Open Standards for Energy Storage

MESA-ESS Specification

DRAFT

Released November 15, 2016

Version Control

Revision	Date	Purpose	Originator
	2016-11-15	Draft for preliminary release	Frances Cleveland

Table of Contents

Table of Figures

Table of Tables

1. Introduction

1.1 Scope and Purpose

The MESA-ESS specification defines the communication requirements for utility-scale energy storage systems (ESS), including ESS configuration management, ESS operational states, and the IEEE 1815 (DNP3) profile for advanced DER functions that are applicable to ESS. This specification references the DNP3 Application Note and DNP3 Mapping Spreadsheet [*currently under development*], which directly maps the IEC 61850 data objects for basic and advanced DER functions to DNP3 data objects.

The purpose of this MESA-ESS specification is to support the use of communication standards, promote interoperability, and minimize the amount of non-recurring engineering that is required to integrate ESS into utility operations using DNP3. It is expected that profiles of other communication standards will also be developed for different types and purposes of ESS (see Section 2).

For more information on MESA, please visit the MESA web site: http://www.mesastandards.org

1.2 References

The following documents are either referenced in this document or provide additional information that may be useful when reading this document.

Table 1: Specifications and Standards

Document	Description
IEEE 1815	IEEE Standard for Electric Power Systems Communications—Distributed Network Protocol (DNP3)
DNP3 AN2013-001	DNP3 Profile for Advanced Photovoltaic Generation and Storage (*being replaced)*
DNP3 AN2017	DNP3 Profile for Advanced Distributed Energy Resource (DER) Systems, based on IEC 61850-7-420 and 7-520 (*being updated in 2016 to replace DNP3 AN2013*)
EPRI 3002002233	Common Functions for Smart Inverters, Version 3
IEC 61850-7-420	Communication networks and systems for power utility automation – Part 7-420: Basic communication structure - Distributed energy resources logical nodes (*currently Committee Draft (CD)*)
IEC 61850-7-520	Communication networks and systems for power utility automation – Part 7-520: Basic communication structure – Distributed energy resources modelling concepts and guidelines (*currently Committee Draft (CD))*
IEC 61850-90-7	Communication networks and systems for power utility automation – Part 90-7: Object models for power converters in distributed energy resources (DER) systems (*has been incorporated into draft version of Part 7-420*)

1.3 Relationship between DNP3 AN2017 and IEC 61850-7-420

After determining that the DNP3 AN2013-001 did not meet all of the requirements for MESA-ESS, a collaborative effort between MESA and EPRI was initiated to develop an updated version, **DNP3 AN2017: DNP3 Profile for**

Advanced Distributed Energy Resource (DER) Systems. As with the previous DNP3 application note, the updated version is mapped from IEC 61850-7-420 and the associated guidelines, IEC 61850-7-520.

In this MESA-ESS specification, while the DNP3 AN2017 document is still under development, each ESS function will identify the pertinent IEC 61850 data objects as well as relevant DNP3 information and will reference the DNP3 profile spreadsheet, which is distributed with this specification. Once the DNP3 AN2017 is completed, the ESS functions will be updated to just reference the appropriate sections of that Application Note.

1.4 Scope Constraints

Although the MESA-ESS specification can be used by any type or size of ESS, this profile is focused initially on utility-scale battery energy storage systems, so battery-specific terminology is sometimes used.

Some ESS requirements are discussed which may or may not involve the use of DNP3. For instance, although DNP3 is used to monitor operational states, the permissions associated with those states may be implemented manually or through some other protocol. It is also expected that some implementations may use DNP3 to collect historical data (as opposed to SCADA data), while other implementations may choose to use other protocols.

1.5 Terminology

The terms in Table 2 are used throughout this document.

Table 2: Terminology

Term	Definition
Battery Bank	A collection of battery cells which can be used to store energy. Connected to a single inverter. A bank may be a shipping container full of lithium ion battery modules, or it may be a redox flow battery string.
Battery Management System (BMS)	An integrated electronic management system for monitoring, measurement, reporting, and protection of a battery storage bank at cell-, module-, and bank-levels.
Distributed Energy Resource (DER)	Generation, storage, and controllable load interconnected to the distribution electric power system
DER System	One or more DER units that have a common DER controller (e.g. PV unit plus energy storage unit with a single controller, multiple energy storage units with a single controller)
DER Unit	A physical DER entity of one single type (e.g. photovoltaic unit, energy storage unit, or controllable load).
Distribution System Operator (DSO)	Utility managing the distribution power system
DNP3	Protocol standardized in IEEE 1815 and used by most US utility SCADA systems for monitoring and controlling substation equipment
Electrical Connection Point (ECP)	The point of electrical connection between a DER system and any electric power system (EPS)

Electric Power System (EPS)	The facilities that deliver electric power to a load or from generation
EPS, Area	The electric power system (EPS) that serves Local EPSs
EPS, Local	An EPS contained entirely within a single premises or group of premises
Energy Storage System (ESS)	A system that can store energy and release that energy as electricity
Independent System Operator (ISO)	Utility managing the balancing of generation and load within a control area by reflecting the bulk power market while still meeting the power system reliability requirements
Inverter	Converts from AC to DC and back again. Typically 4-quadrant. Connected to a single battery bank.
Referenced ECP	The ECP that a DER's function references as the source of power system measurements. Usually this is either the ESS's ECP or the PCC, but other ECPs may be referenced.
Regional Transmission Operator (RTO)	Utility managing the transmission power system
Supervisory Control and Data Acquisition (SCADA)	System used by utilities and other facilities for controlling and monitoring power system equipment
Transmission System Operator (TSO)	Utility managing the transmission power system

2. Information Management for ESS Configurations

2.1 Economic Drivers for ESS Functions

There are many economic drivers for implementing and interfacing Energy Storage Systems. Based on work by the "More Than Smart" efforts, more specific discussions in the Sandia "*Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*" document[1], and discussion with the MESA members, an assessment of the ESS functions identified in this document is shown in Figure 1.

[1] http://www.sandia.gov/ess/publications/SAND2010-0815.pdf

Utilities Incentivize ESS to Provide Grid Support Services

Utilities Grid Support Services that ESS May Provide, as Incentivized / ESS Actions and Functions for Supporting the Grid Services		Install: ESS under Direct Utility Control	Install: ESS under Contract, but 3rd Party Control	Install: ESS to Respond to Market	Market: ESS tariff items	Market: ESS contractual arrangements	Market: ESS bids into Day Ahead Bid-Ask Market	Market: ESS bids into Spot Market	Market: ESS responds to Demand Response	Monitor: Register ESS identity	Monitor: Determine operational characteristics	Monitor: State-of-Charge, status, and measuremen	Monitor: Short-term forecast of ESS capabilities	Monitor: Historical information	Monitor: Metered information	Monitor: ESS detailed data	Control: Enable/disable modes	Control: Set Mode Parameters and Curves	Mode: Set real power charge / discharge rate	Mode: Limit ESS real power to max discharge	Mode: Limit ESS real power to min charge rate	Mode: Load Following	Mode: Generation Following	Mode: Ramp rates for different situations	Mode: Real power smoothing of spikes and sags	Control: Follow schedule real power and modes	Mode: Price and Time-based Charge/Discharge	Control: Automatic Generation Control (Up &	Control: Regulation Up	Control: Regulation Down	Mode: Frequency smoothing	Mode: Fixed power factor	Mode: Power factor correction	Mode: Volt-var control	Mode: Volt-watt control	Mode: Fast var support	Mode: Watt-Power Factor	Control: Start / stop ESS	Control: Permit reconnection	Preset: Frequency Ride-Through	Mode: Frequency-watt (Emergency e.g. spinning	Preset: Voltage Ride-Through	Mode: Dynamic reactive current support	Mode: Soft-Start Reconnection	Control: Separate into islanded microgrid	Control: Provide black start capability	Mode: Backup power
		Install			Market					Situational Awareness									Real Power									Frequency				Voltage						Contingency and Resiliency									
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE	FG(	HH	II	JJ	KK	LL	MM	NN	OO	PP	QQ	RR	SS	TT	UU
ISO and Transmission Near Real-Time Operations (Day Ahead to Real-Time)																																															
Energy Capacity Adequacy																																															
Provide real power	53				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x	x																				
Limit energy (load or generation) on constrained transmission paths	54				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x																				
Minimize transmission losses	55				x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x																							
Smooth real power deviations	56				x	x	x	x	x	x	x	x	x	x	x	x	x	x							x																						
Frequency Support																																															
Provide regulation up and/or down	57				x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x																	
Provide synthetic inertia (frequency smoothing)	58				x	x	x	x	x	x	x	x	x	x	x	x	x	x													x																
Voltage Support																																															
Maintain voltage levels on transmission circuits	59				x	x	x	x	x	x	x	x	x	x	x	x	x	x														x	x	x	x	x	x										
Provide voltage smoothing on transmission circuits	60				x	x	x	x	x	x	x	x	x	x	x	x	x	x																x	x	x	x										
Coordinate voltage support with distribution automation equipment	61				x	x	x	x	x	x	x	x	x	x	x	x	x	x																x	x	x	x										
Support power quality requirements	62				x	x	x	x	x	x	x	x	x	x	x	x	x	x																x	x	x	x										
Provide power factor support	63				x	x	x	x	x	x	x	x	x	x	x	x	x	x														x	x				x										
Contingency and Resiliency Support																																															
Provide long term reserves (e.g. non-spinning)	64				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x																					
Provide fast short term reserves (e.g. spinning and instantaneous)	65				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x																					
Provide emergency frequency support	66				x	x	x	x	x	x	x	x	x	x	x	x	x	x										x	x	x	x									x	x						
Provide emergency voltage support	67				x	x	x	x	x	x	x	x	x	x	x	x	x	x																x	x	x	x					x	x				
Support microgrid islanding	68				x	x	x	x	x	x	x	x	x	x	x	x	x	x																											x		
Disconnect or cease the export of energy generation	69				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																			x	x								
Provide black start support	70				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x																				x	
Distribution Systems Near Real Time Operations (Day Ahead to Real-Time)																																															
Energy Capacity Adequacy																																															
Provide real power at PCC	71				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x																							
Provide a schedule of real power at PCC	72				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x	x																				
Limit energy (load or generation) on constrained distribution circuits	73				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x																				
Minimize distribution losses (e.g. match local generation and loads)	74				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x																				
Avoid or minimize demand peaks	75				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x																				
Smooth real power deviations	76				x	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	x	x		x																				
Voltage Support																																															
Maintaln voltage levels on distribution circuits (e.g. CVR)	77				x	x	x	x	x	x	x	x	x	x	x	x	x	x														x	x	x	x	x	x										
Provide voltage smoothing on distribution circuits	78				x	x	x	x	x	x	x	x	x	x	x	x	x	x																x	x	x	x										
Coordinate voltage support with distribution automation equipment	79				x	x	x	x	x	x	x	x	x	x	x	x	x	x														x	x	x	x	x	x										
Support power quality requirements	80				x	x	x	x	x	x	x	x	x	x	x	x	x	x																		x											
Provide power factor support	81				x	x	x	x	x	x	x	x	x	x	x	x	x	x														x	x				x										
Contingency and Resiliency Support																																															
Provide long term reserves (e.g. non-spinning)	82				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x																					
Provide fast short term reserves (e.g. spinning and instantaneous)	83				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x																					
Provide emergency voltage support	84				x	x	x	x	x	x	x	x	x	x	x	x	x	x																x	x	x	x					x	x				
Minimize number and length of outages	85				x	x	x	x	x	x	x	x	x	x	x	x	x	x																											x	x	x
Disconnect or cease energy generation export	86				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																			x	x								
Provide black start support	87				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							x																			x	x	

Figure 1: Economic Drivers: Near-Real-Time Energy Services Mapped to ESS Actions and Functions

2.2 Overview of DER Hierarchical Configurations

Direct control of Distributed Energy Resources (DER) by distribution system operators (DSOs) is neither technically feasible nor contractually acceptable for the thousands if not millions of DER systems interconnected with the distribution power system. At the same time, utilities are responsible for meeting the reliability and electrical requirements within their distribution systems and therefore require information on the locations, capabilities, and operational status of these DER systems. In addition, these DER systems can greatly assist in meeting these utility requirements effectively and efficiently, thus making them proactive stakeholders in managing the electric power system.

Information exchange is critical to accommodate these complex and dynamic power system requirements, and management of these information exchanges needs to be organized and interoperable. Specifically, a hierarchical approach is necessary for the various stakeholders (utilities, aggregators, facilities, markets, and DER systems) to exchange information. At the local level, DER systems generally manage their own generation and storage activities autonomously based on local conditions, pre-established settings, and DER owner preferences. DER systems can also be active participants in power system operations and must be coordinated with other DER systems and distribution equipment. In addition, the DSOs must interact with transmission system operators (TSOs), also known as regional transmission organizations (RTOs) and/or independent system operators (ISOs), for reliability and market purposes. In some regions, retail energy providers, aggregators, or other energy service providers are responsible for managing groups of DER systems either through operational actions or market actions.

This hierarchical approach can be described as hybrid combinations of five (5) levels across multiple domains, as illustrated in the five-level hierarchical DER system architecture shown in Figure 2 and described below. The circled numbers identify the various logical information exchanges.

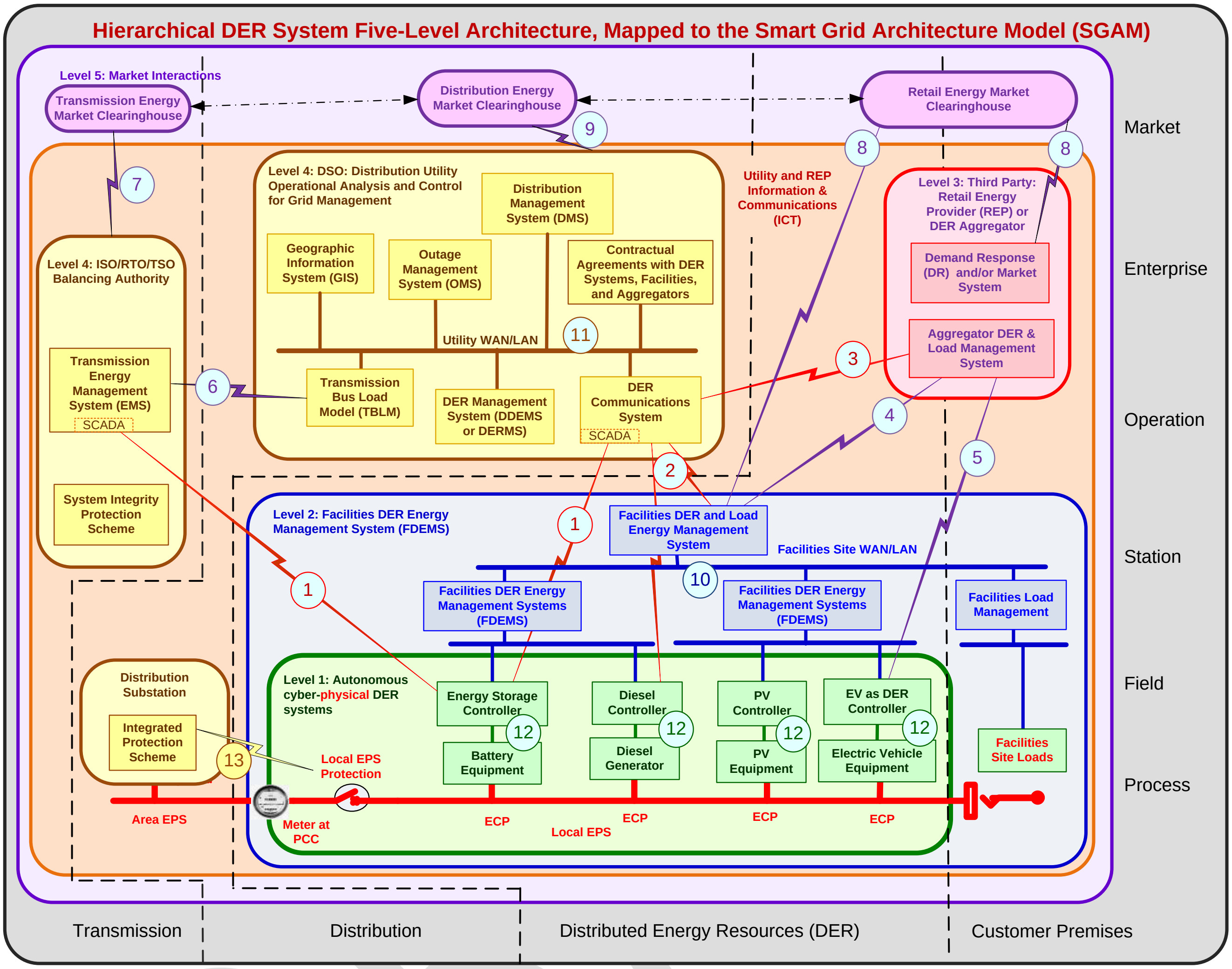

Figure 2: Hierarchical management of information exchanges for DER systems

1. **Level 1 DER Systems** (green in the Figure) is the lowest level and includes the actual cyber-physical DER systems themselves. These DER systems will be interconnected to local grids at Electrical Connection Points (ECPs) and to the utility grid through the Point of Common Coupling (PCC) (the ECP and the PCC may be the same if the DER is directly grid-connected). These DER systems will usually be operated autonomously. In other words, these DER systems will be running based on local conditions, such as photovoltaic systems operating when the sun is shining, wind turbines operating when the wind is blowing, electric vehicles charging when plugged in by the owner, and diesel generators operating when started up by the customer. This autonomous operation can be modified by DER owner preferences, pre-set parameter, and commands issued by utilities and aggregators.

2. **Level 2 Facility DER Management** (blue in the Figure) is the next higher level in which a facility DER management system (FDEMS) manages the operation of the Level 1 DER systems. This FDEMS may be managing one or two DER systems in a residential home, but more likely will be managing multiple DER systems in commercial and industrial sites, such as university campuses and shopping malls. Utilities may also use a FDEMS to handle DER systems located at utility sites such as substations or power plant sites. For utilities, FDEMS are viewed as field systems and shown at the Station level of the SGAM; however, from a facility's point of view, they may be seen as enterprises in their own right, and they could then be shown at the Enterprise and Operations levels.

3. **Level 3 Third Parties: Retail Energy Provider or Aggregators** (red in the Figure) shows market-based aggregators and retail energy providers (REP) who request or even command DER systems (either through the facility's FDEMS or via aggregator-provided direct communication links) to take specific actions, such as turning on or off, setting or limiting output, providing ancillary services (e.g., volt-VAr control), and other grid management functions. Aggregator DER commands would likely be price-based either to minimize customer costs or to respond to utility requirements for safety and reliability purposes. The combination of third parties (this level) and facilities (level 2) may have varying configurations, responsibilities, and operational scenarios but, overall, still fundamentally provide the same services.
4. **Level 4 Utility Operational Grid Management** (yellow in the Figure) applies to utility applications that are needed to determine what requests or commands should be issued to which DER systems. Distribution System Operators (DSOs) must monitor the distribution power system and assess if efficiency or reliability of the power system can be improved by having DER systems modify their operation. This utility assessment involves many utility control center systems, orchestrated by the Distribution Management System (DMS) and including the DER database and management systems (DERMS), Geographical Information Systems (GIS), Transmission Bus Load Model (TBLM), Outage Management Systems (OMS), and Demand Response (DR) systems. Transmission System Operators (TSOs), regional transmission operators (RTOs), or independent system operators (ISOs) may interact directly with larger DER systems and/or may request services for the bulk power system from aggregated DER systems through the DSO or through the REP/Aggregators. Once the utility has determined that modified requests or commands should be issued, it will send these either directly to a DER system, indirectly through the FDEMS, or indirectly through the REP/Aggregator.
5. **Level 5 Market Operations** (purple in the Figure) is the highest level, and it involves the larger energy environment where markets influence which DER systems will provide what services. The TSO markets are typically bid/offer transaction energy markets between individual DER owner/operators and the TSO. At the distribution level, the markets are not yet well-formed, and, over time as they evolve, they may be based on individual contracts, special tariffs, demand response signaling, and/or bid/offer transaction energy markets.

2.3 ESS Structures and Configurations

Energy storage systems come in many shapes and sizes. A simple ESS may consist of a single battery, a power conversion system, and one or two meters as shown in Figure 3.

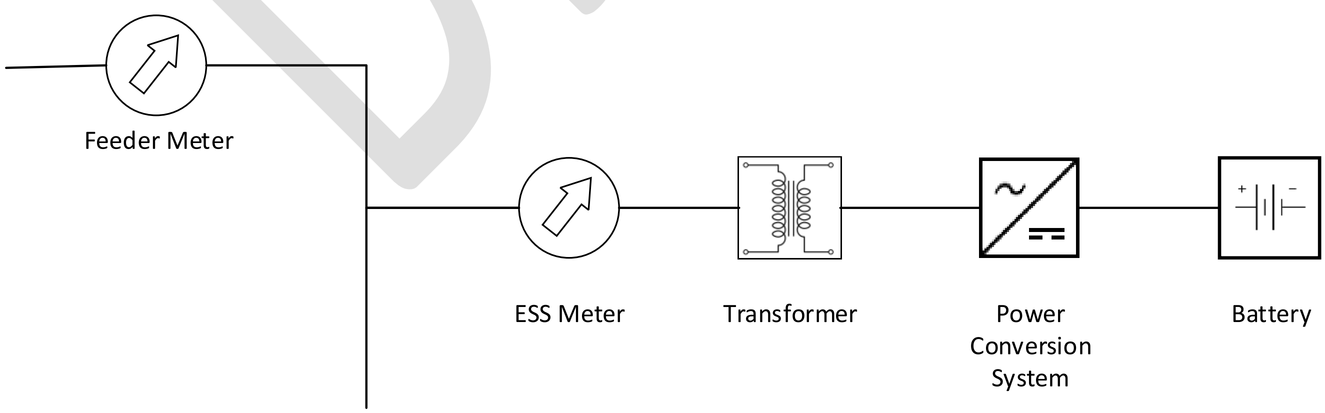

Figure 3: A simple energy storage system

More complex energy systems might include multiple inverters and battery pairs, and they may utilize additional meters to ensure the proper monitoring and control of the ESS. Figure 4 provides an example of a more complex energy storage system.

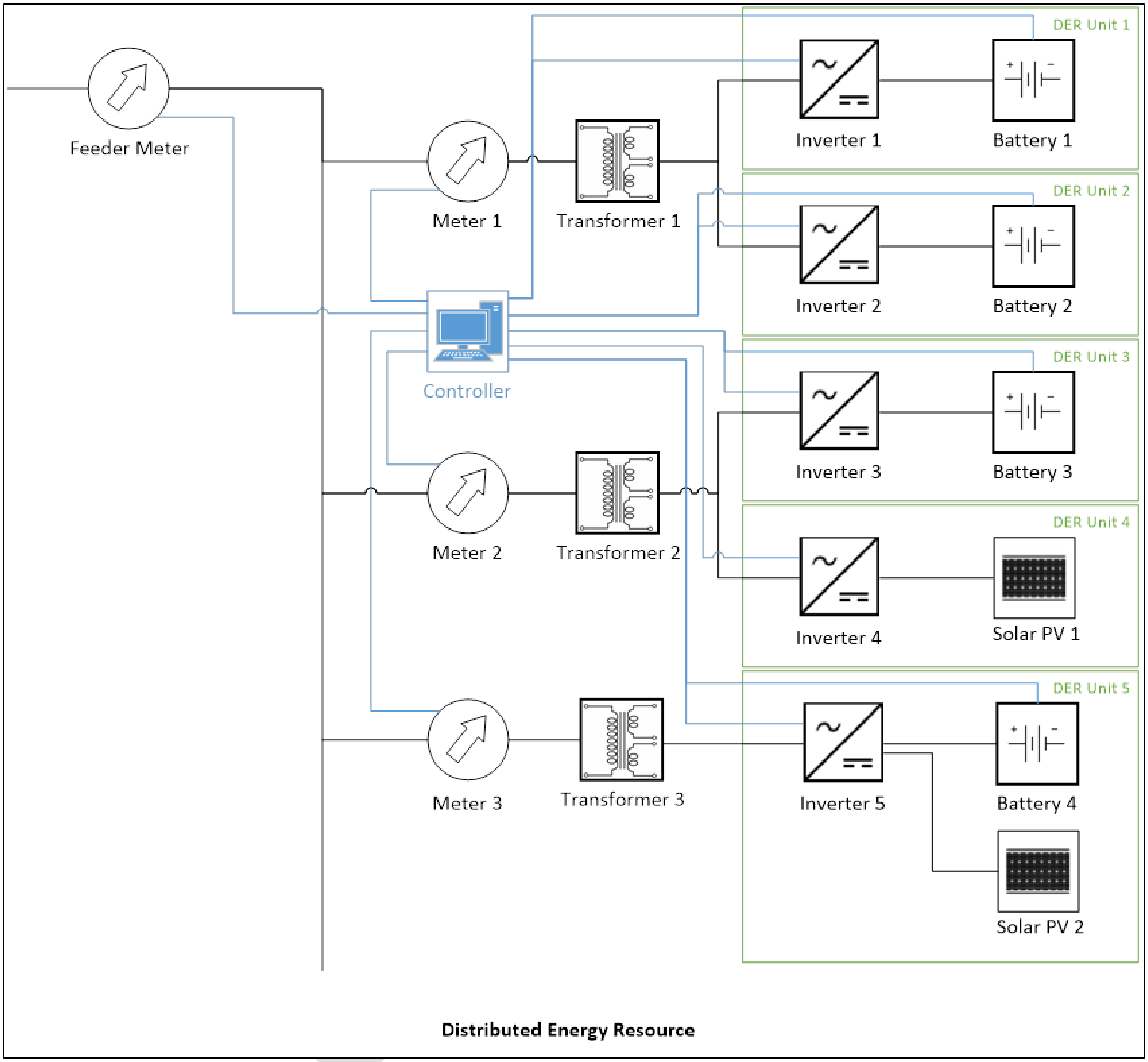

Figure 4: A more complex energy storage system

The MESA-ESS specification has been designed to support these different ESS configurations. In particular, MESA-ESS recognizes that energy storage systems typically consist of one or more inverters connected to a like number of energy storage components (e.g. battery banks). A MESA-ESS compatible ESS may have one or more inverter and battery bank pairs.

To ensure maximum utilization of more complex energy storage systems, the MESA-ESS specification provides monitoring and control points which allow an inverter and battery pair to be taken offline for maintenance while the rest of the system continues to operate normally. For example, for the ESS shown in Figure 4, it is possible to place Inverter 3 and Battery 3 into maintenance mode and continue to use the rest of the system normally.

MESA-ESS also recognizes that energy storage systems typically use multiple power meters to ensure the safe and effective operation of an ESS. These meters typically fall into one of the following categories:

- ESS Meters, such as Meter 1 and Meter 2 in Figure 4, monitor the output of the ESS itself. Aside from providing key measurements to the operator, these meters may be used in conjunction with feedback loops to ensure consistent power output from the ESS.
- Feeder Meters and other power meters at electrical connection points provide valuable operational data. It is often desirable to use the data from these meters to drive the behavior of the operational modes provided by the ESS.
- Auxiliary power meters measure the auxiliary power needed to operate the inverters, batteries, chillers, HVAC systems, etc. within the ESS.

2.4 ESS Actual and Usable Capacity

The definition of the capacity of an ESS depends upon what is important to different types of users. For instance, the vendor of an ESS is concerned about the actual capacity of the ESS, while an operator is only interested in what capacity is available to be used. Therefore, as illustrated in Figure 5, two types of capacities are envisioned: the actual ESS capacity and the usable ESS capacity. The actual ESS capacity is the nameplate information, possibly modified over time if the ESS characteristics change. The usable ESS capacity is what users are permitted to have access to, which is based on the decisions of ESS manufacturers or ESS owner/operators.

In addition to usable capacities, ESS owner/operators may choose to establish maximum and/or minimum reserve capacities (as a percentage of usable capacity) that would normally not be used, but could be used either for emergency situations or other special circumstances.

State-of-charge (SoC) would be based on these capacity definitions, in which the "actual state of charge" is the percentage of actual capacity, while the "usable state of charge" is the percentage of usable capacity.

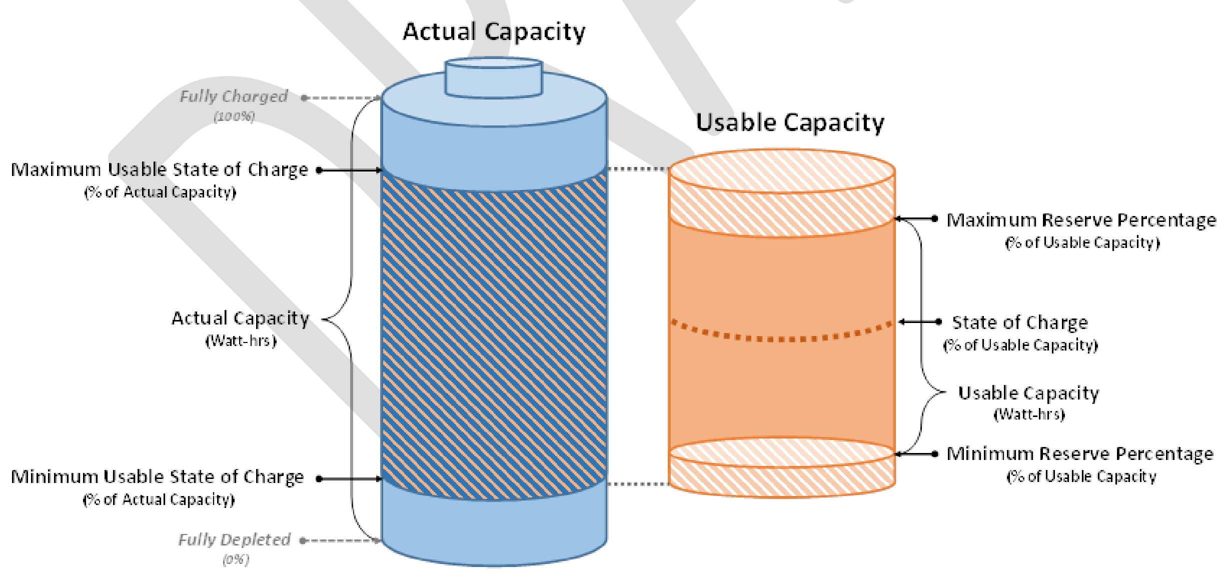

Figure 5: ESS State of Charge: Difference between Actual Capacity and Usable Capacity

2.5 Protocol Alternatives for Information Exchanges with ESS Systems

IEC 61850-7-420 has been developed as the "abstract" information model for interactions with DER systems. A number of protocol alternatives exist that are based on or mapped from this IEC 61850 information model. These protocols generally have specific purposes and characteristics, although there are overlapping areas across them (see Table 3). The numbers represent the circled numbers in the previous figure.

Table 3: Protocol Alternatives for DER Systems

Protocol	Domain	#	Data Format	Availability	Latency	Cyber Security
IEC 61850-7-420 information model and IEC 61850-8-2 (61850 IoT)	Interactions with DER systems	2, 3, 10	XML/XER, using XSDs	High	Low to Medium latency	In IEC 62351 standards
Modbus (SunSpec Alliance mappings)	Widely used between DER components	12	Simple data structures	High	Low latency	None in Modbus, but may use bump-in-the-wire
IEEE 1815 (DNP3)	Widely used by utilities for SCADA interactions with field devices	1	Simple data structures	High	Low latency	In IEEE 1815 standard but not widely implemented
IEEE 2030.5 (SEP2)	Originally home area networks, now being expanded to utility interactions with DER systems	2, 3, 10	XML, using XSD structures using RESTful HTTP	Medium	Medium latency	In IEEE 2030.5 standard
IEC 61850-8-1 (GOOSE)	Protective relaying and substation status signals	12, 13	MMS	Very high	Very low latency	In IEC 62351 standards

Some existing protocols, such as OpenADR and BACnet, may be mapped to appropriate portions of the IEC 61850 Information Model in the future, while other alternatives are under development, such as the Open Field Message Bus (OpenFMB) framework.

Figure 6 illustrates where the protocol alternatives might be used.

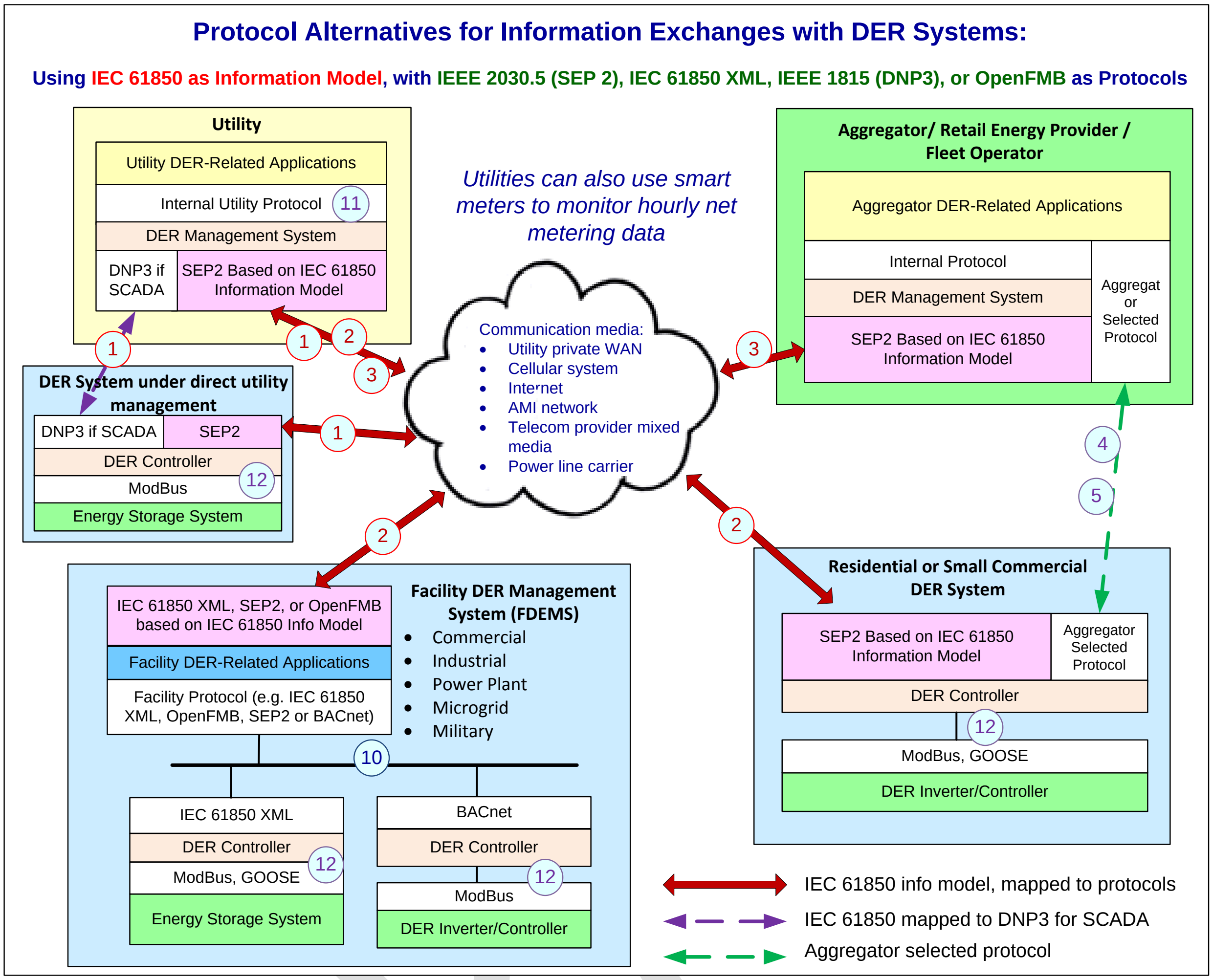

Figure 6: Protocol Alternatives for Information Exchanges with DER Systems, Including ESS

2.6 ECP and PCC Concepts

The electrical connection point (ECP) of a DER system defines its point of electrical connection to any electric power system (EPS). Usually, there is a switch, a circuit breaker, and/or a meter at this point of connection.

ECPs can be hierarchical. Each DER system has an ECP connecting it to its local power system. Groups of DER systems have an ECP where they interconnect to the power system at a specific site or plant. A group of DER systems plus any non-controllable loads have an ECP (termed the point of common coupling (PCC)) where they are interconnected to the utility power system.

In a simple DER configuration, there is one ECP between a single DER system and the utility power system. However, as shown in Figure 7, there may be more ECPs in a more complex DER plant installation. In this figure, ECPs exist between:

- Each single DER system and the local EPS
- Groups of DER systems and the local EPS
- Multiple groups of DER systems and the utility area EPS at the PCC
- An external ECP and the area EPS

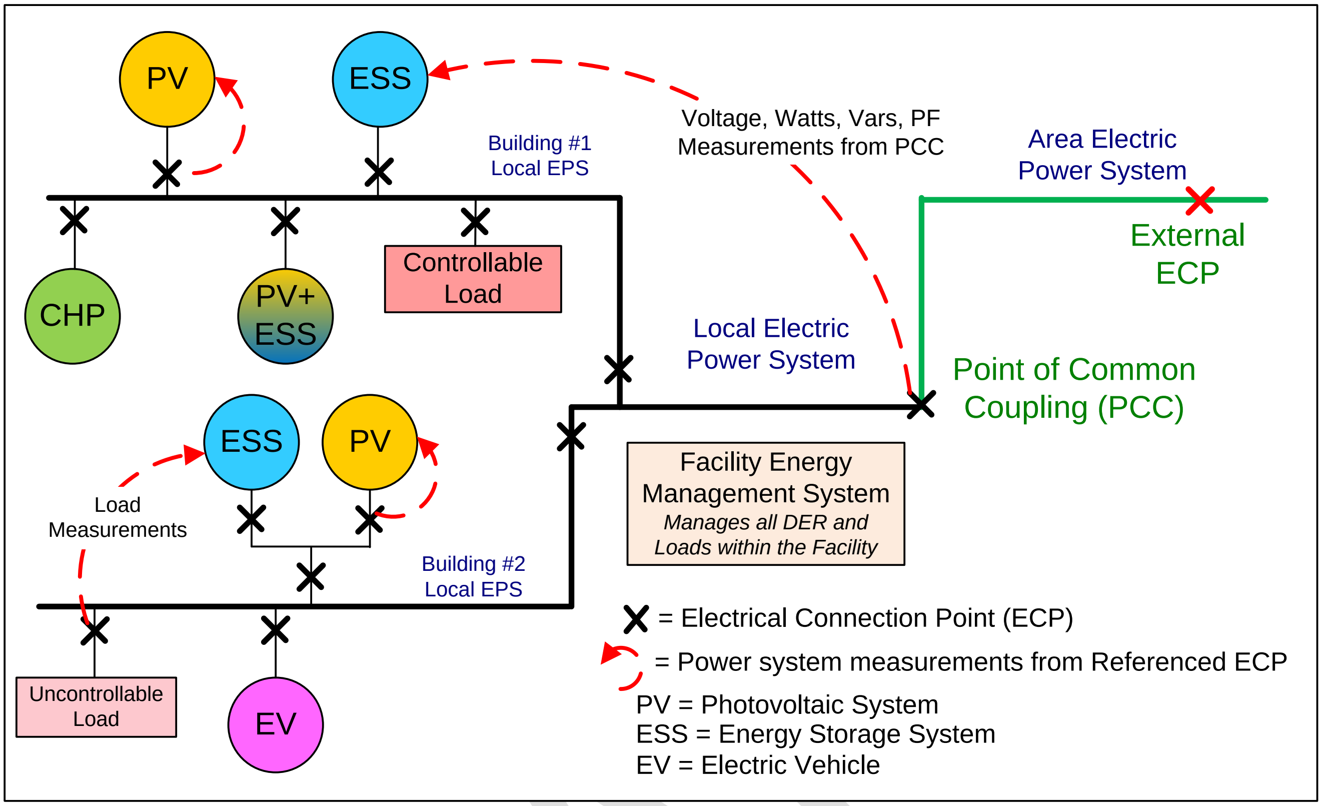

Figure 7: Concept of DER systems (colored circles), electrical connection points (ECP), and the Referenced ECP

The importance of the ECP concept lies in the fact that DER systems may need to use measurements or other information from ECPs that they are not necessarily directed connected to. For instance, if a DER system is providing peak power limiting, it must receive power measurements from the relevant remote ECP (e.g. the PCC as usually required by utilities). Or if an ESS is counteracting generation fluctuations from an external solar plant, it must receive those measurements from that external ECP.

In some deployments, one specific ECP is configured at installation time to be used for all functions. However, in other deployments, different functions may be able to use different ECPs, depending upon the operational requirements. In those cases, the ECP to be used must be identified as part of each function's settings. Therefore, for each function where different ECPs may be indicated, the data object "Referenced ECP" is used to identify the desired ECP.

2.7 Signal Meters

Many of the functions in this profile operate autonomously using data provided by a meter or some other sensor at a Referenced ECP. For example, the Frequency-Watt operational mode described in Section 6.4.10 adjusts the Active Power output of the ESS based on frequency values read from a meter. In this specification, meters which provide signal data which is used by an autonomous function are referred to as "signal meters."

Each meter that is part of the energy storage system or that will be used by one of the ESS operational modes should be assigned a unique identifier (a positive integer). When a function is configured, a signal meter identifier will be specified, which identifies the meter that will provide values to the function.

2.8 Relationship to Other MESA Communication Specifications

As can be seen in Figure 8, MESA-ESS may be combined with MESA-Device communication specifications in the construction of a MESA-compliant energy storage system. Where MESA-ESS is a specification for the DNP3 interface to an energy storage system as a whole, the MESA-Device interfaces (MESA-PCS [1], MESA-Storage [2] and MESA-Meter [3]) provide standardization for the Modbus interfaces that are exposed by many of these devices.

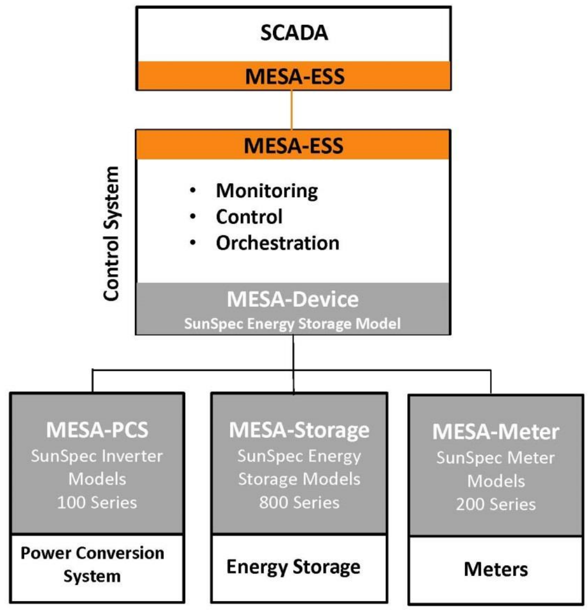

Figure 8: Conceptual Diagram of MESA-ESS

While MESA-ESS and MESA-Device have been designed to work well together, the use of MESA-ESS does not mandate the use of MESA-Device. An ESS that implements MESA-ESS alone still provides significant value to the asset owner.

3. Operational State Model

3.1 Roles, Permissions, and ESS Operational States

There are multiple ways that an electric utility may control a grid-connected energy storage system and 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, which are assigned "permissions" for those actions they are allowed to perform in the different operational states. Users are then assigned to one or more roles when they log into the ESS.

Figure 9 provides a generic overview of Role-Based Access Control (RBAC) based on the international standard IEC 62351-8. This overview shows a list of generic roles, the basic permissions that can be assigned, and how these permissions are modified by Areas of Responsibility (AOR) (equivalent to operational states).

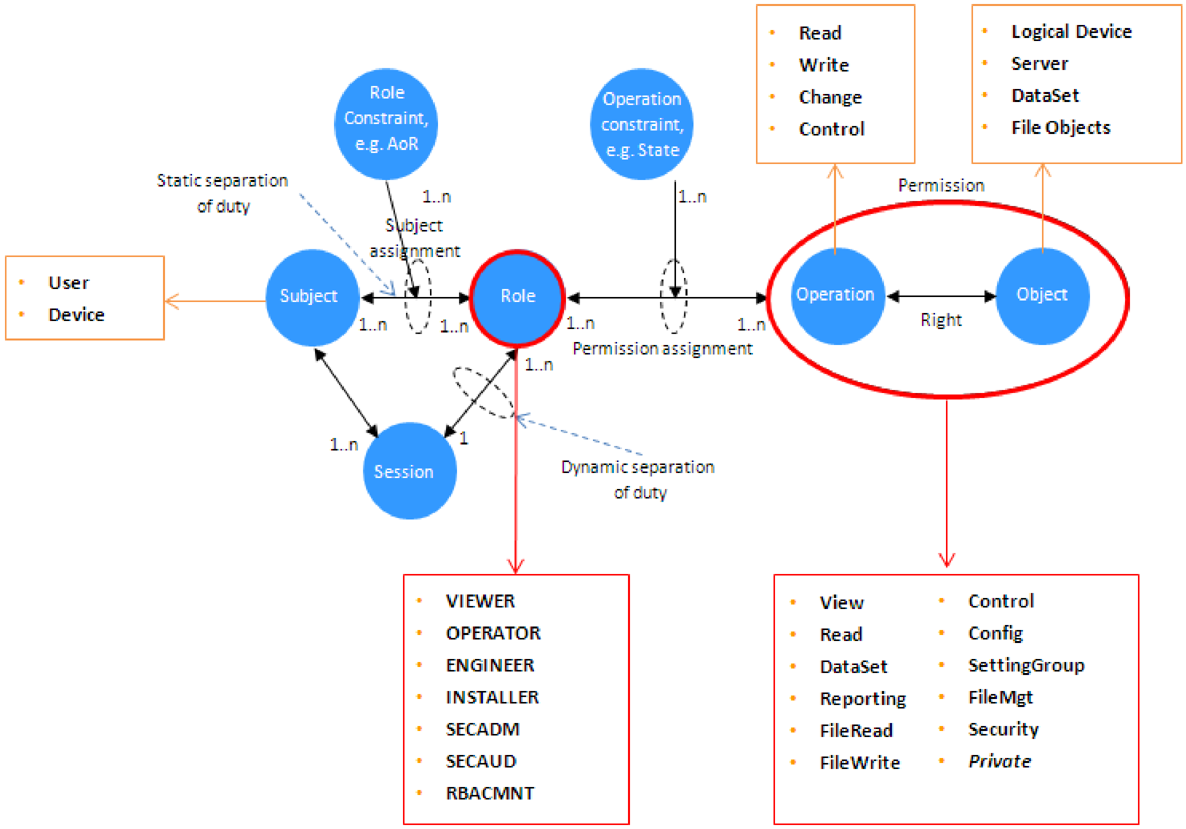

Figure 9: Roles, Permissions, and Operational States

3.2 Default Roles

For ESS user interactions, at least one of each of the roles in the list below is recommended to be implemented with additional roles permitted. Although different mechanisms may be used to assign users to roles, at a minimum, login credentials (e.g. unique username and password) shall be used during the assignment.

- Utility ESS operator
- Utility power scheduler
- Third party aggregator
- Facility ESS operator
- ESS maintenance personnel
- ESS vendor
- Guest viewer

Some role permissions may be different based on whether a user logs in locally or remotely – that situation may be handled by the ESS detecting whether the login is initiated locally or remotely, or may be handled by defining separate roles in which the local roles are only available at the local ESS HMI. For example, in some implementations, there could be two Facility ESS operator roles; one of which is remote, and the other is local. The local Facility ESS operator may be then given permission to perform tasks not allowed for the remote Facility ESS operator for safety reasons.

3.3 Operational States

To ensure the safety of the asset owner's personnel and to help in coordinating control of the ESS across operator roles, the ESS shall support the following mutually exclusive operational states:

- Normal Operations
- Lockout Operations
- Maintenance Operations

The following sections describe these Operational States in further detail.

3.3.1 Normal Operational State

In Normal Operational state, the ESS can respond to authorized commands from utility operators, facility operators, and third party aggregators, as determined by their roles and permissions.

In transitions to and from the Normal Operational state, all ESS settings and actions will remain as they were until modified by an authorized command.

3.3.2 Lockout Operational State

When the energy storage control system (the controller) is powered up for the first time, it should be set to Lockout Operational state. In this state, only authorized personnel with the appropriate permissions will be allowed to control the ESS. In general, a small subset of the ESS operators will be granted permission to control the ESS when it is in Lockout Operation. For example, a manufacturer might specify that only local, onsite operators will be able to control the ESS when it is in the Lockout Operational state.

See Section 3.4 for more information on Roles and Permissions and how they relate to Operational States.

3.3.3 Local or Maintenance Operational State

An engineer who is performing maintenance on site will use the local HMI to control the ESS. If this operator wishes to make maintenance-related changes to the ESS in any way, he or she may need to enable this Local/Maintenance Operational state. Once this occurs, remote users are locked out, as are any scheduled operations, helping to ensure the safety of the on-site personnel and the ESS itself. Upon completion of the maintenance work, the engineer returns the ESS to either Lockout Operational state or Normal Operational state.

It is important to note that the Local/Maintenance Operational state may also be used for system-wide maintenance operations, such as upgrading the ESS software or conducting tests on the ESS as a whole. MESA-ESS also supports maintenance on a subsystem within the ESS.

3.4 Default Permissions for Default Roles

Default assignments of permissions to roles are shown in Table 4, but these may be changed or expanded as necessary for different implementations. 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 possibly modifiable after installation.

Table 4: Default Assignment of Permissions to Roles within Different ESS Operating States

Roles / Permissions	Utility ESS Operator	Utility Power Scheduler	Third-Party Aggregator	Facility ESS Operator	Maintenance Personnel	ESS Vendor	Guest Viewer
When ESS is in Normal Operational State							
• View current operational state	X	X	X	X	X	X	
• Set ESS to lockout operational state				X			
• Set ESS subsystem to maintenance/test mode				X	X		
• View roles and permissions	X	X	X	X	X	X	
• Modify roles and permissions				X		X	
• Monitor site-level ESS information				X	X	X	
• Monitor ESS status, modes, and measurements	X	X	X	X	X	X	X
• Monitor operational logs	X	X	X	X	X	X	
• Monitor security logs				X			
• Monitor historical data	X	X	X	X			
• Monitor configuration information				X	X	X	
• Update parameters of functional modes	X	X	X	X			
• Enable functional modes	X		X	X			
• Disable functional modes	X		X	X			
• Issue disconnect command from grid	X		X	X	X		
• Issue connect command to grid				X			
• Issue operational control command	X		X	X			
• Send schedule	X		X	X			
• Enable schedule	X		X	X			
• Disable schedule	X		X	X			
• Add item to operational log	X		X	X	X		
• Execute diagnostic tests					X		
• Issue test commands							
• Patch or update ESS software							
• Update security measures							
• Modify configurations							

Permissions \ Roles	Utility ESS Operator	Utility Power Scheduler	Third-Party Aggregator	Facility ESS Operator	Maintenance Personnel	ESS Vendor	Guest Viewer
When ESS is in Lockout Operational State							
• View current operational state	X	X	X	X	X	X	
• Set ESS to normal operational state				X			
• Set ESS to subsystem maintenance/test mode				X	X		
• View roles and permissions				X	X	X	
• Modify roles and permissions				X		X	
• Monitor site-level ESS information				X	X	X	
• Monitor ESS status, modes, and measurements	X		X	X	X	X	X
• Monitor operational logs				X	X	X	
• Monitor security logs				X	X		
• Monitor historical data				X	X		
• Update parameters of functional modes				X			
• Enable functional modes				X			
• Disable functional modes				X			
• Issue disconnect command from grid	X		X	X	X		
• Issue connect command to grid				X			
• Issue operational control command				X			
• Send schedule				X			
• Enable schedule				X			
• Disable schedule				X			
• Add item to operational log				X	X		
• Execute diagnostic tests					X		
• Issue test commands							
• Patch or update ESS software							
• Update security measures							
• Modify configurations							

Permissions \ Roles	Utility ESS Operator	Utility Power Scheduler	Third-Party Aggregator	Facility ESS Operator	Maintenance Personnel	ESS Vendor	Guest Viewer
When ESS (or subsystem) is in Maintenance/Test Operational State							
• View current operational state	X	X	X	X	X	X	
• Set ESS to normal operational state				X			
• Set ESS to lockout operational state				X	X		
• View roles and permissions				X	X	X	
• Modify roles and permissions				X		X	
• Monitor site-level ESS information				X	X	X	
• Monitor ESS status, modes, and measurements				X	X	X	X
• Monitor operational logs				X	X	X	
• Monitor security logs				X	X		
• Monitor historical data				X	X		
• Update parameters of functional modes				X	X	X	
• Enable functional modes							
• Disable functional modes				X			
• Issue disconnect command from grid				X			
• Issue connect command to grid							
• Issue operational control command							
• Send schedule							
• Enable schedule							
• Disable schedule							
• Add item to operational log				X	X		
• Execute diagnostic tests					X	X	
• Issue test commands					X	X	
• Patch or update ESS software					X	X	
• Update security measures					X	X	
• Modify configurations					X	X	

4. MESA-ESS DNP3 Interface

4.1 MESA-ESS DNP3 Profile Scope and Constraints

The MESA-ESS DNP3 profile has been designed to allow an energy storage system to be integrated into existing control and monitoring systems. In most installations, it will be most important to expose control and monitoring points to allow the ESS to be integrated into SCADA. For installations that support ESS scheduling, additional points exist in the profile to allow this functionality. Finally, in some installations it may be desirable to expose historical information through the DNP3 profile so that this data may be easily imported into an operational historian.

To support all of these scenarios, the points in the MESA-ESS DNP3 profile fall into one of five distinct categories: Configuration, SCADA, Scheduling, Historical, and Vendor Specific. These categories are described below in Table 5.

Table 5: MESA-ESS DNP3 Point Categories

Category	Description	Examples
Configuration	Configuration data which describe how a given energy storage asset has been configured and which features are enabled.	Power Factor Operating Quadrant, Supports Active Power Smoothing Mode, Reference Voltage
SCADA	Key operational points which allow the energy storage asset to be integrated into SCADA.	System Is In Lockout Mode, System Is Starting Up, System Has P1 Alarms, Charge/Discharge Active Power Target
Scheduling	Points which allow power scheduling personnel to effectively control the behavior of the energy storage system over a distinct time period.	Selected Schedule Is Enabled, Selected Schedule Priority, Selected Schedule Start Time
Historical	Detailed measurement and performance data which may be valuable to record in an operational historian	ESS Is Charging, Meter Active Power, Battery Bank State of Charge
Vendor Specific	Vendor specific data, including implementation-specific data that is not included in other categories	

4.2 MESA-ESS Implementation Levels

For many energy storage system installations, it will be necessary to implement the points in all point categories to ensure complete integration to existing systems. In other installations, only a subset of the points may be required. For example, if the asset owner does not maintain a historian, the points in the Historical category may be unnecessary.

To ensure broad compatibility across a variety of energy storage system controllers and installation types, the MESA-ESS specification includes the notion of “implementation levels.” These implementation levels allow an implementer to subset the DNP3 profile so that only required point categories are implemented. The levels of support are described in Table 6.

Table 6: MESA-ESS Implementation Levels

Level	Summary	Description
1	Configuration + SCADA Points Only	Only the points identified as Configuration or SCADA points are implemented by the MESA-ESS controller.
2	Configuration + SCADA + Scheduling Points	Only the points identified as Configuration, SCADA or Scheduling points are implemented by the MESA-ESS controller.
3	Configuration + SCADA + Scheduling + Historical Points	All points in the MESA-ESS profile are implemented by the controller

A MESA-compatible ESS controller which has decided to implement all three categories will be described as supporting MESA-ESS Level 3—the highest level of compatibility. Another MESA-compatible ESS controller may decide that integrating with SCADA is the only requirement, and, accordingly, only the Configuration and SCADA points will be implemented. This type of controller will be described as support MESA-ESS Level 1.

The points for Level 1 shall start at index 0 for all DNP3 point types. If Level 2 is implemented by the outstation, those points must start at the index which immediately follows the last Level 1 point in that point type. Similarly, if Level 3 is implemented, the first Level 3 point must be placed immediately following the last Level 2 point as shown in Figure 10. Vendor points are placed at the end of the points list after the last block of points from this profile.

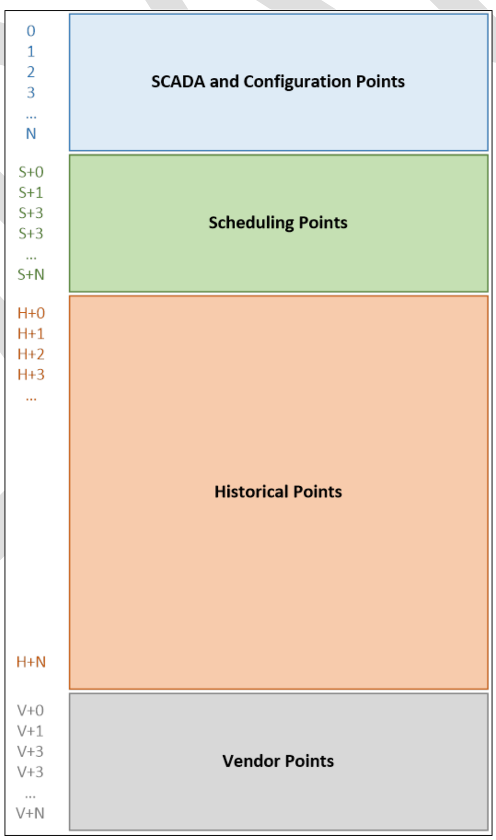

Figure 10: Indexing of DNP3 Categories

Note that in the figure above the points in the Vendor Points section are shown immediately following the points in the Historical Points section. While this is certainly a valid approach, this profile does not mandate that vendor specific points *immediately* follow the last point from the profile.

4.2.1.1 Repeating Blocks

Level 2 and Level 3 implementations must represent one or more repeating elements in the DNP3 point map. For example, Level 2 implementations will repeat three analog inputs for each schedule in the system as shown in the table below.

Table 7: Repeating Schedule Analog Inputs

Analog Input	Meaning
Schedule 1 Status	The status of the first stored schedule.
Schedule 1 Priority	The priority of the first stored schedule.
Schedule 1 Active Time Value	The active time value of the first stored schedule.
Schedule 2 Status	The status of the second stored schedule.
Schedule 2 Priority	The priority of the second stored schedule.
Schedule 2 Active Time Value	The active time value of the second stored schedule.
…	…
Schedule N Status	The status of the nth stored schedule.
Schedule N Priority	The priority of the nth stored schedule.
Schedule N Active Time Value	The active time value of the nth stored schedule.

For Level 3 implementers, blocks of analog inputs and analog outputs will be repeated for each meter, DER unit, inverter, and battery in the configured system as shown in Figure 11.

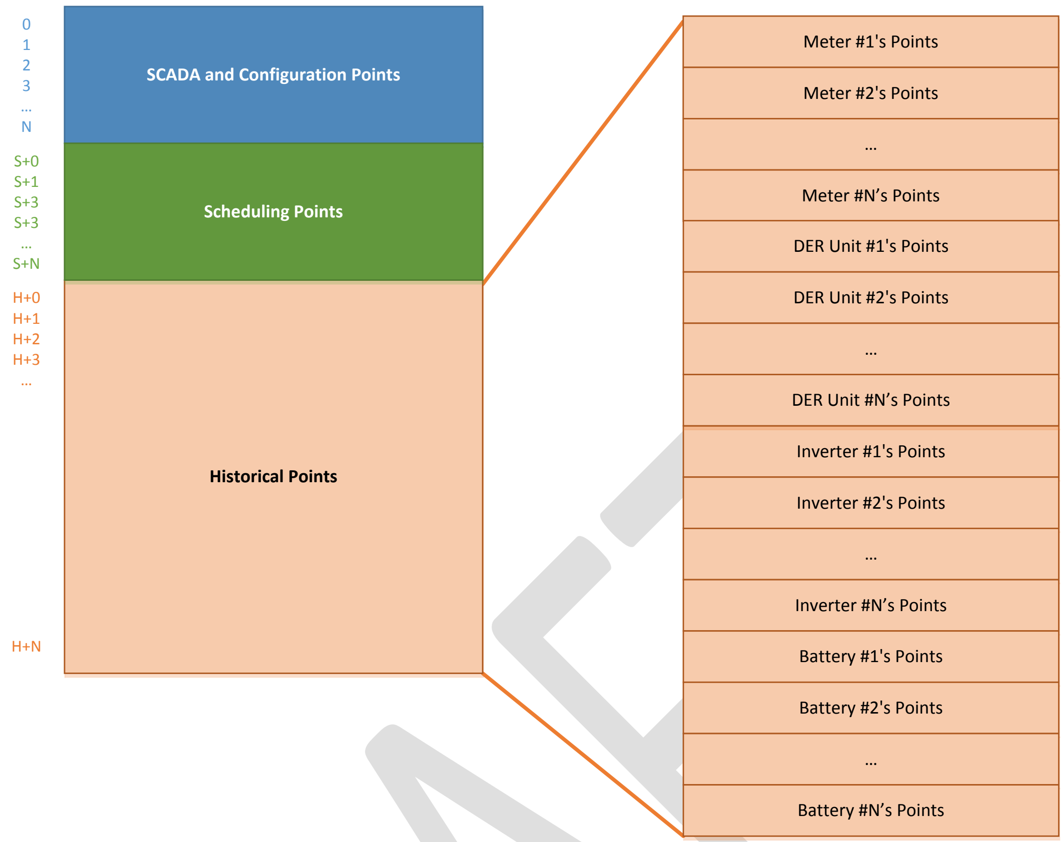

Figure 11: Level 3 Repeating Elements

Because the number of elements in these repeating blocks will vary by installation, the total length of the point lists for Level 2 and Level 3 implementations will also vary. However, Level 1 analog input points exist in the profile which can be used to deterministically calculate the total number of points in the profile. These points are shown in Table 8 below.

Table 8: Profile Information Analog Input Points

Analog Input Point	Description
DER Profile Version Number	Indicates what version of the profile has been implemented by the outstation.
DER Profile Implementation Level	Indicates whether the outstation has implemented Level 1, Level 2 or Level 3.
Number of System Schedules	The number of system schedules stored by the outstation.
Number of Meters	The number of meters that are monitored by the outstation.
Number of Inverters	The number of inverters that are monitored and controlled by the outstation.
Number of Batteries	The number of batteries that are monitored and controlled by the outstation.
Number of DER Units	The number of DER units which are connected to the outstation.

4.3 Profile Background

Unlike DNP3 AN2013-001, the MESA-ESS profile targets DNP3 Level 2. MESA partners and early adopters have indicated that a number of electric utilities that are exploring energy storage have infrastructural limitations which prevent the adoption of more advanced DNP3 features (e.g. Double-Bit Binary Inputs). While a MESA-compatible ESS controller may choose to offer more advanced functionality in some cases, these features are by no means required by MESA-ESS.

For reference, the following DNP3 Level 3 and 4 features are avoided by MESA-ESS:

- DNP3 Level 3 Features
  - Certain specific objects and variations
  - Group 0 (Device Attributes) read and write requests
  - The larger range of function codes specified by Level 3 and Level 4
  - Enabling and disabling of unsolicited responses by class
  - Dynamically reassigning data objects to classes (e.g., at runtime)
- DNP3 Level 4 Features
  - Self-address reservation
  - Double-bit binary input objects
  - The larger range of function codes specified by Level 4
  - Variations with time for frozen counters, frozen counter events, and analog input events
  - Floating-point variations for both analog inputs and analog outputs
  - Analog input reporting deadband
  - Event objects for binary and analog outputs
  - Device attributes
  - LAN time synchronization method

4.4 DNP3 Classes

MESA-ESS uses the criteria in Table 9 for assigning points to default classes.

Table 9: Criteria for Assigning Points to Default Classes

Class	Criteria
1	Critical data. Alarms and other events requiring immediate action.
2	Feedback
3	Measurements and configuration

4.5 Curves and Schedules

A MESA-ESS compatible outstation will typically need to include support for curves (e.g. Volt-VAr curves) and schedules. These objects are similar in that they can be thought of as a two-dimensional graph. For example, a Volt-VAr curve specifies a voltage measurement on the X-axis and a VAr output requirement on the Y-axis. Similarly, a Charge/Discharge schedule is represented with time on the X-axis and power output on the Y-axis.

For the most part, curves and schedules are modeled as a series of points, where each point has an X-value and a Y-value. In DNP3, each of these characteristics maps to a single point in the profile. For a schedule with 100 points, the total number of DNP3 points will be 2 * 100 = 200. Additionally, curves and schedules often have a few top-level properties which translate into a small number of additional DNP3 points per curve/schedule.

It is a design goal of MESA-ESS to allow multiple curves and schedules to be created, updated, and read through the profile. But in order to keep the DNP3 point lists manageable, the points for each curve/schedule are not repeated for every supported curve schedule. Instead, a "selector model" is used for these objects.

In the selector model, the DNP3 master must first indicate which curve or schedule should be read or updated. This is done by writing an index value to a selector analog output. For example, to view or update the 13th schedule in the set of schedules, the master begins by setting the Schedule to Edit Selector point to the value 13. When this occurs, the outstation updates the schedule points (BIs, BOs, AIs, and AOs) to reflect the value in schedule at index 13. In effect, the schedule points in the DNP3 profile act as a window into the full set of schedules. The same is true for curves.

4.6 Ramp Rates Use and Mode Priorities

Additional default ramp rates have been included to include ramp up and ramp down while generating and while charging. In some modes, specific ramp rates and/or ramp times have been included.

Each mode also has a priority field, allowing them to indicate which modes may have precedence over other modes if they might otherwise conflict.

4.7 Alarm Aggregation and Priorities

Each of the devices within an energy storage system may raise alarms when abnormalities occur. Additionally, the energy storage system itself may raise alarms under certain conditions (e.g., failure to communicate with a device). The Historical category of DNP3 points provides detailed alarm and warning information for the ESS and the devices that make up the ESS.

Because this detailed alarm information is generally not desired in SCADA, MESA-ESS exposes aggregate alarm information for the system as a whole. This aggregate data is provided in the following binary inputs:

Table 10: Aggregate Alarm Points

Binary Input	Description
CALH1.GrAlm	System Has P1 Alarms
CALH2.GrAlm	System Has P2 Alarms
CALH3.GrAlm	System Has P3 Alarms

As seen in Table 10, three aggregate alarm points are exposed in the DNP3 Profile, each with a different priority. How individual alarms are mapped to the different priorities is left to the implementer. One MESA-ESS controller may choose to map alarms to priorities based on severity (e.g., Fire Alarms are P1, Fan Warning is P3), while another may choose to map these priorities to roles (e.g., The Facility Operator will handle all P1 alarms, while the Remote Operator will handle all P2s and P3s).

5. ESS Basic Nameplate, Status, Setting, and Measurement Data Objects

Note: Although these ESS functions have been described in IEC 61850-7-420 and IEC 61850-90-7 standards, those standards are currently being updated. In addition, the revised DNP3 Application Note (AN2017-001) is still not final. Therefore, any implementations based on the data objects described in this MESA-ESS Specification may need updates at a later time, as indicated by a different version. In the meantime, these sections will reference the appropriate sections of the DNP3 spreadsheet.

The data objects in this section are organized into 5 main categories, some with subcategories:

- ESS Nameplate and Capability Data Objects
  - ESS Nameplate and Fixed Capability Settings as DNP3 Analog Inputs (AI1 – AI42)
  - ESS Capability Settings as DNP3 Analog Outputs (AO0 – AO412)
  - Freeze Counters as DNP3 Analog Inputs and Outputs (AI 46 – AI47, AO25 – AO26)
- ESS Status and Binary Setting Data Objects
  - ESS Status as DNP3 Binary Inputs (BI0 – BI49)
  - ESS Binary Setting Data Objects (BO0 – BO7)
- ESS Measurement Data Objects from ECPs (AI HM – AI HM+60)
- ESS Historian Data Objects (Historical Data as DNP3 Binary Inputs and Analog Inputs)
  - ESS Historian Status as DNP3 Binary Inputs (BI HM – BI HM+12, BI HDU – BI HDU+3, BI HI – BI HI+32, BI HB – BI HB+38)
  - ESS Historian DER Unit Measurements as DNP3 Analog Inputs (AI HDU – AI HDU+10)
  - ESS Historian Inverter Measurements as DNP3 Analog Inputs (AI HI – AI HI+22)
  - ESS Historian Battery Measurements as DNP3 Analog Inputs (AI HB – AI HB+30)

6. ESS Functions and Modes

6.1 Overview of ESS Functions and Modes

This section provides an overview of the functions and modes that are supported by the MESA-ESS specification.

6.1.1 Table of ESS Functions and Modes

IEC 61850 uses the term “function” for a single DER action while an “operational mode” entails continuous autonomous internal analysis and actions by the DER once the mode is enabled. In this MESA-ESS specification, the distinction between functions and modes is not completely maintained, since there is ultimately a blurring between “a single DER action” and “continuous autonomous actions”.

Modes usually entail the DER system receiving some measurement either at the DER’s ECP, from a remote ECP within the facility, from the PCC, or from an external ECP (termed the “Referenced ECP”), or reacting to some event, and then responding to that measurement or event according the mode’s parameters. These modes are defined in IEC/TR 61850-90-7 (now moved to the IEC 61850-7-520 Guidelines for IEC 61850-7-420) and further described in EPRI 3002002233, *Common Functions for Smart Inverters, version 3*.

The MESA-ESS profile supports the configuration and operation of the functions and modes shown in Table 11. The table also indicates where the functions and modes are described in the EPRI Common Functions report, the IEC 61850-7-520 guidelines, and the proposed updates to IEC 61850-7-420. Implementations are not required to include all of the functions or modes since configuration data objects are used to indicate those supported. Each of these functions and modes can be invoked or enabled/disabled by authorized operators. In addition, some of these functions or modes may be controlled by a schedule. The sections below discuss each of these functions and modes in further detail.

Table 11: MESA-ESS functions and modes

#	Function or Mode	Description and Key Parameters	EPRI Common Functions	IEC 61850-7-520 or Other Sources	IEC 61850-7-420 and 7-4 Proposed LNs
	Functions				
1.	**Monitoring Function** The ESS provides nameplate, configuration, status, measurements, and other requested data	The ESS provides status, measurements, alarms, logs, and other data as authorized and requested by users. Examples include connect status, real and reactive power output/charging, state of charge, voltage, and other measurements.	Section 23	Function DS plus LN DBAT, DBTC	LN DBAT LN DBTC LN DRAT LN DRCT LN MMXU
2.	**Disconnect/Connect Function** Disconnect or connect the ESS from the grid at its ECP	The disconnect command initiates the galvanic separation (usually via switches or breakers) of the ESS at its ECP. The connect command initiates the reconnection of the ESS at its ECP.	Section 3	Function INV1	LN DCND or LN CSWI LN XCBR
3.	**Cease to Energize and Return to Service** Cease any current flow at the ECP or PCC Allow current flow at the ECP or PCC	"Cease to energize" is a different function from disconnect/connect. The purpose is to prevent the flow of current at the ECP or PCC. It may use the Active Power Limit mode with the Active Power output value set to zero. "Return to service" allows current flow at the ECP or PCC.	Section 3	Function INV1	LN DCTE
	Emergency Modes				
4.	**Low/High Voltage Ride-Through Mode** The ESS rides through temporary fluctuations in voltage	The ESS follows the utility-specified voltage ride-through parameters to avoid tripping off unnecessarily. Although normally enabled by default, this ride-through mode may be updated, enabled, and disabled.	Section 14	Mode H/LVRT	LN DVRT
5.	**Low/High Frequency Ride-Through Mode** The ESS rides through temporary fluctuations in frequency	The ESS follows the utility-specified frequency ride-through parameters to avoid tripping off unnecessarily. Although normally enabled by default, this ride-through mode may be update, enabled, and disabled.	Section 15	Mode H/LFRT	LN DFRT

#	Function or Mode	Description and Key Parameters	EPRI Common Functions	IEC 61850-7-520 or Other Sources	IEC 61850-7-420 and 7-4 Proposed LNs
6.	**Dynamic Reactive Current Support Mode** The ESS reacts against rapid voltage changes (spikes and sags) to provide dynamic system stabilization	The ESS provides dynamic reactive current support in response to voltage spikes and sags, similar to acting as inertia against rapid changes. This mode may be focused on emergency situations or may be used during normal operations. When the dynamic reactive current support mode is enabled, the ESS monitors the voltage at the Referenced ECP and responds based on the parameters.	Section 16	Mode TV	LN RDGS
7.	**Dynamic Volt-Watt Mode** The ESS system dynamically absorbs or produces additional watts	The ESS system dynamically absorbs or produces additional watts in proportion to the instantaneous difference from a moving average of the measured voltage. This function utilizes the same basic concepts and settings as the Dynamic Reactive Current function, but uses active power as an output rather than reactive current.	Section 18		LN DVWD
8.	**Frequency-Watt Emergency Mode** The ESS responds to large frequency excursions during H/LFRT events at a Referenced ECP by changing its charging or discharging rate	The ESS is provided with frequency-watt curves that define the changes in its watt output based on frequencies outside the normal range during H/LFRT events. When the emergency frequency-watt mode is enabled, the ESS monitors the frequency and adjusts its discharging or charging rate to follow the specified emergency frequency-watt curve parameters. New data points are provided multiple times per second.	Section 11	Mode FW	LN DWHZ
	Active Power Modes				
9.	**Charge/Discharge Mode** Set the ESS to charge or discharge at the Referenced ECP	The ESS is set to a percentage of maximum charge or discharge rate at the Referenced EC). A positive value indicates discharge, and a negative value means charge.	Section 5	Function INV4	LN DCHD
10.	**Coordinated Charge/Discharge Management Mode** The ESS determines when and how fast to charge or discharge so long as it meets its target state of charge level obligation by the specified time	The ESS is provided with a target state of charge and a time by which that SOC is to be reached. This allows the ESS to determine when to charge or discharge based on price. The ESS takes into account not only the duration at maximum charging / discharging rate, but also other factors, such as, at high SOC, the maximum charging rate may not be able to be sustained, and vice versa, at low SOC, the maximum discharge rate may not be able to be sustained.	Section 7 (modified)	-	LN DTCD

#	Function or Mode	Description and Key Parameters	EPRI Common Functions	IEC 61850-7-520 or Other Sources	IEC 61850-7-420 and 7-4 Proposed LNs
11.	**Active Power Limit Mode** Limits the discharging and/or charging level of the ESS based on the Referenced ECP	The discharging and/or charging of the ESS is limited at the Referenced ECP, indicated as absolute watt values. Separate parameters are provided for discharging or charging limits to permit these to be different.	Section 4	Function INV2	LN DAMG
12.	**Peak Power Limiting Mode** The ESS limits the load at the Referenced ECP after it exceeds a threshold target power level	The Active Power output of the ESS limits the load at the Referenced ECP if it starts to exceed a target power level, thus limiting the power that needs to be imported from the grid. The discharging output is a percentage of the excess load over the target power level. The target power level is specified in percentage of maximum watts.	Section 19	-	LN DPKP
13.	**Load Following Mode** The ESS counteracts the load by a percentage at the Referenced ECP, after it starts to exceed a threshold target power level	The Active Power output of the ESS follows and counteracts the load at the Referenced ECP if it starts to exceed a target power level, thus resulting in a flat power profile. The discharging output is a percentage of the excess load over the target power level. The target power level is specified in percentage of maximum watts.	Section 20		LN DLFL
14.	**Generation Following Mode** The charging and/or discharging of the ESS counteracts generation power at the Referenced ECP.	The charging and/or discharging of the ESS follows and counteracts the generation measured at the Referenced ECP if it starts to exceed a target power level. The charging and/or discharging output is a percentage of the excess generation watts over the target power level. The target power level is specified in percentage of maximum watts.	Section 20	-	LN DGFL
15.	**Automatic Generation Control (AGC) Mode** The ESS responds to raise and lower power level requests to provide frequency regulation support	When AGC mode is enabled, the ESS responds to signals to increase or decrease the rate of charging or discharging every 4 to 10 seconds, with the purpose of managing frequency.	Defined by the Utility Control Area	Function INV4 (requires additional parameters)	LN DAGC

#	Function or Mode	Description and Key Parameters	EPRI Common Functions	IEC 61850-7-520 or Other Sources	IEC 61850-7-420 and 7-4 Proposed LNs
16.	**Active Power Smoothing Mode** The ESS produces or absorbs Active Power in order to smooth the changes in the power level at the Referenced ECP.	The ESS follows the specified smoothing gradient which is a signed quantity that establishes the ratio of smoothing Active Power to the real-time delta-watts of the load or generation at the Referenced ECP. When the power smoothing mode is enabled, the ESS receives the watt measurements from a meter (or another source) at the Referenced ECP. New data points are provided multiple times per second.	Section 17	-	LN DWSM
17.	**Volt-Watt Mode** The ESS responds to changes in the voltage at the Referenced ECP by changing its charging or discharging rate	The ESS is provided with voltage-watt curves that define the changes in its watt output based on voltage deviations from nominal, as a means for countering those voltage deviations. When the volt-watt mode is enabled, the ESS receives the voltage measurement from a meter (or another source) at the Referenced ECP. The ESS adjusts its discharging or charging rate to follow the specified volt-watt curve parameters. New data points will be provided multiple times per second.	Section 10	Mode VW	LN DVWC
18.	**Frequency-Watt Mode** The ESS responds to changes in frequency at the Referenced ECP by changing its charging or discharging rate based on frequency deviations from nominal, as a means for countering those frequency deviations	The ESS is provided with frequency-watt curves that define the changes in its watt output based on frequency deviations from nominal, as a means for countering those frequency deviations and smoothing the frequency. When the frequency-watt mode is enabled, the ESS monitors the frequency and adjusts its discharging or charging rate to follow the specified frequency-watt curve parameters. New data points are provided multiple times per second.	Section 11	Mode FW	LN DFWS
	Reactive Power Modes				
19.	**Fixed Power Factor Mode** The ESS power factor is set to a fixed value.	The ESS power factor is set to the specified power factor. A leading power factor is positive and a lagging power factor is negative, as defined by the IEEE sign convention.	Section 8	Function INV3	LN DFPF

#	Function or Mode	Description and Key Parameters	EPRI Common Functions	IEC 61850-7-520 or Other Sources	IEC 61850-7-420 and 7-4 Proposed LNs
20.	**Volt-VAr Control Mode** The ESS responds to changes in voltage at the Referenced ECP by supplying or absorbing vars in order to maintain the desired voltage level	The ESS is provided with voltage-VAr curves that define the vars for voltage levels. When the Volt-VAr Control Mode is enabled, the ESS receives the voltage measurements from a meter (or another source) at the Referenced ECP. The ESS responds by supplying or absorbing vars according to the specified Volt-VAr curve in order to maintain the desired voltage level. New data points are provided multiple times per second.	Section 9	Mode VV11 and VV12	LN DVVC
21.	**Watt-VAr Mode** The ESS responds to changes in power at the Referenced ECP by changing its power factor	The ESS is provided with watt-reactive curves that define the changes in its power factor based changes of power. When the Watt-Power Factor Mode is enabled, the ESS modifies its power factor setting in response to the power level at the Referenced ECP.	Section 12	Mode WP	LN FPFW
22.	**Power Factor Limiting Mode** The ESS supplies or absorbs VArs to hold the power factor at the Referenced ECP within the PF limit	When the PF Limiting mode is enabled, the ESS is provided with the target PF. The ESS supplies or absorbs vars in order to maintain the PF at the Referenced ECP within the target PF.	-	-	LN DPFC
23.	**Scheduling of Power Settings and Modes**	The ESS follows the schedule which consists of a time offset (specified as a number of seconds) from the start of the schedule and is associated with: • a power system setting • the enabling/disabling of an operational mode • a price signal	Covered in different sections	IEC 61850-90-10	LN FSCH LN FSCC
24.	**Historical Information**	Detailed measurement and performance data which may be valuable to record in an operational historian			LN MMXU
25.	**Microgrid Separation Control** *{Not included}*	Process for normal separation, emergency separation, and reconnection		Identified by many parties	LN DMIC (not defined yet)
26.	**Provide Black Start Capability** *{Not included}*	Ability to start without grid power and the ability to add significant load in segmented groups		Identified by many parties	
27.	**Provide Backup Power** *{Not included}*	Ability to provide power to local loads when not connected to the grid		Identified by many parties	

6.1.2 Compatibility, Coexistence, and Mutual Exclusivity of ESS Modes

Most modes are compatible with each other although some are mutually exclusive. A few could possibly co-exist, but the priority of one mode over the other must be established. For example, all emergency modes could be set with higher priority than modes that would operate during normal conditions. Active Power modes are compatible with reactive power and frequency modes. However, the AGC mode is mutually exclusive with most of the other Active Power modes, but may possibly co-exist with limiting Active Power charge/discharge rates if the latter is given higher priority.

The ESS cross-mode compatibility is shown in Table 12.

Table 12: Compatibility, possible coexistence, and mutually exclusive ESS modes

ESS Modes: Compatible (c), Possibly Coexist (P), or Mutually Exclusive (M) **In all cases, emergency modes take precedence over other modes. For (P) situations, priority may be by agreement**		**Emergency**				**Real Power**								**Reactive Power**			
		Voltage Ride-Through	Frequency Ride-Through	Dynamic reactive current support	Frequency-watt emergency	Limit real power discharge/charge rate	Peak Power Limiting	Load / generation following	Real power smoothing	Volt-watt control	AGC (utility sends Reg /down)	Charge-by management	Frequency-watt smoothing	Fixed power factor	Volt-var control	Watt-PF	Power factor correction
4	Voltage Ride-Through		c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
5	Frequency Ride-Through			c	c	c	c	c	c	c	c	c	c	c	c	c	c
6	Dynamic reactive current support				c	c	c	c	c	c	c	c	c	c	c	c	c
19	Frequency-watt emergency					c	c	c	c	c	c	c	c	c	c	c	c
7	Limit real power discharge/charge rate						**P**	**P**	**P**	**P**	**P**	c	c	c	c	c	c
8	Peak Power Limiting							**M**	**P**	**P**	**M**	c	c	c	c	c	c
9	Load / generation following								**P**	**P**	**M**	c	**P**	c	c	c	c
10	Real power smoothing									**P**	**M**	c	c	c	c	c	c
11	Volt-watt control										**M**	c	c	c	c	c	c
12	AGC (utility sends Reg up and down commands)											c	c	c	c	c	c
13	Charge-by management												c	c	c	c	c
18	Frequency-watt smoothing													c	c	c	c
14	Fixed power factor														**M**	**M**	**M**
15	Volt-var control															**P**	**P**
16	Watt-PF																**P**
17	Power factor correction																

6.2 ESS Functions

6.2.1 Monitoring Function

The monitoring function supports the acquisition by a utility, a facility energy management system, aggregator, or any other third party of data from the ESS. The detailed input requirements of the monitoring function are covered in Section 4.

6.2.2 Disconnect and Connect Function

This function permits a utility, a facility energy management system, aggregator, or any other third party to command an ESS to reconnect to or to galvanically disconnect from the local and/or area EPS at the ESS's ECP through the use of a switch device.

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.
- **Ramp Time**: a time to ramp down for a disconnect or to ramp up after a reconnect.
- **Reversion Timeout**: a time, after which a command to disconnect expires and the device reconnects. Reversion Timeout = 0 means that there is no timeout. There is no reversion for reconnect.

Table 13 indicates the steps to perform and the data objects involved for disconnect.

Table 13: Steps to perform a Disconnect

Step	IEC 61850	Description	M / O / C	Function Codes	Data Type
1.	DCND.WinTms	Set Time Window	O	Direct Operate / Response	AI, AO
2.	DCND.RmpTms	Set Ramp Time	O	Direct Operate / Response	AI, AO
3.	DCND.RvrtTms	Set Timeout Period	O	Direct Operate / Response	AI, AO
4.	If switch, CSWI.Pos	Issue switch open control command, and receive response	C	Operate / Response	BI, BO
5.	If not switch, DCND.DERStop	Set ESS to cease to energize and receive confirmation	C	Operate / Response	BI, BO

Table 13 indicates the steps to perform and the data objects involved for reconnect or return to service.

Table 14: Steps to perform a Reconnect

Step	IEC 61850	Description	M / O / C	Function Codes	Data Type
1.	DCND.StrWinTms	Set Start Time Window	O	Direct Operate / Response	AI, AO
2.	DCND.RmpTms	Set Ramp Time	O	Direct Operate / Response	AI, AO
3.	DCND.ECPStrAuth	Permission to reconnect	O	Direct Operate / Response	BI, BO
4.	If switch, CSWI.Pos	Issue switch close control command, and receive response	C	Operate / Response	BI, BO
5.	If not switch, DCND.DERStr	Set the ESS to return to service and receive confirmation	C	Operate / Response	BI, BO

6.2.3 Cease to Energize and Return to Service Function

As mutually agreed during the interconnection process, the ESS disconnect could use "cease to energize". IEEE 1547 (tentatively) defines "cease to energize" as "cessation of active power output at the PCC."

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.
- **Ramp Time**: a time to ramp down for a cease to energize or to ramp up after a return to service.
- **Reversion Timeout**: a time after which a command to cease to energize expires and the device reconnects. Reversion Timeout = 0 means that there is no timeout. There is no reversion for reconnect.

Table 15 indicates the steps to perform and the data objects involved for cease to energize.

Table 15: Steps to perform a Cease to Energize

Step	IEC 61850	Description	M / O / C	Function Codes	Data Type
1.	DCTE.WinTms	Set Time Window	O	Direct Operate / Response	AI, AO
2.	DCTE.RmpTms	Set Ramp Time	O	Direct Operate / Response	AI, AO
3.	DCTE.RvrtTms	Set Timeout Period	O	Direct Operate / Response	AI, AO
4.	DCTE.DERStop	Set ESS to cease to energize and receive confirmation	C	Operate / Response	BI, BO

Table 16 indicates the steps to perform and the data objects involved for return to service.

Table 16: Steps to perform a Return to Service

Step	IEC 61850	Description	M / O / C	Function Codes	Data Type
1.	DCTE.StrWinTms	Set Start Time Window	O	Direct Operate / Response	AI, AO
2.	DCTE.RmpTms	Set Ramp Time	O	Direct Operate / Response	AI, AO
3.	DCTE.ECPClsAuth	Permission to return to service	O	Direct Operate / Response	BI, BO
4.	DCTE.DERStr	Set the ESS to return to service and receive confirmation	C	Operate / Response	BI, BO

6.3 Emergency Modes

6.3.1 Low/High Voltage Ride-Through Mode

Four curves are defined for Low/High voltage ride-through. Each curve defines the boundary between the different zones. Only the Must Trip curves are mandatory.

- High Voltage Must Trip boundary
- High Voltage Momentary Cessation boundary
- Low Voltage Momentary Cessation boundary
- Low Voltage Must Trip boundary

Figure 12 illustrates the concept of the different zones. The actual H/LVRT values are provided by utilities, reflecting regulatory requirements and utility-specific requirements.

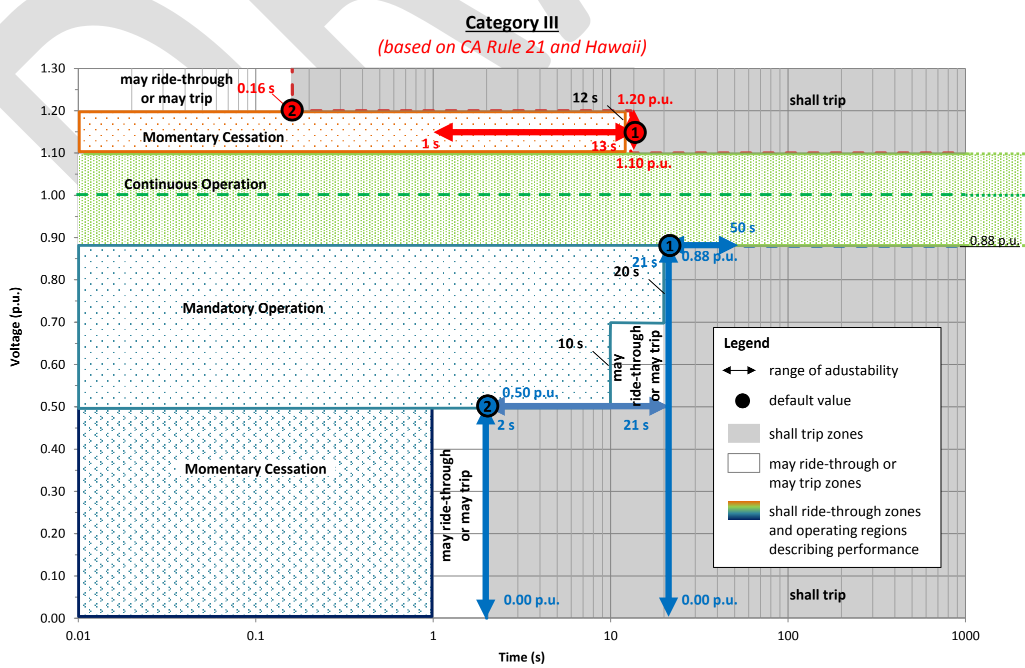

Figure 12: Example of California's Voltage Ride-Through requirements

The data items in Table 17 identify the steps for managing the H/LVRT mode, first by establishing the reference voltage level and offset, defining the time-voltage curves, enabling the mode, then optionally monitoring the H/LVRT alarm to determine if a H/LVRT event has taken place.

Table 17: Steps to manage the H/LVRT mode

Step	IEC 61850	Description	M / O / C	Function Codes	DNP3 Type
28.	DVRT.ECPRefId	Low/High Voltage Ride-Through Signal Meter ID. Ride through limited voltage spikes and sags, while still ensuring anti-islanding cease-to-energize when required	M		AI, AO
29.	DVRT.VolRef	H/LVRT Reference Input. Voltage measurements from the referenced connection point	M		AI, AO
30.	DRCT.VRef	Set the Reference Voltage if it is not already set	O	Direct Operate / Response	AI, AO
31.	DRCT.VRegOfs	Set the Reference Voltage Offset if it is not already set	O	Direct Operate / Response	AI, AO
32.	DVRT.CurveVHiTr	Paired array of independent and dependent variables: xVal = time yVal = HVRT Must Trip voltage values	M	Direct Operate / Response	AI, AO
33.	DVRT.CurveVHiCea	Paired array of independent and dependent variables: xVal = time yVal = HVRT Momentary Cessation voltage values	O	Direct Operate / Response	AI, AO
34.	DVRT.CurveVLoCea	Paired array of independent and dependent variables: xVal = time yVal = LVRT Momentary Cessation voltage values	O	Direct Operate / Response	AI, AO
35.	DVRT.CurveVLoTr	Paired array of independent and dependent variables: xVal = time yVal = LVRT Must Trip voltage values	M	Direct Operate / Response	AI, AO
36.	DVRT.ModEna	Enable Low/High voltage ride-through	M	Select / Response, Operate / Response	BI, BO
37.	DVRT.ModVRtSt	Alarm indicating that a Voltage Ride-Through event has occurred	O		BI

6.3.2 Low/High Frequency Ride-Through Mode

Four curves are defined for Low/High Frequency ride-through. Each curve defines the boundary between the different zones, as illustrated. Only the Must Trip curves are mandatory.

- High Frequency Must Trip boundary
- High Frequency Mandatory Operation boundary
- Low Frequency Mandatory Operation boundary
- Low Frequency Must Trip boundary

The data items in Table 18 identify the steps for managing the H/LFRT mode, first by establishing the reference voltage level and offset, defining the time-frequency curves, enabling the mode, then optionally monitoring the H/LFRT alarm to determine if a H/LFRT event has taken place.

Table 18: Steps to manage the H/LFRT mode

Step	IEC 61850	Description	M / O / C	Function Codes	DNP3 Type
1.	DFRT.ECPRef	Low/High Frequency Ride-Through Signal Meter ID. Ride through limited voltage spikes and sags, while still ensuring anti-islanding cease-to-energize when required	M		AI, AO
2.	DFRT.HzRef	H/LFRT Reference Input. Frequency measurements from the referenced connection point	M		AI, AO
3.	DFRT.NomHz	Set the nominal frequency if it is not already set	O	Direct Operate / Response	AI, AO
4.	DFRT.CurveHzHiTr	Paired array of independent and dependent variables: xVal = time yVal = HFRT Must Trip frequency values	M		AI, AO
5.	DFRT.CurveHzHiCea	Paired array of independent and dependent variables: xVal = time yVal = HFRT Momentary Cessation frequency values	O		AI, AO
6.	DFRT.CurveHzLoCea	Paired array of independent and dependent variables: xVal = time yVal = LFRT Momentary Cessation frequency values	O		AI, AO
7.	DFRT.CurveHzLoTr	Paired array of independent and dependent variables: xVal = time yVal = LFRT Must Trip frequency values	M		AI, AO

Step	IEC 61850	Description	M / O / C	Function Codes	DNP3 Type
8.	DFRT.ModEna	Enable Low/High voltage ride-through	M	Select / Response, Operate / Response	BI, BO
9.	DFRT.ModHzRtSt	Alarm indicating that a Frequency Ride-Through event has occurred	O		BI

6.3.3 Dynamic Reactive Current Support Mode

6.3.3.1 Basic Concepts of Dynamic Reactive Current Support Mode

The basic concept of the Dynamic Reactive Current Support mode is illustrated in Figure 13. This function provides dynamic reactive current support in response to a sudden rise or fall in the voltage at the Referenced ECP. Since its purpose is to react to these sudden voltage spikes and sags, it is considered as an emergency mode, but it could be used not only if HLVRT is in effect but also during normal operations which are experiencing locally-caused voltage spikes and sags. There are also slightly different algorithms that could be used, as described below.

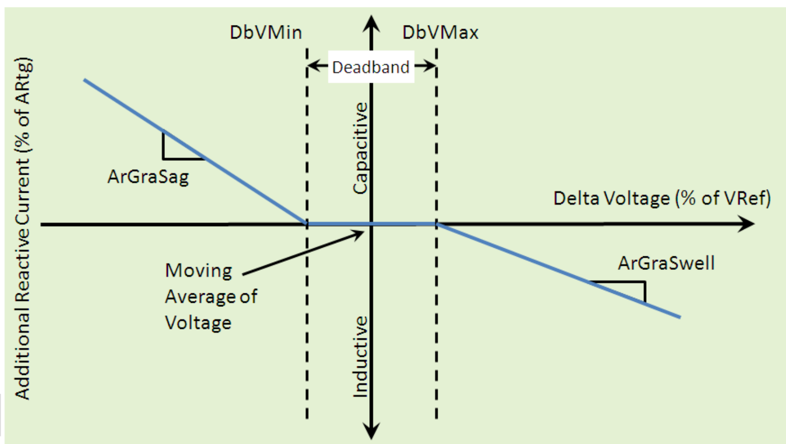

Figure 13: Dynamic Reactive Current Support Function, Basic Concept

The "Delta Voltage" is 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 14.

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.

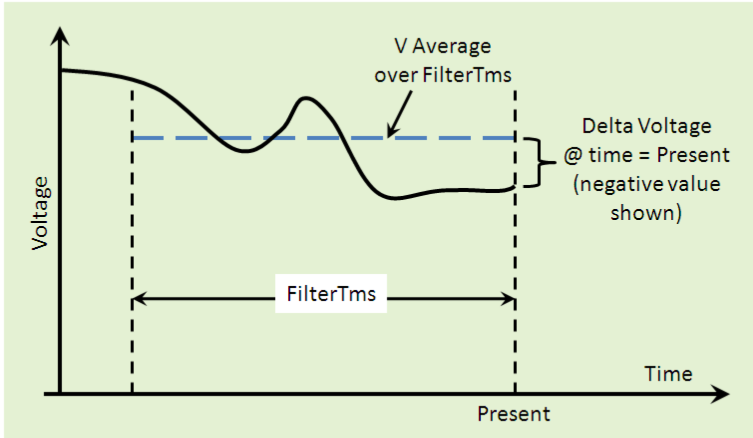

Figure 14: Delta-Voltage Calculation

6.3.3.2 Event-Based Behavior

The dynamic reactive current support mode can be triggered by a voltage spike or sag event, as illustrated in Figure 15. Identifying a particular voltage spike or sag as an "event" allows other functions to be coordinated with this function. 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 Volt-VAr function) may be 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.

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. Reactive current support continues until a time t1 at which point the voltage returns above DbVMin. In order to make sure that the voltage has really returned within the deadband range, a time period of HoldTmms is initiated and this event continues to be considered active until time t2 (which is t1 + HoldTmms). If during the HoldTmms time period the voltage again exceeds DbVMin, dynamic reactive current support continues as part of the same event.

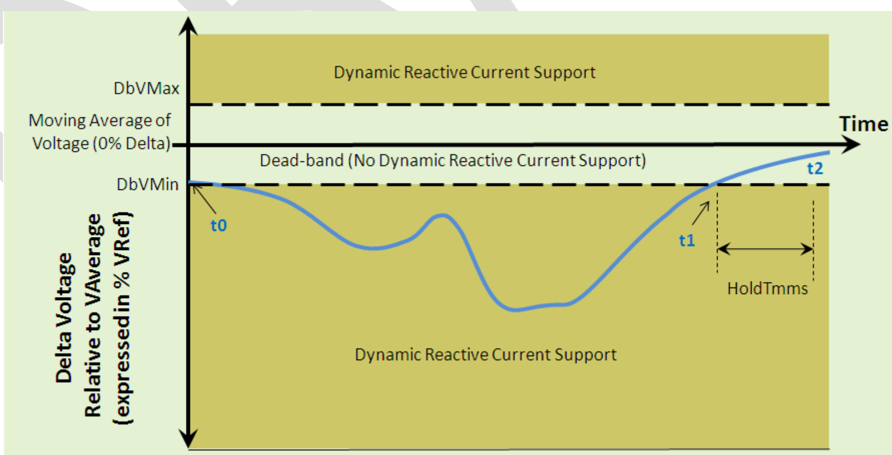

Figure 15: Activation Zones for Reactive Current Support

6.3.3.3 Alternative Gradient Shape

An alternative behavior to that shown in Figure 13 is illustrated in Figure 16. In this alternative, ArGraMod is used to select between the behavior of Figure 13 (gradients trend toward zero at the deadband edges) and that of Figure 16 (gradients trend toward zero at the center) in which 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.

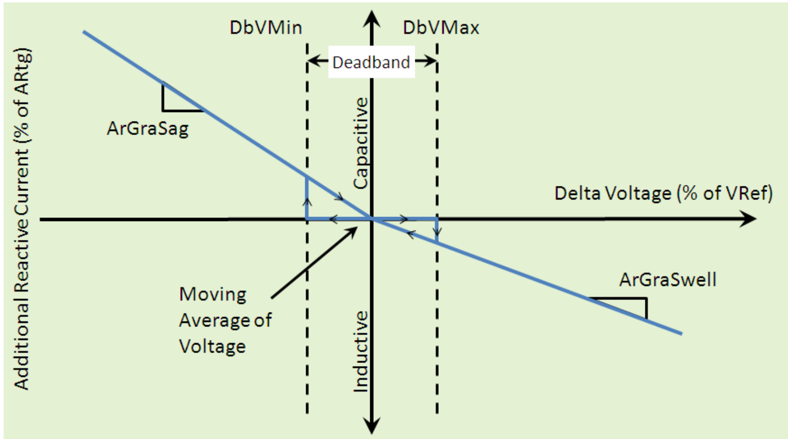

Figure 16: Alternative Gradient Behavior, Selected by ArGraMod

6.3.3.4 Blocking Zones

Another optional addition is that of a blocking zone, inside which additional reactive current support is not provided. As illustrated in Figure 17, this zone is defined by the three parameters: BlkZnTmms, BlkZnV, and HysBlkZnV. It is understood that all ESS 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.

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 or spike "event" as described previously.

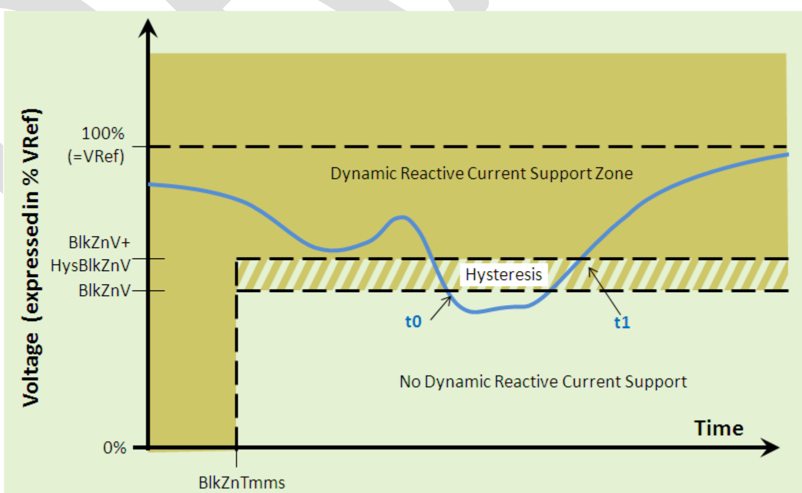

Figure 17: Settings to Define a Blocking Zone

6.3.3.5 Priority of Dynamic Reactive Current Support 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 19: Dynamic Reactive Current Mode Control. Implementation and utilization of this Boolean is optional. If it is not used or supported, the default behavior is that Active Power levels (Watts) are curtailed as needed to support this function.

Table 19: 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 support	Inverter is Delivering Active Power, Voltage Sags	Dynamic reactive current takes priority over Watts
		Inverter is Delivering Active Power, Voltage	Dynamic reactive current takes priority over Watts
		Inverter is Absorbing Active Power, Voltage	Dynamic reactive current takes priority over Watts
		Inverter is Absorbing Active Power, Voltage	Dynamic reactive current takes priority over Watts
DynamicReactive CurrentMode = 1	Watts are preferred over reactive current for grid support	Inverter is Delivering Active Power, Voltage Sags	Watts take priority over dynamic reactive current
		Inverter is Delivering Active Power, Voltage	Dynamic reactive current takes priority over Watts
		Inverter is Absorbing Active Power, Voltage	Dynamic reactive current takes priority over Watts
		Inverter is Absorbing Active Power, Voltage	Watts take priority over dynamic reactive current

6.3.3.6 Settings to Manage this Function

As illustrated in the previous figures, the settings used to configure this function are shown in Table 20:

Table 20: Settings for Dynamic Reactive Current Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	RDGS.ECPRefId	Referenced ECP	O		AI, AO
2.	RDGS.ArGraMod	Mode of reactive current characteristic: selects between that behaviour where gradients trend toward zero at the deadband edges, and where the gradients trend toward zero at the centre False = Gradients trend toward zero at the deadband True = Gradient trend toward zero at the center	O		AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
3.	RDGS.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.	O		AI, AO
4.	RDGS.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 deadband, inside of which the system does not generate additional reactive current support.	O		AI, AO
5.	RDGS.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.	O		AI, AO
6.	RDGS.ArGraSwl	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.	O		AI, AO
7.	RDGS.FilTms	This is the time, expressed in seconds, over which the moving linear average of voltage is calculated to determine the Delta-Voltage.	O		AI, AO
8.	RDGS.HysBlkZnV	Hysteresis voltage	O		AI, AO
9.	RDGS.BlkZnV	Block zone voltage	O		AI, AO
10.	RDGS.BlkZnTmms	Block zone time (in milliseconds)	O		AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
11.	RDGS.HoldTmms	Hold time (in milliseconds)	O		AI, AO
12.	RDGS.ModPrity	Dynamic Reactive Current Support Mode Priority	O		AI, AO
13.	RDGS.ModEna	Enable/disable dynamic reactive current support mode	M		BI
14.	RDGS.EvtEna (not in IEC 61850 yet)	This is a Boolean that selects whether or not the event-based behavior is enabled.	O		BI, BO
15.	RDGS.VArMaxAvl (not in IEC 61850 yet)	This is a Boolean that selects the priority of whether or not Watts should be curtailed in order to produce the reactive current required by this function.	O		BI, BO
16.	RDGS.DelV	Delta voltage measurement	O		AI
17.	RDGS.VAv	Moving average voltage calculation	O		AI

6.3.4 Dynamic Volt-Watt Mode

The steps in Table 21 describe how to cause the ESS system to dynamically absorb or produce additional watts in proportion to the instantaneous difference from a moving average of the measured voltage. This function utilizes the same basic concepts and settings as the Dynamic Reactive Current function but uses active power as an output rather than reactive current.

Figure 18 illustrates how the outstation calculates a continuous Moving Average Voltage over a specified number of seconds known as the Dynamic Volt-Watt Filter Time.

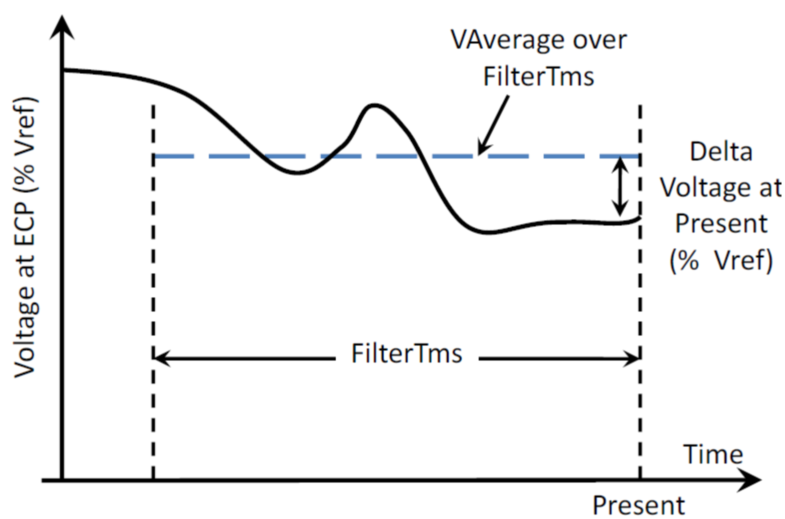

Figure 18: Delta Voltage Calculation for Dynamic Volt-Watt Mode

The difference between this Moving Average Voltage and the currently measured voltage at any moment is calculated as:

$$\textit{Percent Delta Voltage} = \frac{\textit{Measured Voltage} - \textit{Moving Average Voltage}}{\textit{Reference Voltage (AO25)}} \times 100\,\%$$

It is a local matter whether the designated measured voltage is one of the per-phase voltages or an average or total of these voltages, provided the moving average voltage is calculated the same way. Unlike the Dynamic Reactive Current Mode, neither the Moving Average Voltage nor the Percent Delta Voltage for the Dynamic Volt-Watt mode can be read by the master.

Figure 19 illustrates how the outstation either generates or absorbs active power, in proportion to the Delta Voltage at any moment, *in addition* to any active power produced or absorbed by other functions.

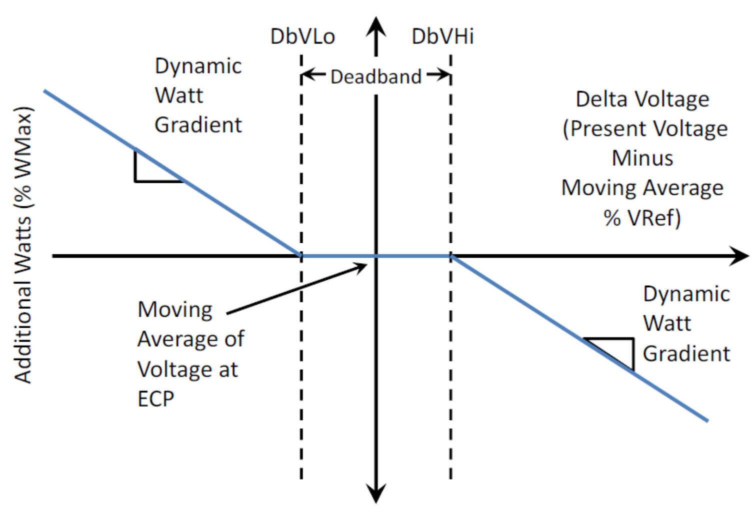

Figure 19: Dynamic Volt-Watt Function

The master specifies the curve in Figure 19 using three values. Firstly, it specifies two voltage thresholds that define a “deadband.” When the Percent Delta Voltage is above the Dynamic Volt-Watt Lower Deadband and below the Dynamic Volt-Watt Upper Deadband the outstation shall not generate or absorb additional active power. The deadband values are specified as percentages of the Reference Voltage, as is the Percent Delta Voltage.

Secondly, the master specifies a gradient, defined as follows:

$$\text{Percent Additional Watts} = \frac{\text{Additional Watts Supplied}}{\text{Maximum Active Power (AO22)}} \times 100\,\%$$

$$\text{Dynamic Volt-Watt Gradient (AO759)} = \frac{\text{Percent Additional Watts}}{\text{Percent Delta Voltage}}$$

This active power will be in addition to the active power generated by any other functions active on the outstation. Unlike the Dynamic Reactive Current function, the outstation applies the same gradient regardless of whether the Percent Delta Voltage is positive or negative. The Dynamic Volt-Watt Gradient is a signed quantity. A negative value will cause generation at low voltages and charging at high voltages.

Note that this function does not use a time window or ramp time parameter.

Table 21: Settings for Dynamic Volt-Watt Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DVWD.ECPRefId	Referenced ECP	M		AI, AO
2.	DVWD.DynVWGra	Dynamic Volt-Watt Gradient. Signed unit-less quantity that establishes the ratio of additional Watts supplied (expressed in terms of % DRCT.WMax) to the present difference from the moving average voltage (expressed as % DRCT.VRef).	M		AI, AO
3.	DVWD.VWFilTms	Dynamic Volt-Watt Filter Time. The time in seconds used to calculate the moving average voltage for dynamic Volt-Watt support.	O		AI, AO
4.	DVWD.DbVWLo	Dynamic Volt-Watt Lower Deadband. Percentage of the nominal voltage (DRCT.Vref) measured below the moving average voltage. If the present voltage is above this value, no additional Watts shall be supplied.	O		AI, AO
5.	DVWD.DbVWHi	Dynamic Volt-Watt Upper Deadband. Percentage of the nominal voltage (DRCT.Vref) measured above the moving average voltage. If the present voltage is below this value, no additional Watts shall be supplied.	O		AI, AO
6.	DVWD.RevtTms	Dynamic Volt-Watt Reversion Timeout Period	O		AI, AO
7.	DVWD.ModEna	Enable/disable dynamic Volt-Watt mode	O		AI, AO
8.	DVWD.ModPrty	Dynamic Volt-Watt Mode Priority	O		AI, AO
9.	DVWD.DelV	Delta voltage measurement	O		AI

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
10.	DVWD.VAv	Moving average voltage calculation	O		AI

6.3.5 Frequency-Watt Emergency Mode

The Frequency-Watt Emergency mode is focused on emergency situations when the frequency exceeds normal high or low limits and frequency ride-through is in effect, although it could be used under other situations to counter frequency swings. Its purpose is to influence the frequency to return toward nominal.

It uses a basic set of parameters, rather than the curves which can be used for other Frequency-Watt modes. These basic parameters are shown in Figure 20 for increasing frequency resulting in decreasing watts. The reverse would hold for decreasing frequency causing increasing watts.

Note: Discussions are taking place in IEEE 1547 on whether an open loop response time is needed as necessary for testing performance requirements.

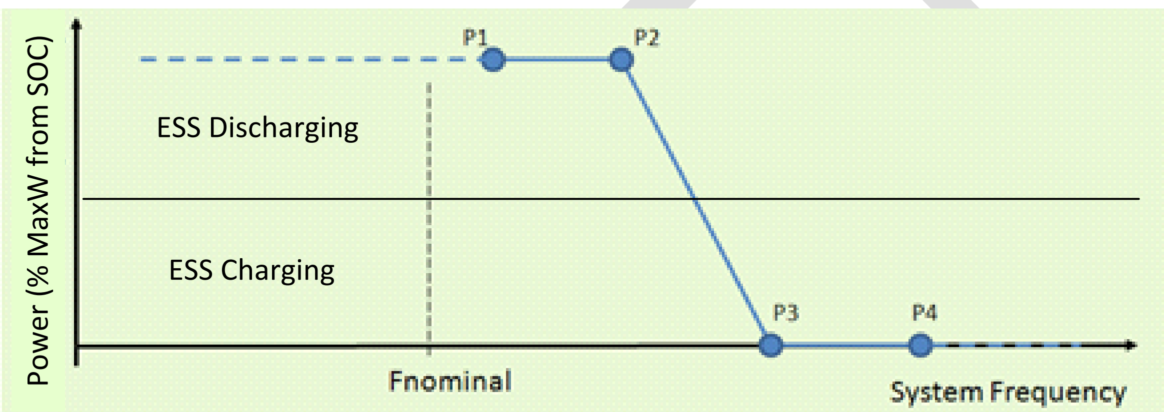

Figure 20: Basic Frequency-Watt Emergency Mode Configuration

The steps to use a Frequency-Watt curve are shown in Table 22.

Table 22: Steps to use a Frequency-Watt curve

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	FWHZ.ECPRefId	Set Referenced ECP	M		AI, AO
2.	FWHZ.HzRef	Frequency measurement from the Referenced ECP	M		AI
3.	FWHZ.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	FWHZ.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	FWHZ.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DOPR.ECPNomHz	Nominal frequency	M		AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
7.	FWHZ.HzStr	F-W Starting frequency: Delta frequency between start frequency and nominal grid frequency	M	Direct Operate / Response	AI, AO
8.	FWHZ.HzStop	F-W Stopping frequency: Delta frequency between stop frequency and nominal grid frequency	M	Direct Operate / Response	AI, AO
9.	FWHZ.HzStopWGra	F-W Maximum W change rate: The maximum rate at which the output may be increased after releasing the frozen value of snap shot function. This is represented in terms of % WMax per minute.	O	Direct Operate / Response	AI, AO
10.	FWHZ.ActDlTmms	F-W Activation delay: Intentional delay in ms before function activation	O	Direct Operate / Response	AI, AO
11.	FWHZ.HysEna	F-W Hysteresis enable/disable True = Use of hysteresis; False = No use of hysteresis	O	Direct Operate / Response	AI, AO
12.	FWHZ.SnptW	F-W Snapshot of power: True = Snapshot is active; False = Off, the snapshot is not active	O	Direct Operate / Response	AI, AO
13.	FWHZ.ModPrty	Freq-Watt Emergency Mode Priority	O	Direct Operate / Response	AI, AO
14.	FWHZ.WCtlHzEna	F-W enable	M		BI, BO

6.4 Active Power Modes

6.4.1 Charge/Discharge Mode

The steps in Table 23 describe how to directly manage the charging and discharging of the energy storage system. The controller starts the time window, reversion timeout, and ramp time at the moment the master successfully operates the mode enable command. Note that the Charge/Discharge, Peak Power Limiting, Load Following, Generation Following, Active Power Smoothing, Dynamic Volt-Watt, Power Smoothing, and Automatic Generation Control functions are all mutually exclusive, as each controls Active Power.

- When discharging, the target power output is a positive analog value, specified in Watts.
- When charging, the target power input is a negative analog value, specified in Watts.
- When charging, the controller will continue to charge at the selected rate until the maximum State of Charge is reached. When discharging, the controller will continue to discharge at the selected rate until the minimum State of Charge is reached.
- If the Charge or Discharge Rate is changing as a result of a schedule or a curve, the amount this setpoint can change per minute is limited by the Maximum Power Charging Gradient.
- The present Usable State of Charge for the battery bank can be read by the master at any time.

Table 23: Steps to Set Charge or Discharge Rate of the Energy Storage System

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DCHD.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
2.	DCHD.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O		AI, AO
3.	DCHD.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
4.	DCHD.WTgt	Set charge or discharge target. Positive is discharging, negative is charging	M	Direct Operate / Response	AI, AO
5.	DCHD.RmpUpRte	Discharging ramp up rate	O	Direct Operate / Response	AI, AO
6.	DCHD.RmpDnRte	Discharging ramp down rate	O	Direct Operate / Response	AI, AO
7.	DCHD.ChaRmpUpRte	Charging ramp up rate	O		AI, AO
8.	DCHD.ChaRmpDnRte	Charging ramp down rate	O		AI, AO
9.	DCHD.ModPrty	Charge/Discharge Mode Priority	O		AI, AO
10.	DCHD.VArAct	Charge/Discharge VAr Action to take when switching between charging and discharging: <0> Reserved <1> Reverse: producing/absorbing Vars when changing between charging and discharging (go to diagonal quadrant Q1/Q3 or Q2/Q4) <2> Do not reverse: producing/absorbing Vars (go to adjacent quadrant Q1/Q2 or Q3/Q4)	O		AI, AO
11.	DCHD.ModEna	Enable Charge/Discharge mode and receive response	M	Select / Response, Operate / Response	BI, BO

6.4.2 Coordinated Charge/Discharge Management Mode

Note: This mode has not been reviewed in detail. Any implementations may need updates at a later time.

The Coordinated Charge/Discharge Management mode establishes time constraints that allow the ESS to determine the best times and rates for charging and discharging to reach the target state of charge by a specified time. Figure 21 illustrates the basic concept of maximum charging when the energy price is low and decreasing the rate of charging during higher demand prices, while still meeting the target state of charge before the required time.

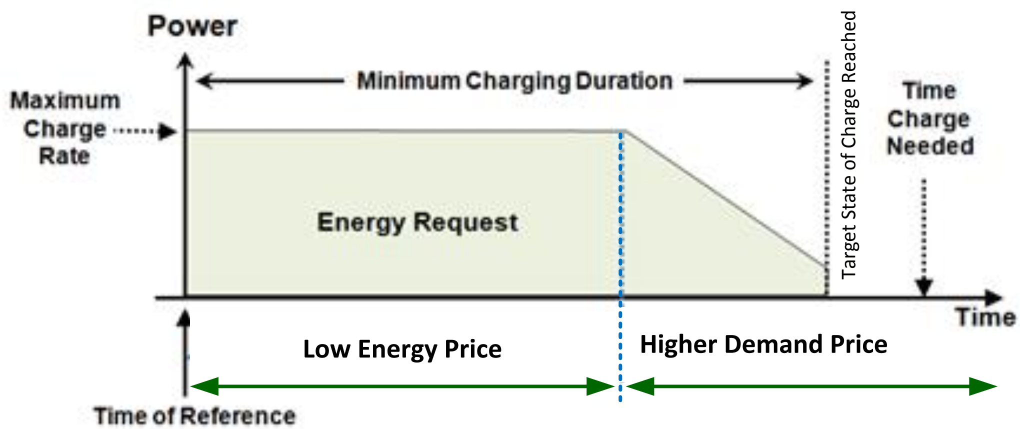

Figure 21: Coordinated Charge/Discharge Management Mode

One key purpose 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 to drive the EV. However, this mode can permit any ESS to determine the most cost-effective manner to participate in grid activities. For instance, the ESS may be scheduled to provide load following during peak hours, but it can determine the most cost-effective time and charging rate to reach the target state of charge before the peak period starts. Or if the ESS is scheduled to provide AGC services during the evening, it can take advantage of the higher afternoon prices to discharge down to the middle state of charge best suited for AGC.

For this reason, other Active Power functions may be active at the same time as this function so long as those other functions permit the ESS to reach the target SOC at the target time.

Table 24 provides the parameters for Coordinated Charge/Discharge Management mode.

Table 24: Parameters for Coordinated Charge/Discharge Management Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
12.	DTCD.WinTms	Time window within which to randomly initiate mode.	O	Direct Operate / Response	AI, AO
13.	DTCD.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings.	O	Direct Operate / Response	AI, AO
14.	DTCD.RvrtTms	Reversion timeout period upon which to take reversion default action.	O	Direct Operate / Response	AI, AO
15.	DTCD.SOCUseTgt	Target usable state of charge that the system is expected to achieve, as a percentage of the usable capacity.	M		AI, AO
16.	DTCD.DateTgt	Target date and time by which the storage system must reach the target SOC.	C		AI, AO
17.	DTCD.Tms.Tgt	Target duration to move from the current SOC to the target SOC.	C		AI, AO
18.	DTCD.ModEna	Coordinated Charge/Discharge mode enable.	M		BI,BO
19.	DRCT.MaxRmpUpRte	Maximum Ramp Up Rate. Ramp up	O		AI

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
		rate during generating (discharging). Ramp rate as percentage of NomRmpUpRte.			
20.	DRCT.MaxRmpDnRte	Maximum Ramp Down Rate. As percentage of nominal maximum ramp rate. Ramp down rate during generating (discharging). Ramp rate as percentage of NomRmpDnRte.	O		AI

6.4.3 Active Power Limit Mode

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

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 Power 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 Power 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.

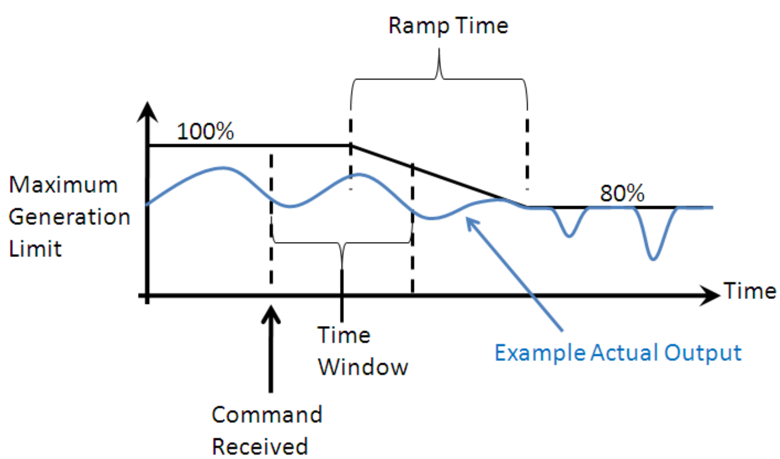

Figure 22: Example of Limiting Maximum Generation

The steps in Table 25 describe the Active Power Limit Mode and how to set the maximum generation level of the energy storage system at the Referenced ECP, such as the PCC, as a percentage of its nominal capacity or as absolute watts. The controller shall start the time window, reversion timeout, and ramp time at the moment the master successfully operates the mode enable command.

The setpoint for maximum Active Power generation is an analog value, specified as a percentage of maximum active power capability.

Table 25: Steps to Limit Maximum Generation or Maximum Load

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DAMG.ECPRefId	Set Referenced ECP	M		AI, AO
2.	DAMG.WRef	Measurement from the Referenced ECP	M		AI
3.	DAMG.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DAMG.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DAMG.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DAMG.WImpLimPct	Active Power Limit Charge Setpoint. Limit of imported Watts as a percentage of Maximum Active Power capability	C		AI, AO
7.	DAMG.WExpLimPct	Active Power Limit Discharge Setpoint. Limit of exported Watts as a percentage of Maximum Active Power capability	C		AI, AO
8.	DAMG.ModPrty	Active Power Limit Mode Priority	O		AI, AO
9.	DAMG.ModEna	Enable Limited Watts mode and receive response	M	Select / Response, Operate / Response	BI

6.4.4 Peak Power Limiting Mode

In the Peak Power Limiting Mode, the ESS limits the import of power to a specified limit, as illustrated in Figure 23.

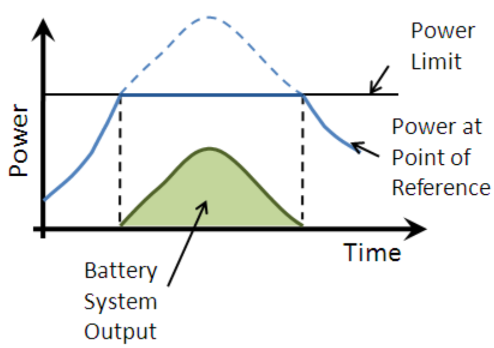

Figure 23: Peak Power Limiting results

In this illustration, the solid blue line represents the power measurement at the selected Referenced ECP for the function. This point could be physically located anywhere but is often the PCC. Without support from the peak-power limiting function, this hypothetical power measurement would have followed the dashed blue line.

The horizontal black line represents a peak-power limit setting established at the ESS by the utility or other asset owner. The green shaded area represents the power output of the ESS. 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.

There are practical limits to an ESS 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 24, these could result in failure to hold the power level at the reference point to the desired limit for the desired duration.

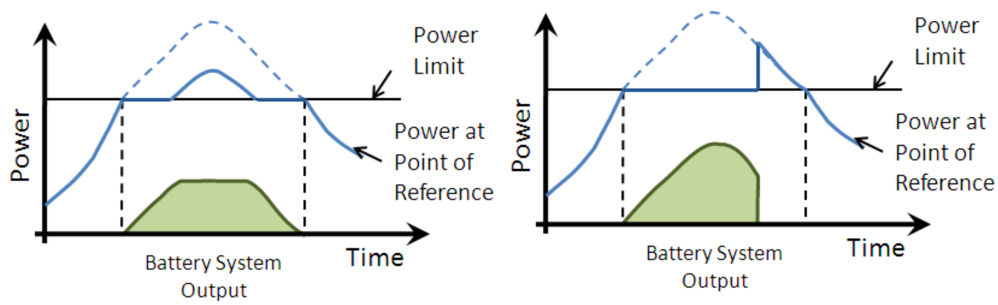

Figure 24: Practical Limitations – Watt Limit (left) and ESS Capacity Limit (right)

Several possibilities might exist for how a ESS might receive the measurement data indicative of the power flow at the Referenced ECP for the peak power limiting function. Figure 25 illustrates two such possibilities.

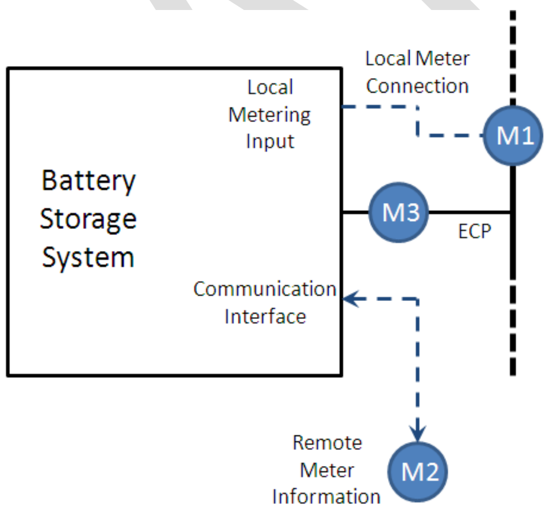

Figure 25: Referenced ECPs for Power Limiting

The steps in Table 26 describe the Peak Power Limiting Mode.

Table 26: Steps to Peak Power Limiting Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DPKP.ECPRefId	Referenced ECP	M		AI, AO
2.	DPKP.WRef	Measurement from the Referenced ECP	M		AI
3.	DPKP.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
4.	DPKP.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DPKP.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DPKP.PkPwrWLim	Target value of the reference load power in watts. The ESS shall generate watts to ensure the reference load does not exceed this limit.	C		AI, AO
7.	DPKP.PkPwrFolPct	Peak Power Limiting Ratio. If 100%, then peak power is limited to the limit value. If < 100%, then peak power is limited to the remaining percentage over the limit.	C		AI, AO
8.	DPKP.RmpUpRte	Discharging Ramp Up Rate. Maximum ramp up rate	O		AI, AO
9.	DPKP.RmpDnRte	Discharging Ramp Down Rate. Maximum ramp down rate	O		AI, AO
10.	DPKP.ModPrty	Active Power Limit Mode Priority	O		AI, AO
11.	DPKP.ModEna	Enable Limited Watts mode and receive response	M	Select / Response, Operate / Response	BI

6.4.5 Load Following Mode

In the Load Following mode, the ESS correlates its charging and/or discharging output to a percentage of an external Active Power signal at the Referenced ECP. This mode is similar to the Limited Watts mode, except the limit is not static but is dynamically input from the Referenced ECP. This concept is illustrated in Figure 26. The controller shall start the time window, reversion timeout, and ramp time at the moment the master successfully operates the mode enable command. Note that this function may be combined with the Charge/Discharge mode, with the Load Following mode having priority. In this case, if the Load Following mode detects that no discharging is required given the current value of the power signal, control will fall to the Charge/Discharge mode.

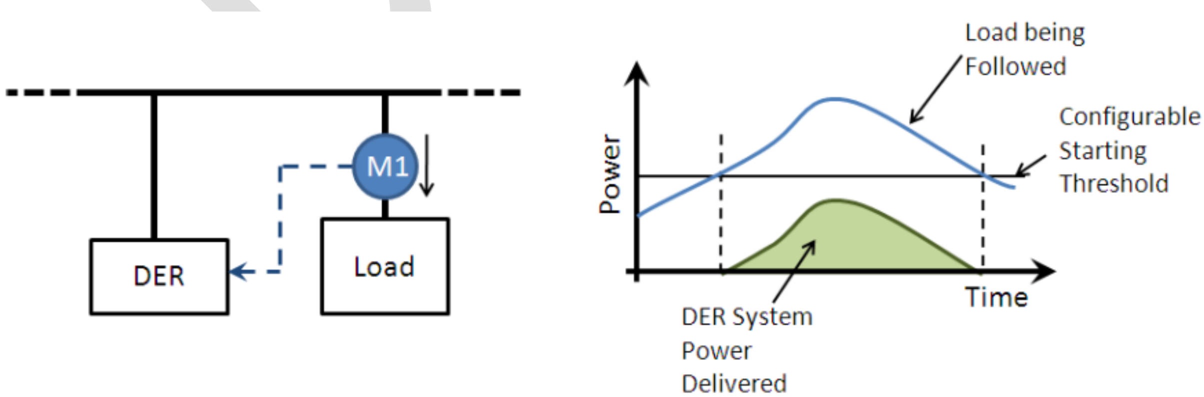

Figure 26: Load Following Function Arrangement and Waveform

The Load Following mode requires Active Power readings from an external reference point. This external reference source will generally be a meter on the distribution network which feeds power information directly into the ESS.

An alternate use of this operational mode will be to limit power output based on the difference between load forecast and actual load. In this case, the target power level limit is a delta which is not to be exceeded, and the temporal signal is the current delta between forecast and actual. Both measurements are provided in Watts.

This signal can be provided to the controller using a power meter located at the same site as the ESS or at another site. The signal may also be provided by a data file containing time-stamped data values or through SCADA. When this function is enabled, the controller shall continuously compare the reference power input to a specified Peak Power Limit and adjust its Active Power output as needed to ensure the reference power input does not exceed the limit.

This function somewhat resembles the Peak Power Limiting function described in Section 6.4.4 in that they both supply Active Power when the reference power measurement exceeds a threshold. However, they differ in the following fundamental manner: the Load Following function supplies Active Power in a specified ratio to the power transferred at the reference point, while the Peak Power Limiting function supplies as much Active Power as necessary (within the physical limits of the controller) to ensure the measured reference does not exceed the threshold.

The steps in Table 27 describe the process to establish and enable the Load Following mode.

Table 27: Steps to Load Following Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DLFL.ECPRefId	Set the Referenced ECP	M		AI, AO
2.	DLFL.WRef	Measurement from the Referenced ECP	M		AI
3.	DLFL.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DLFL.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DLFL.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DLFL.LodFolThrshW	Threshold to start actively following load in watts.	M		AI, AO
7.	DLFL.PkPwrFolPct	Load Following Ratio. If 100%, then Load Following follows the load exactly. If < 100%, then Load Following follows the load as a percentage of the load over the threshold.	O		AI, AO
8.	DLFL.RmpUpRte	Discharging Ramp Up Rate. Maximum ramp up rate	O		AI, AO
9.	DLFL.RmpDnRte	Discharging Ramp Down Rate. Maximum ramp down rate	O		AI, AO
10.	DLFL.ModPrty	Active Power Limit Mode Priority	O		AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
11.	DLFL.ModEna	Enable Limited Watts mode and receive response	M	Select / Response, Operate / Response	BI

6.4.6 Generation Following Mode

In the Generation Following Mode, the ESS discharges and/or charges Active Power in proportion to a measured generation at the Referenced ECP (as illustrated in Figure 27).

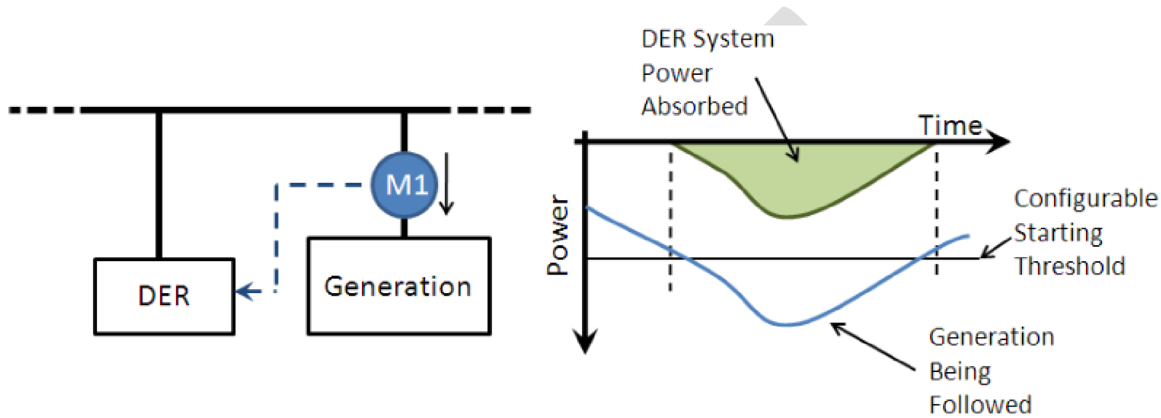

Figure 27: Generation Following Function Arrangement and Waveform

The Generation Following mode requires Active Power readings from an external reference point. These readings will typically come from a meter located at the same site as the ESS or at another site on the distribution network which feeds power information directly into the ESS.

Regarding the Active Power readings from the external reference point, it is assumed that:

- A positive value represents a load and the ESS should produce Active Power to support the load.
- A negative value represents generation and the ESS should absorb excess Active Power.

The Load and Generation Following mode will not take action unless the reference value exceeds the Load and Generation Following Starting Threshold (AO18) – either a larger positive value if the threshold is positive or a larger negative value if the threshold is negative. The ratio is a percentage.

The function will generate or absorb Active Power in proportion to the Reference Power Input based on a specified ratio, as follows:

$$Additional\ Output\ Active\ Power = \frac{Reference\ Power\ Input - Starting\ Threshold}{100\%} * Following\ Ratio$$

The Load/Generation Following Ratio is a configurable setting that controls the ratio by which the ESS follows the load once the magnitude of the load exceeds the threshold. This setting is a unit-less percentage value. As an example, consider an ESS 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 ESS would be 30kW.

The steps in Table 28 describe the process to establish and enable the Generation Following Mode.

Table 28: Steps to Generation Following Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DGFL.ECPRefId	Set the Referenced ECP	M		AI, AO
2.	DGFL.WRef	Measurement from the Referenced ECP	M		AI
3.	DGFL.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DGFL.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DGFL.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DGFL.GenFolThrshW	Threshold to start actively following generation in watts.	M		AI, AO
7.	DGFL.GenFolPct	Generation Following Ratio. If 100%, then Load Following follows the load exactly. If < 100%, then Load Following follows the load as a percentage of the load over the threshold.	O		AI, AO
8.	DGFL.RmpUpRte	Discharging Ramp Up Rate. Maximum ramp up rate	O		AI, AO
9.	DGFL.RmpDnRte	Discharging Ramp Down Rate. Maximum ramp down rate	O		AI, AO
10.	DGFL.ChaRmpUpRte	Charging ramp up rate Maximum ramp up rate	O		AI, AO
11.	DGFL.ChaRmpDnRte	Charging ramp down rate Maximum ramp up rate	O		AI, AO
12.	DGFL.ModPrty	Active Power Limit Mode Priority	O		AI, AO
13.	DGFL.ModEna	Enable Limited Watts mode and receive response	M	Select / Response, Operate / Response	BI

6.4.7 Automatic Generation Control Mode

The steps in Table 29 describe how Automatic Generation Control (AGC) manages the charging and discharging of the energy storage system. The controller shall start the time window, reversion timeout, and ramp time at the moment the master successfully operates the mode enable command.

When charging, the controller will continue to charge until the maximum Usable State of Charge is reached. When discharging, the controller will continue to discharge until the minimum Usable State of Charge is reached. The amount this setpoint can change per AGC time period is limited by the ESS's maximum ramp up and ramp down rates.

Table 29: Steps for Automatic Generation Control

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DAGC.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
2.	DAGC.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
3.	DAGC.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
4.	DAGC.RmpUpTms	Set ramp up time by which the Active Power target is reached	O	Direct Operate / Response	AI, AO
5.	DAGC.RmpDnTms	Set ramp down time by which the Active Power target is reached	O	Direct Operate / Response	AI, AO
6.	DAGC.SOCUseMin	Minimum Usable SOC for AGC	O		AI, AO
7.	DAGC.SOCUseMax	Maximum Usable SOC for AGC	O		AI, AO
8.	DAGC.PerTms	Periodicity of AGC signals	O	Direct Operate / Response	AI, AO
9.	DAGC.WTgt	Set charge or discharge Active Power target in watts. Positive is discharging, negative is charging	M	Direct Operate / Response	AI, AO
10.	DAGC.ModEna	Enable Charge/Discharge mode and receive response	M	Select / Response, Operate / Response	BI, BO
11.	DAGC.ModPrty	AGC Mode Priority	O		AI, AO
12.	DRCT.MaxRmpUpRte	Maximum Ramp Up Rate. Ramp up rate during generating (discharging). Ramp rate as percentage of NomRmpUpRte.	O		AI
13.	DRCT.MaxRmpDnRte	Maximum Ramp Down Rate. As percentage of nominal maximum ramp rate. Ramp down rate during generating (discharging). Ramp rate as percentage of NomRmpDnRte.	O		AI

6.4.8 Active Power Smoothing

The steps in Table 30 describe how to request that the energy storage system absorb or produce additional Watts in such a way as to smooth-out variations in the power level of a remote point of reference.

The Active Power Smoothing mode requires Active Power readings from an external reference point. This signal can be provided to the controller using a power meter located at the same site as the ESS or at another site. The signal may also be provided by a data file containing time-stamped data values, or through SCADA. See Section 5.2 for more information on the capabilities offered by the controller.

This function operates by computing the instantaneous difference in the reference meter power level and a moving average of the power level over a sliding time window. In this way, the system helps to "smooth" the power waveform at the reference point.

The system may also include an option that smooth Active Power based on instantaneous rate of change.

Figure 28 illustrates how the controller will calculate a moving average of the Reference Power Measurement over a specified number of seconds known as the Filter Time.

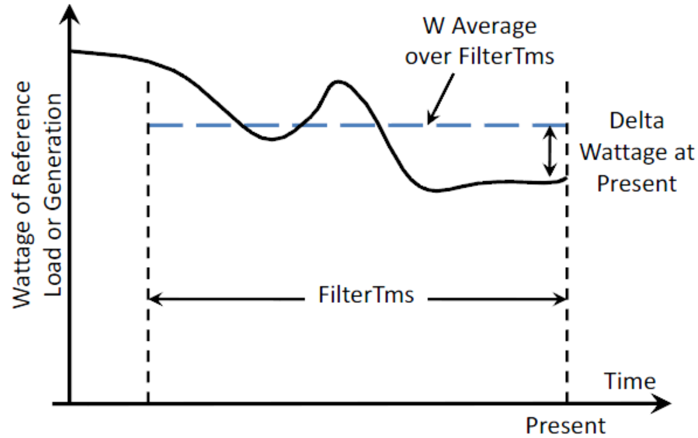

Figure 28**:** Delta Wattage Calculation

The difference between this Moving Average Power and the Measured Reference Power at any moment is defined to be the Delta Wattage, as follows:

$$Delta\ Wattage = (Measured\ Reference\ Power) - (Moving\ Average\ Power)$$

Figure 29 illustrates how the outstation generates or absorbs Active Power in proportion to the Delta Wattage at any moment, *in addition* to any Active Power produced or absorbed by other functions.

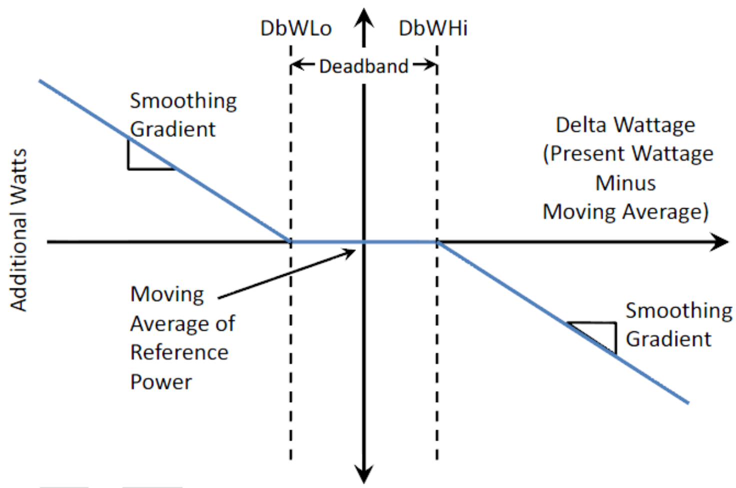

Figure 29: Active Power Smoothing Function

The master specifies the curve in Figure 29using three values. Firstly, it specifies two Wattage thresholds that define a “deadband.” When the Delta Wattage is above the Active Power Smoothing Lower Limit (AO31) and below the Active Power Smoothing Upper Limit (AO32), the outstation shall not perform Active Power smoothing.

Secondly, the master specifies a unit-less gradient, defined as follows:

$$Real\ Power\ Smoothing\ Gradient = \frac{Additional\ Watts\ Produced}{Delta\ Wattage}$$

Note that the outstation applies the same gradient regardless of whether the Delta Wattage is positive or negative.

The Active Power Smoothing Gradient is a signed quantity. Positive values of this gradient are for following load (increasing reference load results in a dynamic increase in ESS output), and negative values are for following generation (increasing reference generation results in a dynamic decrease in ESS output).

Table 30: Steps to Enable Active Power Smoothing

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DWSM.ECPRefId	Set the Referenced ECP	M		AI, AO
2.	DWSM.WRef	Measurement from the Referenced ECP	M		AI
3.	DWSM.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DWSM.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DWSM.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DWSM.WSmthGra	Active Power Smoothing Gradient. Signed quantity that establishes the ratio of additional smoothing Watts provided to the present Delta Watts of the reference load or generation. Delta Watts is the difference between the moving average and the present value of the reference power.	M		AI, AO
7.	DWSM.WSmthLoLim	Active Power Smoothing Lower Limit. Difference in Watts from the moving average of the reference power above which no smoothing shall be applied.	O		AI, AO
8.	DWSM.WSmthHiLim	Active Power Smoothing Upper Limit. Difference in Watts from the moving average of the reference power below which no smoothing shall be applied.	O		AI, AO
9.	DWSM.FilTms	Active Power Smoothing Filter Time (seconds). Time used to calculate the moving average of the reference load or generation being smoothed.	O		AI, AO
10.	DWSM.RmpUpRte	Discharging Ramp Up Rate. Maximum ramp up rate	O		AI, AO
11.	DWSM.RmpDnRte	Discharging Ramp Down Rate. Maximum ramp down rate	O		AI, AO
12.	DWSM.ChaRmpUpRte	Charge Ramp Up Rate. Maximum ramp up rate	O		AI, AO
13.	DWSM.ChaRmpDnRte	Charge Ramp Down Rate. Maximum ramp up rate	O		AI, AO
14.	DWSM.ModPrty	Active Power Limit Mode Priority	O		AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
15.	DWSM.ModEna	Enable Limited Watts mode and receive response	M	Select / Response, Operate / Response	BI

6.4.9 Volt-Watt Mode

The steps in Figure 30 describe how to cause the ESS to absorb or produce additional watts in proportion to the instantaneous difference from a moving average of the measured voltage. In this configuration, the voltages are to be represented in the form of "Percent of VRef", in which "VRef" represents the nominal voltage for the Referenced ECP. Figure 30 shows one example for reducing watts generated versus voltage.

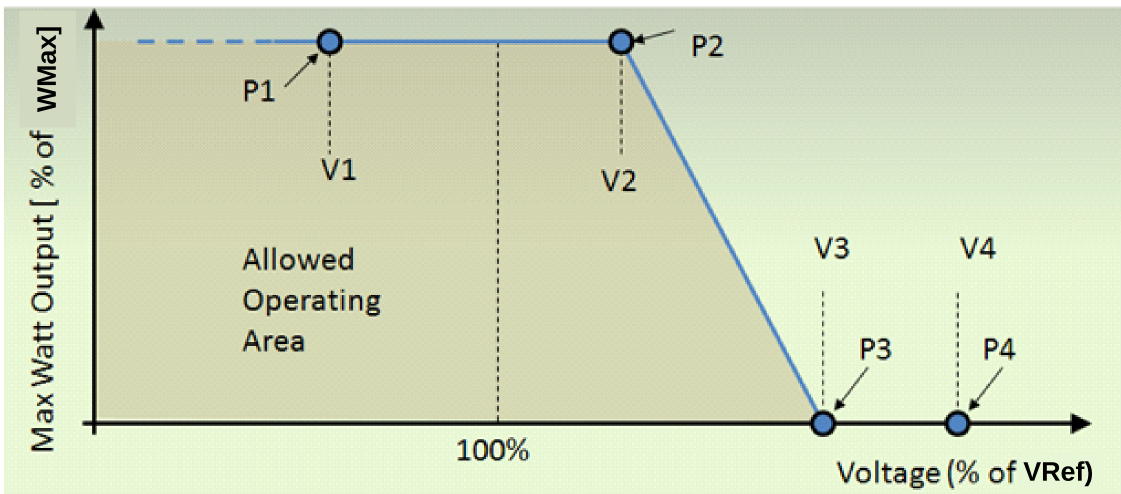

Figure 30: Configuration curve for ESS to reduce export of watts as voltage exceeds V2

In addition to voltage-based management of generation, charging of ESS also can be affected by voltage-watt management. Figure 31 illustrates maximum watts absorbed by a storage device versus voltage. The vertical axis is a percentage of the maximum ESS capacity, constrained by the maximum charging rate, and the horizontal axis is voltage, with reference voltage (VRef) shown in the middle.

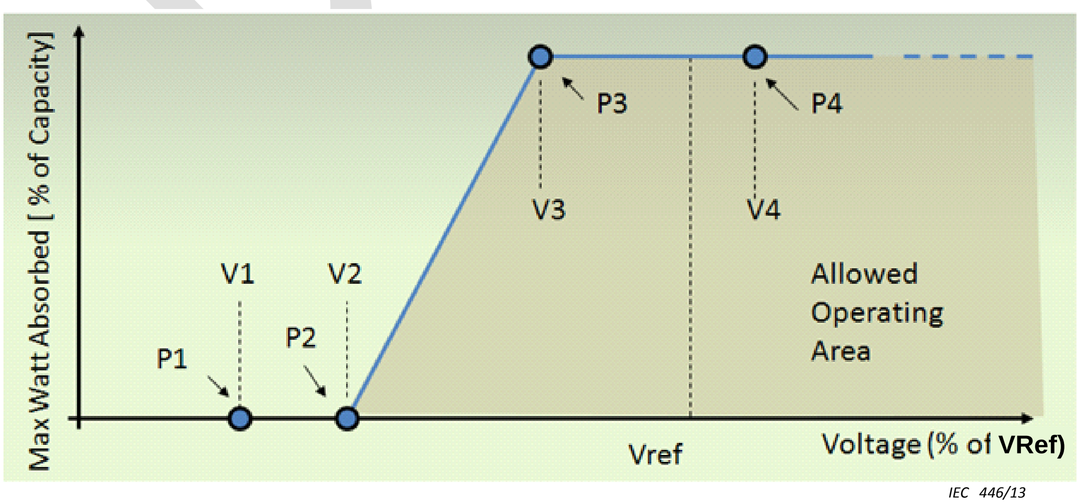

Figure 31: Configuration curve for ESS to increase export of watts as voltage drops below V3 (Note: diagram shows decrease in charging)

The settings for this mode include a voltage-watts-delivered curve (generation) and/or a voltage-watts-received curve (storage), ramp rates for discharging and charging, filtering time of the input voltage measurement, and as with other functions, a time window, ramp rate, and timeout.

If only simple linear “curves” are needed, two linear curves can be established, consisting of:

- An upper voltage limit (positive percent of VRef) and a gradient for decreasing the export of power
- A lower limit (negative percent of VRef) and a gradient for increasing the export of power
- A time filter for the voltage measurement being monitored

The Volt-Watt mode requires a voltage measurement from an external reference point (Referenced ECP). This signal can be provided to the controller using a power meter located at the same site as the ESS or at another site. The signal may also be provided by a data file containing time-stamped data values or through SCADA.

Table 31: Steps to for Volt-Watt Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DVWG.ECPRefId	Set the Referenced ECP	M		AI, AO
2.	DVWG.WRef	Measurement from the Referenced ECP	M		AI
3.	DVWG.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DVWG.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DVWG.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DVWG.VWDecGra	Volt-Watt Decreasing Watt Gradient. Percent of WMax	M		AI, AO
7.	DVWG.VWIncrGra	Volt-Watt Increasing Watt Gradient. Percent of WMax or AMax (depending on Watts/Amps agreement)	O		AI, AO
8.	DVWG.VWLoLim	Volt-Watt Lower Limit: start to increase export of watts	O		AI, AO
9.	DVWG.VWHiLim	Volt-Watt Upper Limit: start to decrease export of watts	O		AI, AO
10.	DVWG.FilTms	Volt-Watt Filter Time (Seconds)	O		AI, AO
11.	DVWG.RmpUpRte	Volt-Watt Discharging Ramp Up Rate. Maximum ramp up rate	O		AI, AO
12.	DVWG.RmpDnRte	Volt-Watt Discharging Ramp Down Rate. Maximum ramp down rate	O		AI, AO
13.	DVWG.ChaRmpUpRte	Volt-Watt Charge Ramp Up Rate. Maximum charging ramp up rate	O		AI, AO
14.	DVWG.ChaRmpDnRte	Volt-Watt Charge Ramp Down Rate. Maximum charging ramp down rate	O		AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
15.	DVWG.ModPrty	Active Power Limit Mode Priority	O		AI, AO
16.	DVWG.ModEna	Enable Limited Watts mode and receive response	M	Select / Response, Operate / Response	BI

6.4.10 Frequency-Watt Mode

The Frequency-Watt Mode is focused on providing primary frequency support by the ESS modifying its discharging and/or charging rates to counteract frequency deviations from nominal while these are still within normal frequency ranges.

The F-W mode parameters are defined in two arrays, one for increasing frequency and the second for decreasing frequency.

6.4.10.1 F-W Mode with Increasing Frequency

The first array (see Figure 32) is for decreasing discharging (or increasing charging) if the frequency is increasing above nominal frequency beyond a threshold (P2 in the figure) but below the abnormal high frequency limit (see Section 6.3.5 on Frequency-Watt Emergency Mode for parameters above and below the abnormal frequency limits). P3 is the point where the ESS no longer responds to increasing frequency due either to its own constraints or because the F-W emergency mode becomes effective. ESS constraints could include reaching SOC high limits if the ESS is charging or if discharging rate has become zero and the ESS is not going to start charging. If desired, the curve could be limited to only discharging or only to charging. (The points P1 and P4 can be randomly selected as a way to indicate that the curve is flat between P1 and P2, as well as between P3 and P4.)

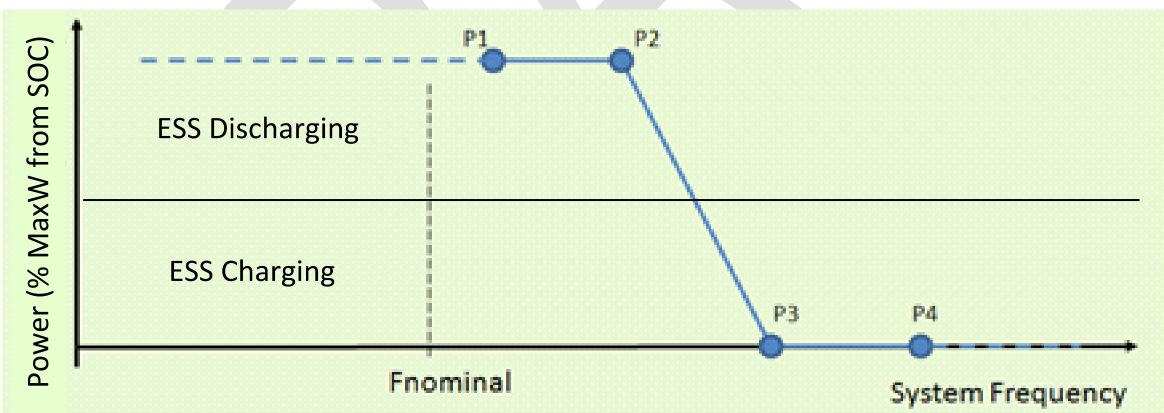

Figure 32: Example of a Basic Frequency-Watt Mode Configuration

Hysteresis can be enabled for this frequency-watt function. The hysteresis provides a type of deadband, 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. Rather than the configuration array containing only points incrementing from left to right (low frequency to high frequency, hysteresis is enabled by additional points in the configuration array which progress back to the left. Figure 33 illustrates this concept.

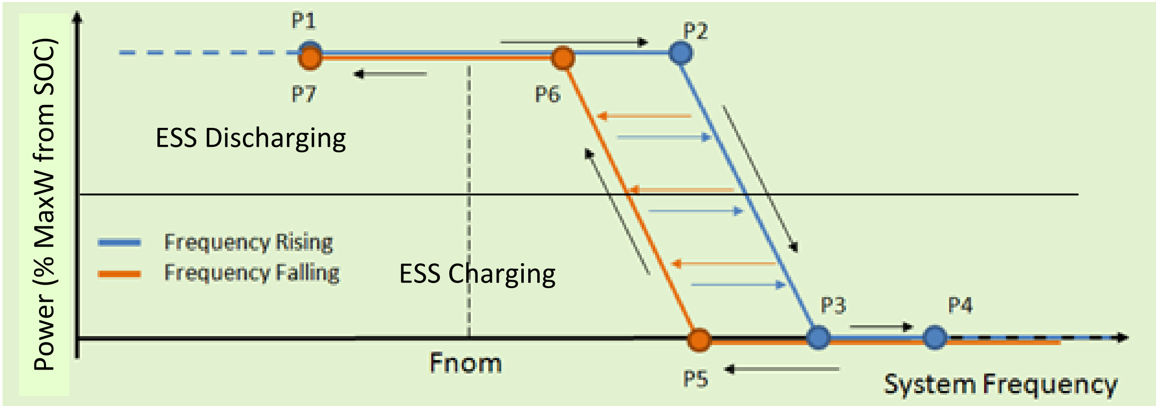

Figure 33: Example Array Settings with Hysteresis

The return hysteresis curve does not have to follow the same shape as the rising curve and may be configured only for discharging. Figure 34 illustrates an example of such a case.

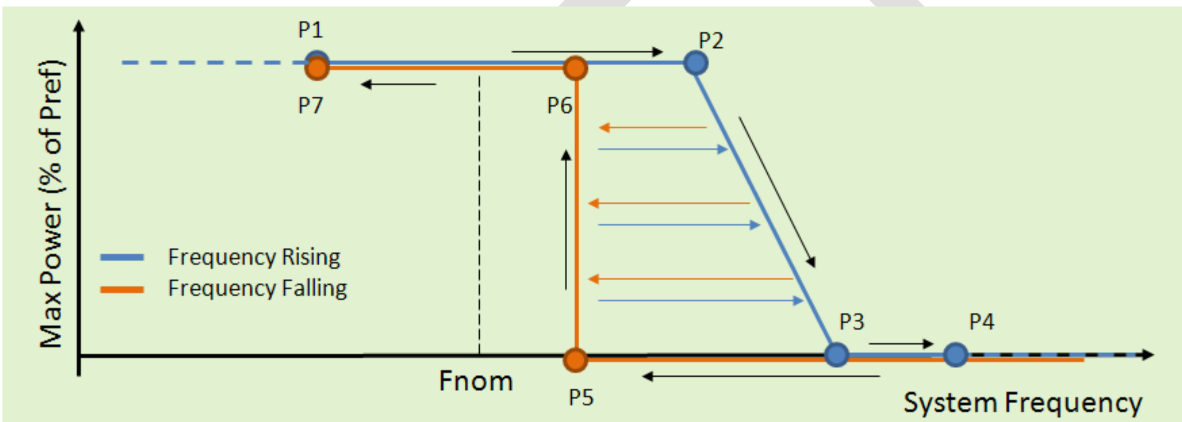

Figure 34: Example of an Asymmetrical Hysteresis Configuration for Discharging Only

6.4.10.2 F-W Mode with Decreasing Frequency

The second array is identical to that described above except that the vertical axis is defined as maximum watts absorbed rather than maximum watts delivered. This allows ESSs to decrease charging and/or increase discharging rates when grid frequency drops. Figure 35 illustrates an example setting with hysteresis in which the ESS absorbs power and can cross the zero point between charging and discharging.

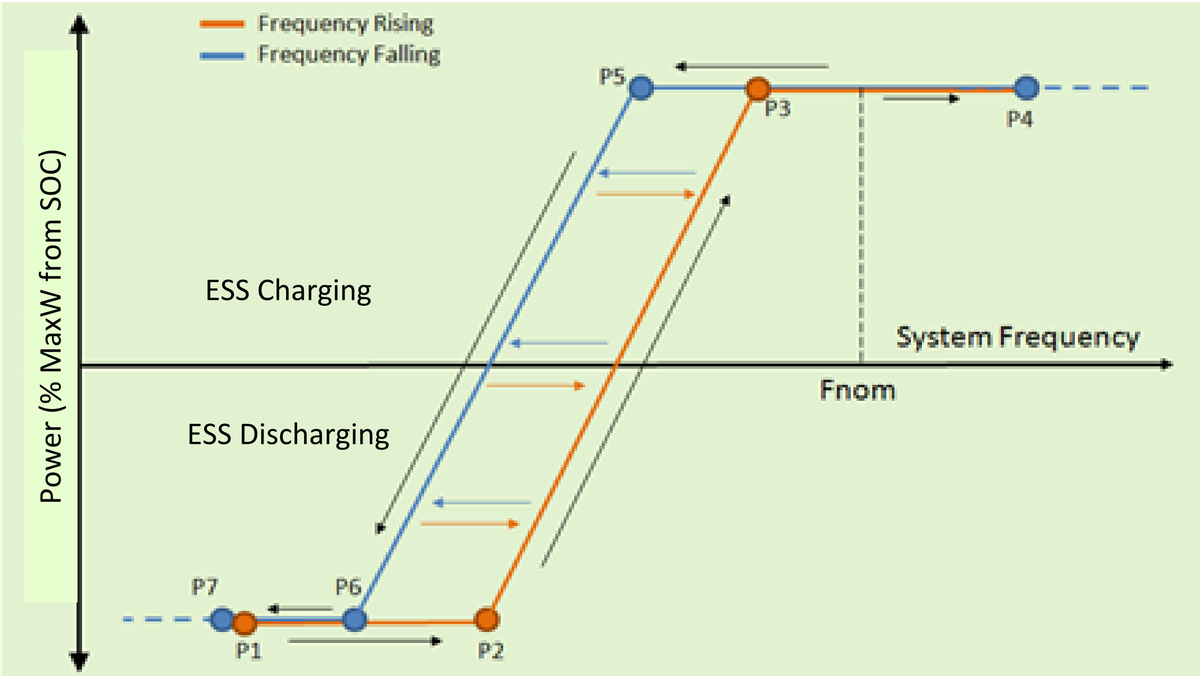

Figure 35: Example Configuration for Frequency Decreasing Below Nominal (note reversal of charging and discharging)

6.4.10.3 Parameters for Frequency Watt Mode

The steps in describe how to create the curves for frequency-watt mode using the generic curve data points.

The X-value of each point on the curve is defined as:

Frequency Deviation (X-Value) = Locally Measured Frequency – Nominal Frequency

The Y-value of each point on the curve is the percentage of active power (Watts) to be provided at the given amount of deviation from nominal frequency. This percentage may be calculated in relation to the maximum active power that the system can generate, as follows:

$$\text{Maximum Percent Active Power Output (Y-Value)} = \frac{\text{Maximum Allowed Output Active Power}}{\text{Maximum Active Power}} \times 100\ \%$$

This is the default calculation and default behavior – essentially a function that is continuously active when enabled.

Alternatively, this function may be setup to operate intermittently, activated by a certain frequency deviation and deactivated when frequency returns to normal. In this mode of operation, the maximum output limits specified by the curve are calculated in relation to a “snapshot” of the active power that the system is producing at the moment the measured frequency deviates from the nominal frequency by a specified threshold, as follows:

$$\text{Maximum Percent Active Power Output (Y-Value)} = \frac{\text{Maximum Allowed Output Active Power}}{\text{Snapshot Active Power}} \times 100\ \%$$

The steps to use a Frequency-Watt curve are shown in Table 32.

Table 32: Steps to use a Frequency-Watt curve

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DFWS.ECPRefId	Set Referenced ECP	M		AI, AO
2.	DFWS.HzRef	Frequency measurement from the Referenced ECP	M		AI
3.	DOPR.ECPNomHz	Nominal frequency	O		AI, AO
4.	DFWS.PairArrHzW	Curve of Frequency-Watt pairs	M		AI, AO
5.	DFWS.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
6.	DFWS.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
7.	DFWS.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
8.	DFWS.Mod	F-W enable	M		BI, BO

6.5 Reactive Power Modes

6.5.1 Fixed Power Factor Mode

The Fixed Power Factor mode sets the power factor produced by the energy storage system. The controller starts the time window, reversion timeout, and ramp time at the moment the master successfully operates the mode enable command. Note that this mode and the Power Factor Correction mode are mutually exclusive, as only one can be used at a given time to control the reactive behavior of the ESS.

The steps for Fixed Power Factor mode are shown in Table 33.

Table 33: Steps for Fixed Power Factor mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DFPF.ECPRefId	Set Referenced ECP	M		AI, AO
2.	DFPF.PFRef	PF measurement from the Referenced ECP	M		AI
3.	DFPF.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DFPF.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DFPF.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DFPF.PFTgt	Target Power Factor	M		AI, AO
7.	DFPF.ModEna	Enable fixed PF mode	M		BI, BO
8.	DFPF.ModPrty	Fixed Power Factor Mode Priority	O		AI, AO

Note that in this profile power factor is a signed value between -1.00 and +1.00. Both -1.00 and +1.00 produce the same result, no VArs. A power factor setting of 0 is not allowed.

In IEC 61850, the meaning of the sign of the value varies depending on the sign convention used:

- IEC, in which supplying or generating Active Power is positive and demanding Active Power is negative.
- IEEE, in which leading (capacitive) power factor is positive and lagging (inductive) power factor is negative.

IEC 61850 provides a parameter (DRCT.PFSign) which normally permits changing the sign convention between IEC and IEEE (EEI). However, the IEEE convention is always used. There is no provision in this profile for changing the convention.

6.5.2 Volt-VAr Control Mode

The Volt-VAr function allows ESS systems to counteract voltage deviations from the nominal voltage level (but still within normal operating ranges) by consuming or producing reactive power.

The Volt/VAr function specifies the changes in reactive power that the ESS makes in response to changes in either the local voltage or in a voltage from an external reference point. The amount of reactive power can be established by a piece-wise linear curve of up to 10 curve points defining voltage versus percentage of reactive power. Percentage of reactive power can be calculated as:

- **Percentage of available reactive power** for the measured percentage of the reference voltage. “Available vars” implies the consumption or production of reactive power that does not affect the Active Power output.
- **Percentage of maximum reactive power**. In this case, consumption or production of reactive power may affect the Active Power output.

The volt/VAr curve using available vars is shown In Figure 36, including a deadband between P2 and P3.

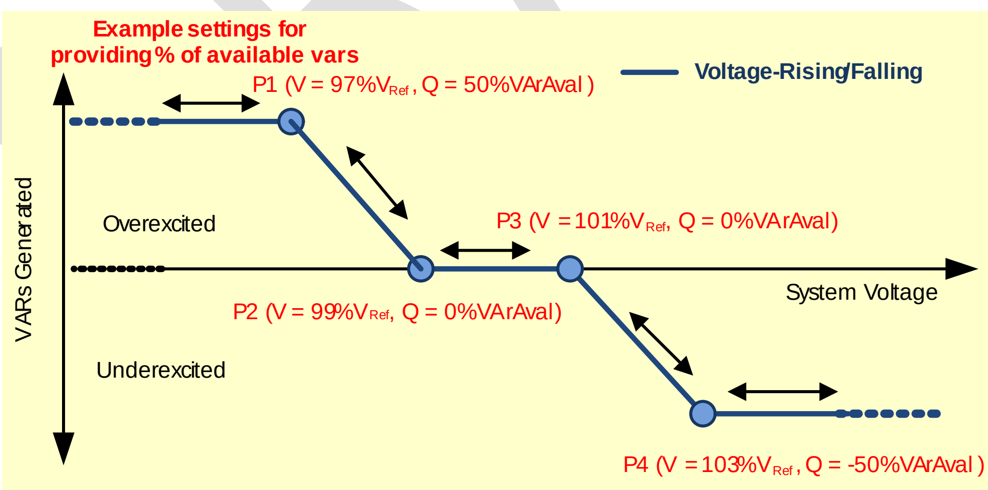

Figure 36: Example of Volt/VAr mode using available vars and a deadband around the nominal voltage (P2-P3)

Hysteresis can be included in the curve to dampen unnecessary swings, as shown in Figure 37. This profile permits each Volt/VAr curve to be set in such a way that hysteresis can be specified, i.e., a different curve is to be used depending on whether voltage is increasing or decreasing. To do so, the Voltage (X-values) of each curve must initially always increase, up to a maximum voltage value for that curve. In Figure 37, the maximum voltage is shown as P2. If the curve used by the ESS is to be different when voltage is decreasing, the Voltage (X-Value) of the next point and all subsequent points after the maximum voltage point must always decrease (e.g. P3 and P4).

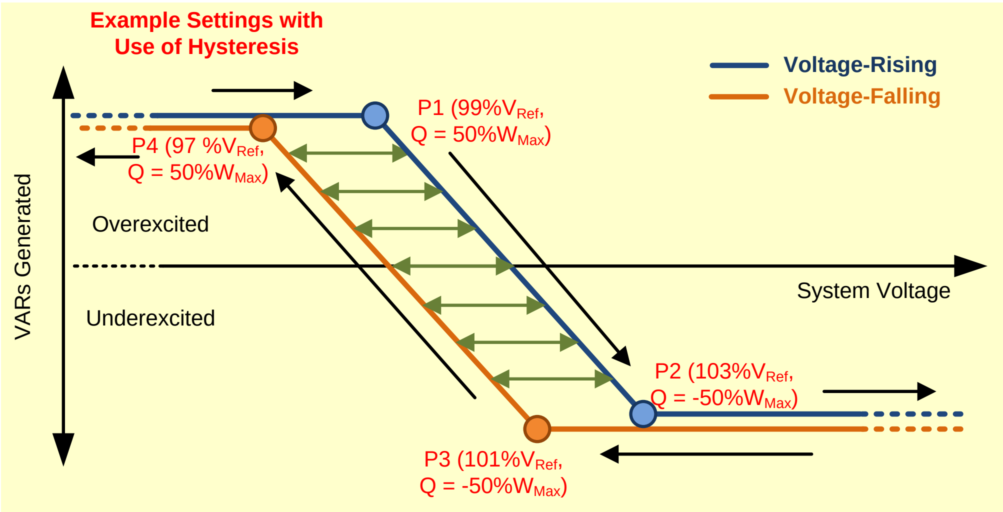

Figure 37: Example of Volt/VAr curve with hysteresis, with arrows indicating direction of voltage changes

This function makes use of the concept of generic curves. The maximum number of Volt/VAr curves is only limited by the resources available on the outstation.

The steps to enable the Volt-VAr Control Mode are shown in

Table 34.

Table 34: Steps to Enable the Volt-VAR Control Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DVVC.ECPRefId	Set Referenced ECP	M		AI, AO
2.	DVVC.VRef	Voltage measurement from the Referenced ECP	M		AI
3.	DVVC.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DVVC.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DVVC.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DVVC.PairArrVVar	Volt-VAR curve, using CSG	M		AI, AO
7.	DVVC.ModEna	Volt-VAR enable	M		BI, BO
8.	DVVC.ModPrty	Volt-VAR Control Mode Priority	O		AI, AO

6.5.3 Watt-VAr Power Mode

The ESS is provided with Watt-VAr curves that define the changes in its reactive power based changes of power. When the Watt-Reactive Power Mode is enabled, the ESS modifies its reactive power setting in response to the power level at the Referenced ECP.

The steps to enable the Watt-VAR Mode are shown in

Table 34.

Table 35: Steps to enable the Watt-VAR Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DWVR.ECPRefId	Set Referenced ECP	M		AI, AO
2.	DWVR.VRef	Voltage measurement from the Referenced ECP	M		AI
3.	DWVR.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DWVR.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DWVR.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO
6.	DWVR.PairArrVVar	Watt-VAr curve, using CSG	M		AI, AO
7.	DWVR.ModEna	Watt-VAr enable	M		BI, BO
8.	DWVR.ModPrty	Watt-VAr Control Mode Priority	O		AI, AO

6.5.4 Power Factor Correction Mode

The steps in Table 36 describe how to set the power factor produced by the energy storage system. The controller shall start the time window, reversion timeout, and ramp time at the moment the master successfully operates the mode enable command. Note that this mode and the Fixed Power Factor mode are mutually exclusive, as only one can be used at a given time to control the reactive behavior of the ESS.

The Power Factor Limiting mode requires real and reactive power readings from an external reference point, i.e., the Referenced ECP. Power readings will typically come from a meter located at the same site as the ESS or at another site on the distribution network which feeds power information directly into the ESS.

Table 36: Steps to Enable Power Factor Limiting Mode

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	DPFC.ECPRefId	Set Referenced ECP	M		AI, AO
2.	DPFC.PFRef	PF measurement from the Referenced ECP	M		AI
3.	DPFC.WinTms	Time window within which to randomly initiate mode	O	Direct Operate / Response	AI, AO
4.	DPFC.RmpTms	Ramp time for moving from current operational mode settings to new operational mode settings	O	Direct Operate / Response	AI, AO
5.	DPFC.RvrtTms	Reversion timeout period upon which to take reversion default action	O	Direct Operate / Response	AI, AO

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
6.	DPFC.PFRef.rangeC	Power Factor Limiting Lower PF Limit	M		AI, AO
7.	DPFC.PFRef.rangeC	Power Factor Limiting Upper PF Limit			
8.	DPFC.ModPrty	Power Factor Correction Mode Priority	O		AI, AO
9.	DPFC.ModEna	Power Factor Correction enable	M		BI, BO

6.6 Scheduling of Modes

MESA-ESS controllers may provide a mechanism to schedule the operational modes shown in section 4. This facility allows a power scheduler or other operator to create a schedule which governs the ESS' behavior over time. A schedule is a curve in which the X-value is a time offset (specified as a number of seconds) from the start of the schedule and the Y-value is the set point for one of the core operational modes in the profile.

When a schedule is enabled by the master, it is queued until time specified by the schedule's start time. When the start time is reached, the controller activates the operational mode identified by the type of schedule. As the corresponding time values (X-value), elapse, mode parameter values (Y-values) are fed to the operational mode to vary its behavior over time.

Multiple schedules may be running over the same period of time so long as they are not mutually exclusive. Schedules may have different priorities, thus allowing a higher priority schedule to pre-empt a lower priority schedule for the same resources. For example, a normal charge/discharge schedule may be running, but the ISO indicates the need for emergency "operational reserve" from the ESS for the next four hours, which triggers an "emergency" schedule with a different set of charge/discharge values. An illustration of priority management is shown in Figure 38.

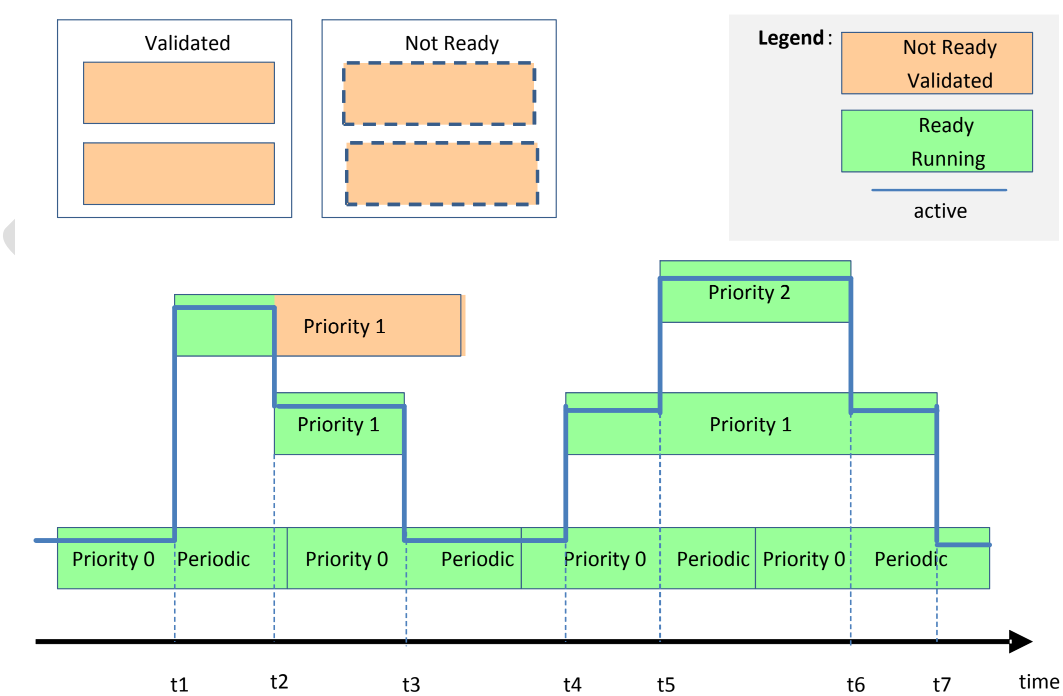

Figure 38: Handling priorities of schedules

Configuring a schedule through DNP3 is accomplished using the steps listed in Table 37.

Table 37: Steps to Create Schedules

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	FSCHxx (the xx refers to the schedule number (index)	Select which schedule to edit by writing a number to this point. This is the “index” of the schedule, not its “identity”. The indexes shall be the monotonically increasing integers 1, 2, 3, etc. while the curve identities may be any unique number.	M	Direct Operate / Response	AI, AO
2.	FSCHxx.ValASG (with FSCH.ClcIntvTyp set to seconds)	Set the Time Offset (X-Value) for each schedule point. Time Offsets must increase with each point. Time Offsets represent relative seconds from each repetition of the schedule.	O	Direct Operate / Response	AI, AO
3.	FSCHxx.ValASG (set for power system values and pricing signals)	Set the Y-value for each schedule point for power system values (watts,VARs, PF, pricing signal, etc.).	O	Direct Operate / Response	AI, AO
4.	FSCHxx.ING (set to the operational mode identity)	Set the Y-value for enabling or disabling operational modes (VV, FW, VW, etc.) at each schedule point.	C		AI, AO
5.	FSCHxx.RmpTms	Set the Ramp Type for entire schedule point.	O	Direct Operate / Response	AI, AO
6.	FSCHxx.NumEntr	Set the number of points used for the schedule. Set this value to zero to disable the schedule (there are other ways to enable and disable schedules).	M	Direct Operate / Response	AI, AO
7.	FSCHxx.SchdPrio	Set the priority for the schedule.	O	Direct Operate / Response	AI, AO
8.	FSCHxx.ValMV (for power system values or pricing signals) or FSCH.ValINS (for operational modes) (meanings of pricing signals need to be defined)	Set the meaning of the Y-values of the schedule.	O	Direct Operate / Response	AI, AO

The steps to enable and manage schedules are shown in Table 38.

Table 38: Steps to Enable and Manage Schedules

Step	IEC 61850	Description	M / O /C	Function Codes	Data Type
1.	FSCC.Schd	Identify the schedule to enable	M	Direct Operate / Response	AI, AO
2.	FSCHxx.StrTm	Set the start time for the selected schedule TBD: Discuss time format for DNP3	M	Direct Operate / Response	AI, AO

3.	FSCHxx.IntvPer	Set the repeat interval for the selected schedule	O	Direct Operate /Response	AI, AO
4.	FSCHxx.ClcIntvTyp	Set the repeat interval units for the selected schedule	O	Direct Operate / Response	AI, AO
5.	FSCHxx.Enable	Enable the Schedule by changing its state to "ready"	M	Select / Response, Operate / Response	BI, BO
6.	FSCH.SchdSt.2	Selected Schedule is Validated	O		BI, BO
7.	FSCHxx.SchdReuse	Selected Schedule Repeat Weekly Sunday	O		BI, BO
8.	FSCHxx.SchdReuse	Selected Schedule Repeat Weekly Monday	O		BI, BO
9.	FSCHxx.SchdReuse	Selected Schedule Repeat Weekly Tuesday	O		BI, BO
10.	FSCHxx.SchdReuse	Selected Schedule Repeat Weekly Wednesday	O		BI, BO
11.	FSCHxx.SchdReuse	Selected Schedule Repeat Weekly Thursday	O		BI, BO
12.	FSCHxx.SchdReuse	Selected Schedule Repeat Weekly Friday	O		BI, BO
13.	FSCHxx.SchdReuse	Selected Schedule Repeat Weekly Saturday	O		BI, BO
14.	FSCC.ActSchdRef	One of more Schedules Running	O		BI, BO

7. Maintenance of ESS Components

During normal operations, actions initiated by the controller and its operational modes affect all inverter and battery bank pairs that are under control. When maintenance is required on an inverter or battery bank, the operator performing the maintenance must be able to safely work with the inverter and its batteries without interference from ongoing controller processes. Rather than shutting down the entire ESS to perform maintenance on a single inverter or battery, a given DER unit (i.e., an inverter and battery bank pair) may be placed into the maintenance operational state.

When a DER unit is in the maintenance operational state, the **DER Unit #N Is In Maintenance Operational State** Binary Input should return a value of 1 which indicates that the unit is not currently online. While the DER unit is in this state, the unit is removed from autonomous control, and the inverter no longer responds to actions initiated by operational modes. Any operational modes which are executed while the DER unit is in the maintenance operational state will only apply to other DER units which are not in the maintenance operational state. Additionally, the **System Available Apparent Power** and **State of Charge** Analog Inputs should both be updated automatically by the controller to indicate that the system is running at reduced capacity.

No facility is provided by the profile to allow an operator to place a DER unit into the maintenance operational state using DNP3. However, it is reasonable for a local HMI to provide this ability to the local operator. Additionally, a local HMI may choose to provide functions which operate directly on the unit under maintenance such as:

- Stopping and starting the inverter.
- Disconnecting (opening connectors) and connecting (closing connectors) the battery bank.
- Charging and discharging the battery bank.

The exact behavior of the local HMI and the functionality that it provides for DER units in the maintenance operational state is not specified here as it is outside the scope of this document.

8. Bibliography

1. MESA-PCS, available at http://mesastandards.org/mesa-downloads/
2. MESA-Storage, available at http://mesastandards.org/mesa-downloads/
3. MESA-Meter, available at http://mesastandards.org/mesa-downloads/