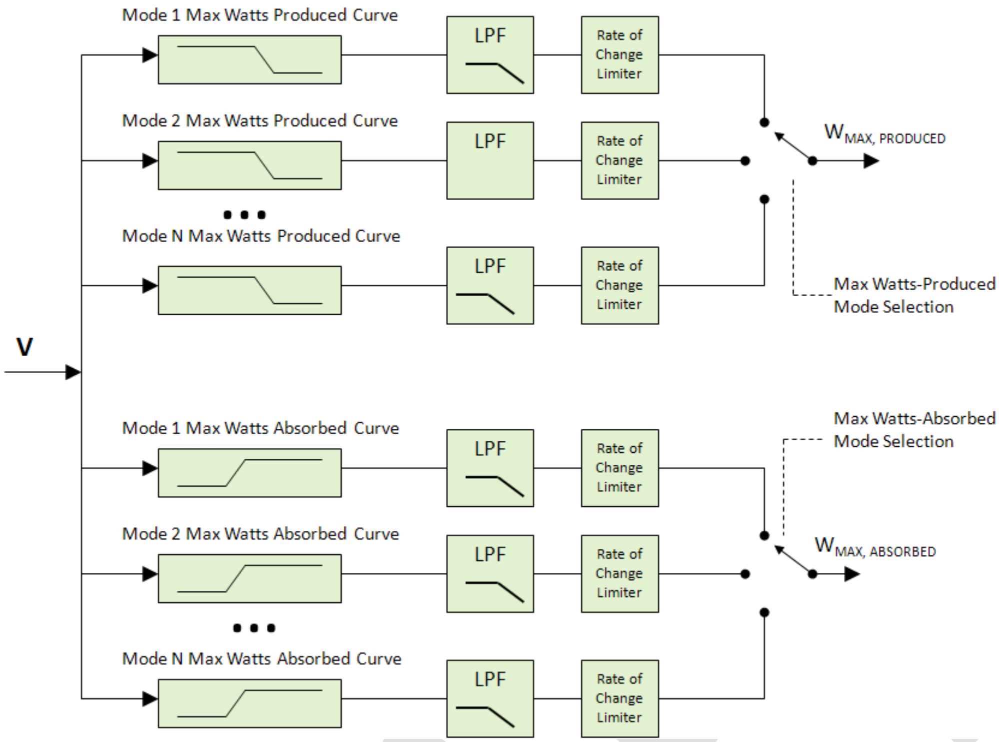

Figure 18: Overall Functional Block Diagram

11.3.7 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 12: 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

Parameter	Description
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).

11.3.8 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.

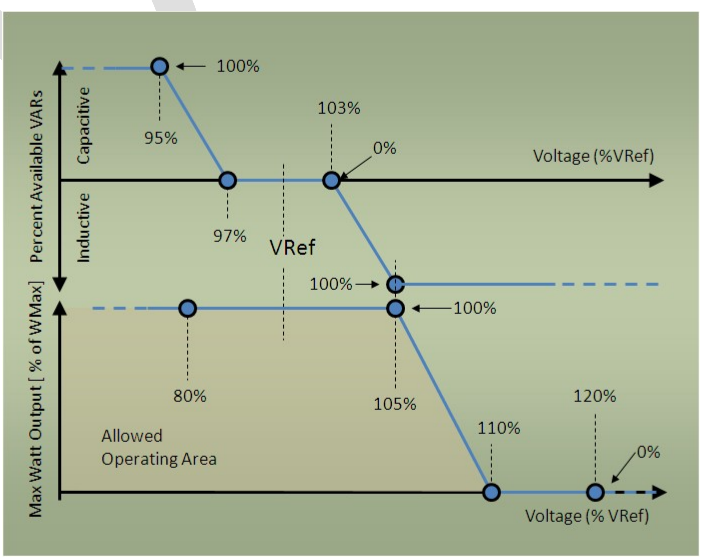

Figure 19: Example Settings for Volt-Var and Volt-Watt Modes

12. Dynamic Volt-Watt Function

12.1 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 real power (Watts) in order to resist fast variations in the local voltage at the ECP.

12.2 Requirements/Use Cases

Use cases have been identified (TBD).

12.3 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 20, 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.

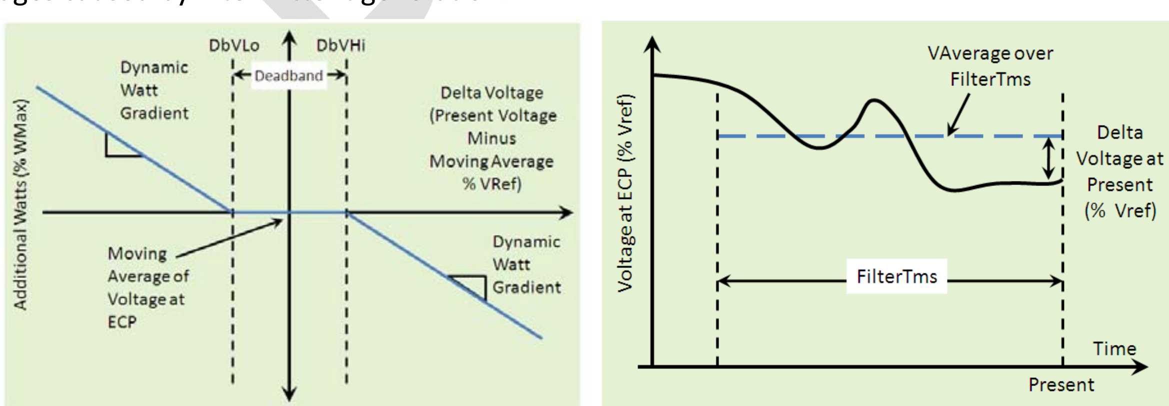

Figure 20: Dynamic Volt-Watt Function Behavior

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.

12.3.1 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.

12.3.2 Settings to Manage this Function

The following settings are defined to manage this function:

Table 13: 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. 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. Dynamic Reactive Current Support Function

13.1 Scope

In the Dynamic Reactive Current Function, 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.

13.2 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.

13.3 Description of Function

It is proposed to provide support for a behavior as illustrated in Figure 21. 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).

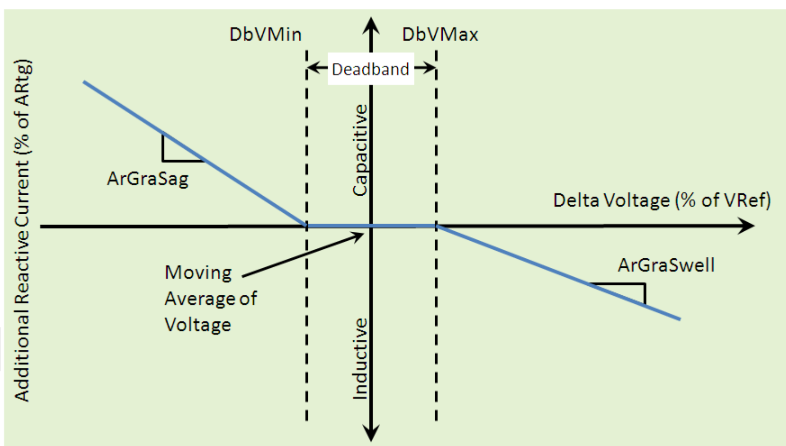

Figure 21: Dynamic Reactive Current Support Function, Basic Concept

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 22.

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.

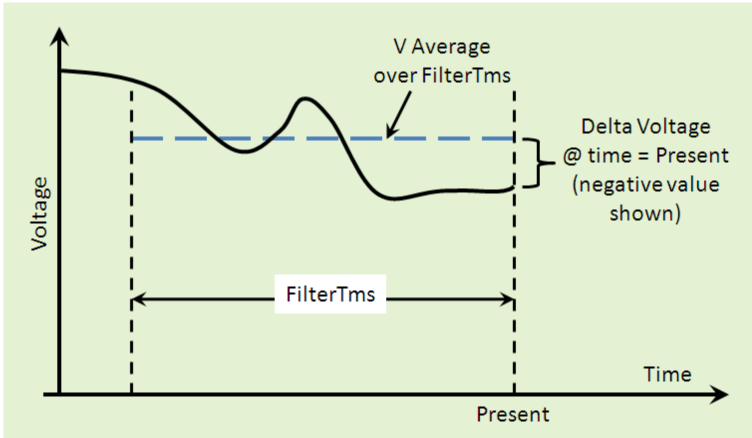

Figure 22: Delta-Voltage Calculation

13.3.1 Event-Based Behavior

This function includes an option to manage how the dynamic reactive current support function is managed, as indicated in Figure 23 and described below.

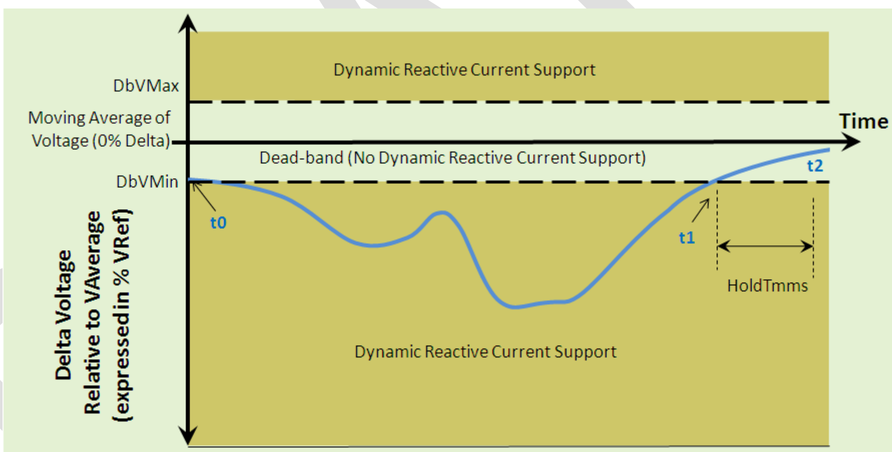

Figure 23: Activation Zones for Reactive Current Support

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.

13.3.2 Alternative Gradient Shape

This function includes the option of an alternative behavior to that shown in Figure 24. **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.

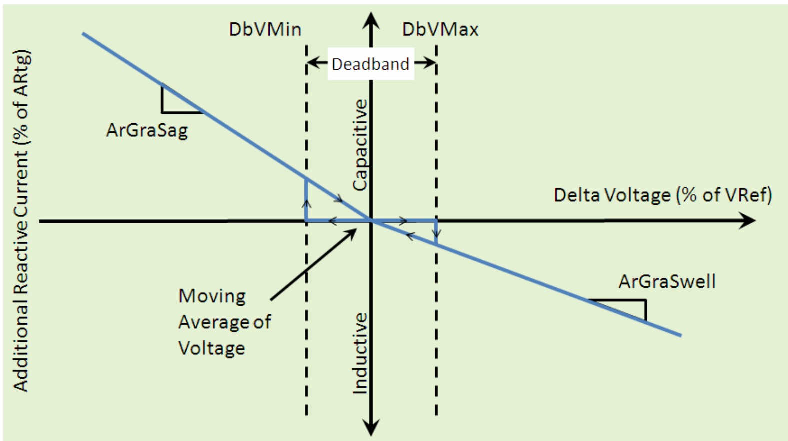

Figure 24: Alternative Gradient Behavior, Selected by ArGraMod

13.3.3 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 25, 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.

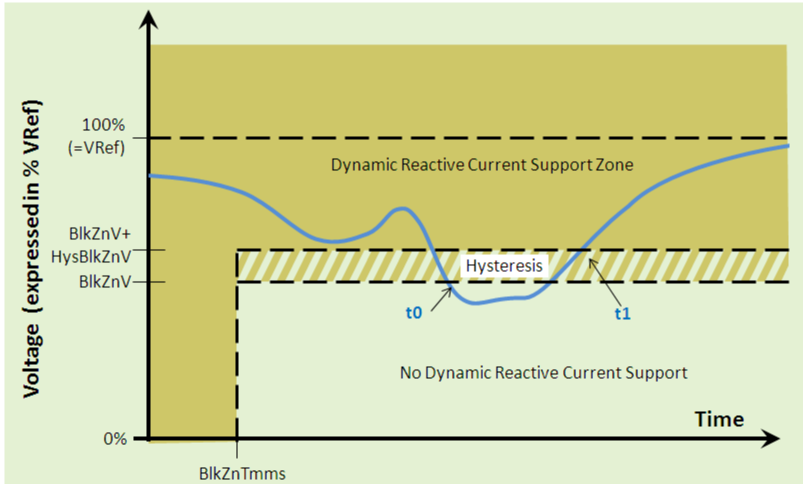

Figure 25: Settings to Define a Blocking Zone

13.3.4 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.

13.3.5 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 14: Dynamic Reactive Current Mode ControlTable 14. Implementation and utilization of this Boolean is optional. If it is not used or supported, the default behavior is that real power levels (Watts) are curtailed as needed to support this function.

Table 14: 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 Real Power, Voltage Sags	Dynamic reactive current takes priority over Watts
		Inverter is Delivering Real Power, Voltage Swells	Dynamic reactive current takes priority over Watts

Setting	Implication	Present Condition	Behavior of this Function
		Inverter is Absorbing Real Power, Voltage Sags	Dynamic reactive current takes priority over Watts
		Inverter is Absorbing Real Power, Voltage Swells	Dynamic reactive current takes priority over Watts
DynamicReactive CurrentMode = 1	Watts are preferred over reactive current for grid	Inverter is Delivering Real Power, Voltage Sags	Watts take priority over dynamic reactive current
		Inverter is Delivering Real Power, Voltage Swells	Dynamic reactive current takes priority over Watts
		Inverter is Absorbing Real Power, Voltage Sags	Dynamic reactive current takes priority over Watts
		Inverter is Absorbing Real Power, Voltage Swells	Watts take priority over dynamic reactive

13.3.6 Settings to Manage this Function

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

Table 15: Settings for Dynamic Reactive Current Function

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.
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.

Name	Description
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.

14. Scheduling of Settings and Modes

14.1 Scope of this Function

This function addresses scheduling of settings and modes.

14.2 Requirements/Use Cases

TBD.

14.3 Description of Function

TBD

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

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. **Watt-Power Factor**: Power factor is shifted based on real power output. 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.
2. **Frequency smoothing**: Smooth minor frequency deviations by rapidly modifying real power output to these deviations. The DER system modifies real power output rapidly to counter minor frequency deviations. The frequency-watt settings define the percentage of real-power output to modify for different degrees of frequency deviations on a second or even sub-second basis.
3. **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.
4. **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.
5. **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.
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 real-power output based on AGC "reg-up" and "reg-down" signals on a multi-second basis.
7. **Provide "spinning" or operational reserve as bid into market**: The DER system provides emergency real 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.
8. **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.
9. **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.

10. **FDEMS or Aggregator provides expected Generation and Storage Schedules:** The FDEMS or Aggregator provides schedules of expected generation and storage reflecting customer requirements, maintenance, local weather forecasts, etc.
11. **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.
12. **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.
13. **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.
14. **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.
15. **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.
16. **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.
17. **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.
18. **Respond to Real Power Pricing Signals**: Manage real 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 real power to output at that time.

19. **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.

16. Additional Functions Described in the EPRI Document

Some of the functions that are listed as “also important, but less important to utilities” in Section 15 have already been described in the EPRI document. Those descriptions are included in this section.

16.1 Watt-Power-factor Function

16.1.1 Scope of this Function

This function modifies PF based on watts.

16.1.2 Requirements/Use Cases

TBD.

16.1.3 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 real power output, expressed as a percentage of maximum nameplate real 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.

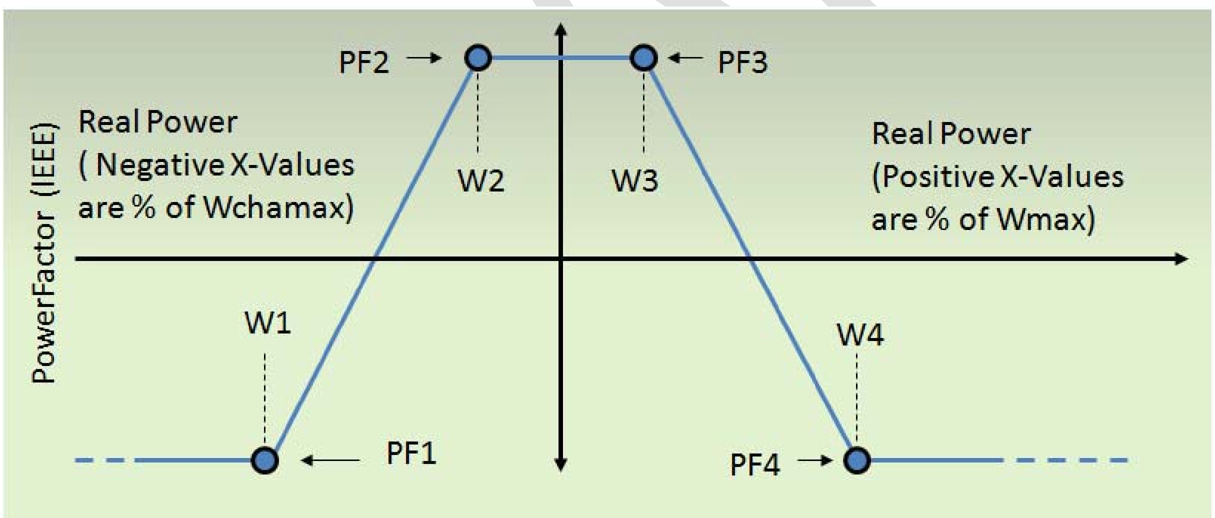

Figure 26: Example Watt – Power Factor Configuration

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 real 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.

16.2 Price or Temperature Driven Functions

16.2.1 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.

16.2.2 Requirements/Use Cases

None captured.

16.2.3 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.

16.3 Peak Power Limiting Function

16.3.1 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.

16.3.2 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.

16.3.3 Description of Function

This proposal describes a method by which distributed energy resources (DER) may perform peak load limiting, as illustrated in Figure 27.

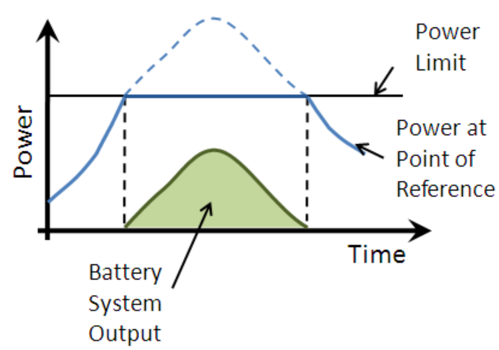

Figure 27: Example Peak Power Limiting Waveform

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.

16.3.3.1 *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 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 28, these could result in failure to hold the power level at the reference point to the desired limit for the desired duration.

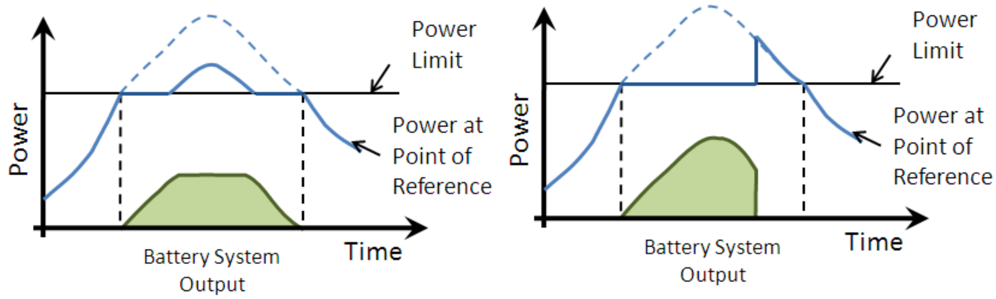

Figure 28: Examples of Practical Limitations – Watt Limit (left) and Battery Capacity Limit (right)

16.3.3.2 *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 29 illustrates two such possibilities.

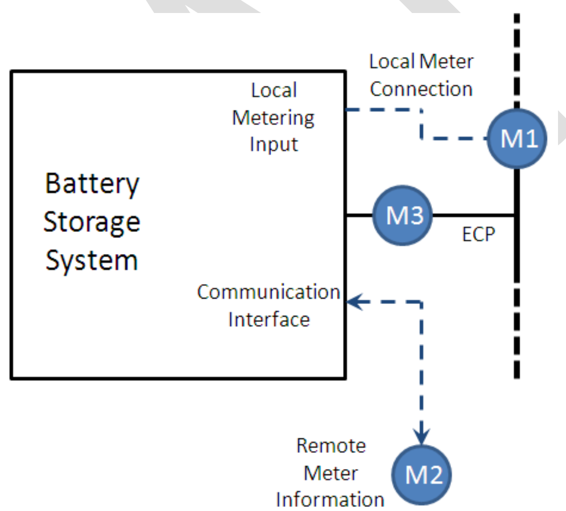

Figure 29: Example Points of Reference for Power Limiting

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.

16.3.3.3 *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 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.
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.

16.4 ESS: Price-Based Charge/Discharge Function

16.4.1 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.

16.4.2 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.

16.4.3 Description of Function

16.4.3.1 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.

16.4.3.2 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.

16.4.3.3 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.

16.5 ESS: Coordinated Charge/Discharge Management Function

16.5.1 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.

16.5.2 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.

16.5.3 Description of Function

16.5.3.1 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 (WMaxStoCh)
- Set Maximum Storage Discharge Rate (WMaxStoDis)
- Randomization Time Window
- Reversion Timeout
- Ramp Time
- Read Charge/Discharge Rate
- Set Charge/Discharge Rate
- Activate Direct Charge/Discharge Management Mode

16.5.3.2 *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 30 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.

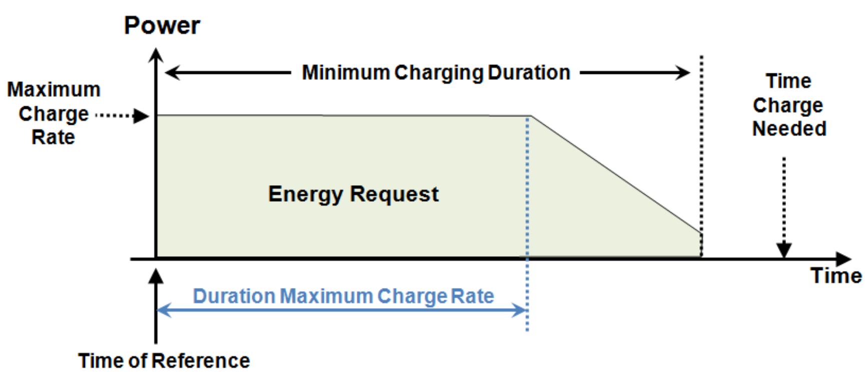

Figure 30: Storage System Model: Time-Base

16.5.4 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 31. 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.

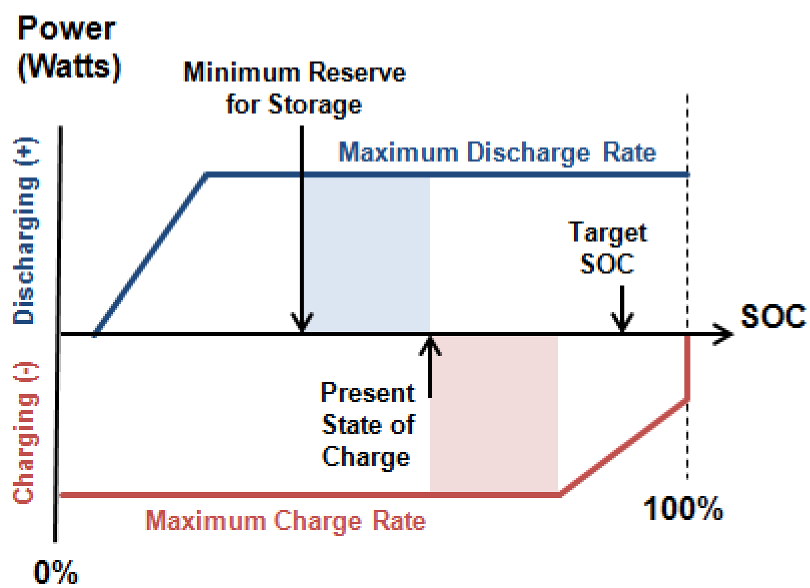

Figure 31: Storage System Model: SOC-Base

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 17: 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. This quantity may be: 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. 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. 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).
Minimum Charging Duration (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 (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. 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.

Name	Description
Duration Maximum Discharge Rate (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. In effect, the energy that can be delivered to the grid is the product of the Duration at Maximum Discharge Rate and the Maximum Discharge Rate. 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. 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.

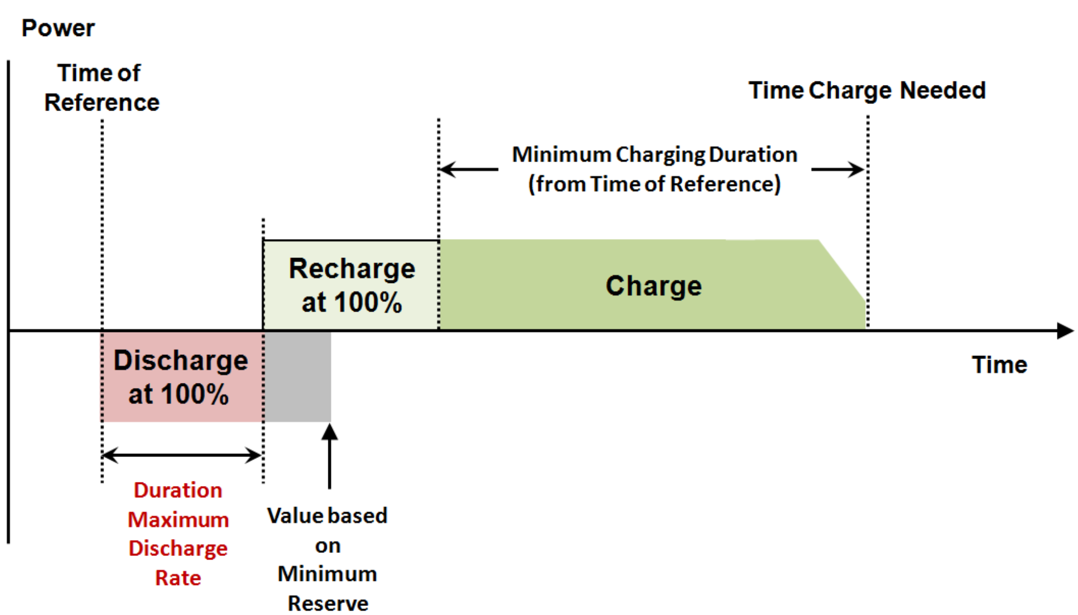

Figure 32: Example of Using the Duration at Maximum Discharge Rate

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 setpoint. 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.