

# TECHNICAL REPORT



**Communication networks and systems for power utility automation –  
Part 90-7: Object models for power converters in distributed energy resources  
(DER) systems**

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INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

ICS 33.200

ISBN 978-2-8322-7452-1

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## CONTENTS

FOREWORD.....	7
1 Scope.....	9
2 Normative references .....	9
3 Terms, definitions, acronyms and abbreviated terms .....	10
3.1 Terms and definitions.....	10
3.2 Acronyms.....	10
3.3 Abbreviated terms.....	15
4 Overview of power converter-based DER functions.....	15
4.1 General.....	16
4.2 Power converter configurations and interactions .....	17
4.3 Power converter methods .....	19
4.4 Power converter functions.....	20
4.5 Differing DER architectures.....	21
4.5.1 Conceptual architecture: electrical coupling point (ECP).....	21
4.5.2 Conceptual architecture: point of common coupling (PCC).....	21
4.5.3 Utility interactions directly with power converters or indirectly via a customer EMS .....	22
4.5.4 Communication profiles .....	22
4.6 General sequence of information exchange interactions.....	23
5 Concepts and constructs for managing power converter functions .....	24
5.1 Basic settings of power converters.....	24
5.1.1 Nameplate values versus basic settings .....	24
5.1.2 Power factor and power converter quadrants .....	24
5.1.3 Maximum watts, vars, and volt-amp settings .....	26
5.1.4 Active power ramp rate settings .....	28
5.1.5 Voltage phase and correction settings .....	28
5.1.6 Charging settings.....	28
5.1.7 Example of basic settings .....	29
5.1.8 Basic setting process.....	29
5.2 Modes for managing autonomous behaviour .....	29
5.2.1 Benefits of modes to manage DER at ECPs.....	29
5.2.2 Modes using curves to describe behaviour .....	30
5.2.3 Paired arrays to describe mode curves .....	31
5.2.4 Percentages as size-neutral parameters: voltage and var calculations.....	32
5.2.5 Hysteresis as values cycle within mode curves .....	33
5.2.6 Low pass exponential time rate.....	34
5.2.7 Ramp rates.....	35
5.2.8 Randomized response times.....	35
5.2.9 Timeout period .....	35
5.2.10 Multiple curves for a mode.....	35
5.2.11 Multiple modes .....	35
5.2.12 Use of modes for loosely coupled, autonomous actions .....	36
5.3 Schedules for establishing time-based behaviour.....	36
5.3.1 Purpose of schedules .....	36
5.3.2 Schedule components .....	36
6 DER management functions for power converters.....	38
6.1 Immediate control functions for power converters .....	38

6.1.1	General .....	38
6.1.2	Function INV1: connect / disconnect from grid .....	38
6.1.3	Function INV2: adjust maximum generation level up/down .....	39
6.1.4	Function INV3: adjust power factor .....	39
6.1.5	Function INV4: request active power (charge or discharge storage).....	40
6.1.6	Function INV5: pricing signal for charge/discharge action .....	41
6.2	Modes for volt-var management .....	41
6.2.1	VAr management modes using volt-var arrays .....	41
6.2.2	Example setting volt-var mode VV11: available var support mode with no impact on watts.....	42
6.2.3	Example setting volt-var mode VV12: maximum var support mode based on WMax.....	44
6.2.4	Example setting volt-var mode VV13: static power converter mode based on settings .....	45
6.2.5	Example setting volt-var mode VV14: passive mode with no var support.....	46
6.3	Modes for frequency-related behaviours .....	47
6.3.1	Frequency management modes .....	47
6.3.2	Frequency-watt mode FW21: high frequency reduces active power .....	48
6.3.3	Frequency-watt mode FW22: constraining generating/charging by frequency .....	50
6.4	Dynamic reactive current support during abnormally high or low voltage levels .....	53
6.4.1	Purpose of dynamic reactive current support .....	53
6.4.2	Dynamic reactive current support mode TV31: support during abnormally high or low voltage levels .....	53
6.5	Low/high voltage ride-through curves for “must disconnect” and “must remain connected” zones .....	57
6.5.1	Purpose of L/HVRT .....	57
6.5.2	“Must disconnect” (MD) and “must remain connected” (MRC) curves .....	57
6.6	Modes for watt-triggered behaviours .....	59
6.6.1	Watt-power factor mode WP41: feed-in power controls power factor .....	59
6.6.2	Alternative watt-power factor mode WP42: feed-in power controls power factor .....	59
6.7	Modes for voltage-watt management.....	60
6.7.1	Voltage-watt mode VW51: voltage-watt management: generating by voltage .....	60
6.7.2	Voltage-watt mode VW52: voltage-watt management: charging by voltage .....	60
6.8	Modes for behaviours triggered by non-power parameters .....	61
6.8.1	Temperature mode TMP .....	61
6.8.2	Pricing signal mode PS.....	61
6.9	Setting and reporting functions .....	62
6.9.1	Purpose of setting and reporting functions .....	62
6.9.2	Establishing settings DS91: modify power converter-based DER settings.....	62
6.9.3	Event logging DS92: log alarms and events, retrieve logs.....	62
6.9.4	Reporting status DS93: selecting status points, establishing reporting mechanisms .....	66
<del>7.9.5</del>	<del>Time synchronization DS94: time synchronization requirements .....</del>	<del>.....</del>
<del>8</del>	<del>IEC 61850 information models for power converter-based functions .....</del>	<del>.....</del>
<del>8.1</del>	<del>Overall structure of IEC 61850 .....</del>	<del>.....</del>

8.2	IEC 61850 system logical nodes .....	
8.3	Key components of IEC 61850 information modelling of power converter-based functions.....	
8.3.1	Subsets of 61850 models for power converter-based DER functions.....	
8.3.2	Types of interactions for settings, functions, and modes .....	
8.3.3	Key common data classes (CDCs).....	
8.3.4	Messaging services .....	
8.3.5	Message errors.....	
8.4	Basic settings in IEC 61850 .....	
8.4.1	Logical nodes for basic settings.....	
8.4.2	IEC 61850 models for basic settings .....	
8.5	Mode settings in IEC 61850 .....	
8.5.1	Logical nodes for establishing and managing modes .....	
8.5.2	IEC 61850 models for modes.....	
8.6	Schedules in IEC 61850.....	
8.6.1	Scheduling structures .....	
8.6.2	IEC 61850 models for schedules .....	
8.7	Immediate control functions in IEC 61850 .....	
8.7.1	IEC 61850 models for INV1: connect/disconnect.....	
8.7.2	IEC 61850 models for INV2: adjust maximum generation level up/down.....	
8.7.3	IEC 61850 models for INV3: adjust power factor.....	
8.7.4	IEC 61850 models for INV4: charge/discharge storage.....	
8.7.5	IEC 61850 models for INV5: pricing signal for charge/discharge of storage .....	
8.8	Volt var management modes in IEC 61850 .....	
8.8.1	IEC 61850 models for VV10 – VV12: volt var curve settings .....	
8.8.2	IEC 61850 models for VV13 – VV14: volt var parameter settings.....	
8.9	Frequency related modes in IEC 61850 .....	
8.9.1	IEC 61850 for FW21: frequency driven active power modification .....	
8.9.2	IEC 61850 for FW22: Frequency watt mode FW22: generating/charging by frequency.....	
8.10	Voltage management modes in IEC 61850.....	
8.10.1	IEC 61850 for TV31: dynamic reactive current support .....	
8.10.2	IEC 61850 for “must disconnect”.....	
8.10.3	IEC 61850 for “must remain connected”.....	
8.11	Watt triggered behaviour modes in IEC 61850 .....	
8.11.1	IEC 61850 for WP41 and WP42: feed-in watts control of power factor .....	
8.12	Voltage watt management modes in IEC 61850 .....	
8.12.1	IEC 61850 for VW51: voltage watt management in generation and charging .....	
8.13	Non power mode behaviours in IEC 61850 .....	
8.13.1	IEC 61850 models for temperature mode TMP.....	
8.13.2	IEC 61850 models for pricing signal mode PS .....	
8.14	IEC 61850 reporting commands .....	
8.14.1	IEC 61850 models for DS91: modify DER settings .....	
8.14.2	IEC 61850 models for DS92: event/history logging .....	
8.14.3	IEC 61850 models for DS93: status reporting .....	

Figure 1 – DER management hierarchical interactions: autonomous, loosely-coupled, broadcast/multicast.....	19
Figure 2 – Electrical Connection Points (ECP) and Point of Common Coupling (PCC) .....	22
Figure 3 – Producer and Consumer Reference Frame conventions .....	25
Figure 4 – EEI power factor sign convention .....	26
Figure 5 – Working areas for different modes.....	27
Figure 6 – Example of voltage offsets ( $V_{RefOfs}$ ) with respect to the reference voltage ( $V_{Ref}$ ).....	28
Figure 7 – Example of modes associated with different ECPs .....	30
Figure 8 – Example of a volt-var mode curve .....	31
Figure 9 – Example of hysteresis in volt-var curves.....	33
Figure 10 – Example of deadband in volt-var curves .....	34
Figure 11 – Local function block diagram .....	34
Figure 12 – Time domain response of first order low pass filter.....	35
Figure 13 – Interrelationships of schedule controllers, schedules, and schedule references .....	37
Figure 14 – Volt-var mode VV11 – available vars mode .....	43
Figure 15 – Power converter mode VV12 – Maximum var support mode based on $W_{Max}$ .....	44
Figure 16 – Power converter mode VV13 – Example: static var support mode based on $VAr_{Max}$ .....	46
Figure 17 – Frequency-watt mode curves.....	48
Figure 18 – Frequency-based active power reduction .....	49
Figure 19 – Frequency-based active power modification with the use of an array.....	50
Figure 20 – Example of a basic frequency-watt mode configuration .....	51
Figure 21 – Example array settings with hysteresis .....	52
Figure 22 – Example of an asymmetrical hysteresis configuration.....	52
Figure 23 – Example array configuration for absorbed watts vs. frequency .....	53
Figure 24 – Basic concepts of the dynamic reactive current support function .....	54
Figure 25 – Calculation of delta voltage over the filter time window.....	54
Figure 26 – Activation zones for dynamic reactive current support .....	55
Figure 27 – Alternative gradient behaviour, selected by ArGraMod .....	56
Figure 28 – Settings to define a blocking zone .....	56
Figure 29 – Must disconnect and must remain connected zones .....	58
Figure 30 – Examples of “must remain connected” requirements for different regions .....	58
Figure 31 – Power factor controlled by feed-in power.....	59
Figure 32 – Example configuration curve for maximum watts vs. voltage .....	60
Figure 33 – Example configuration curve for maximum watts absorbed vs. voltage .....	61
<del>Figure 34 – Structure of the IEC 61850 Parts.....</del>	<del>.....</del>
<del>Figure 35 – Interrelationships of schedule controllers, schedules, and schedule references .....</del>	<del>.....</del>
Table 1 – Producer Reference Frame (PRF) conventions.....	25
Table 2 – Example basic settings for a storage DER unit .....	29
Table 3 – Events.....	64

Table 4 – Examples of status points.....	66
Table 5 – Interpretation of logical node tables.....	
Table 6 – LPHD class.....	
Table 7 – Common LN class.....	
Table 8 – LLN0 class.....	
Table 9 – CDC SPS.....	
Table 10 – CDC SPC.....	
Table 11 – CDC DPC.....	
Table 12 – CDC INC.....	
Table 13 – CDC ING.....	
Table 14 – CDC ASG.....	
Table 15 – CDC ORG.....	
Table 16 – CDC CSG.....	
Table 17 – Schedule (SCR) common data class specification.....	
Table 18 – Service error type definitions.....	
Table 19 – LN DRCT – DER controller characteristics.....	
Table 20 – LN FMAR – set mode array.....	
Table 21 – LN DGSM – issue mode command.....	
Table 22 – LN DOPM – operations.....	
Table 23 – INV1 – LN CSWI – issue and respond to control.....	
Table 24 – LN FWHZ – set power levels by frequency for FW21.....	
Table 25 – LN RDGS – dynamic reactive current support for TV31.....	
Table 26 – LN FPFW – set power factor by feed-in power for WP41.....	
Table 27 – DS92 – IEC 61850 log structure.....	
Table 28 – LN DRCS – DER state for DS93.....	
Table 29 – DS93 – Status, settings, and measurement points.....	

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### COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

#### Part 90-7: Object models for power converters in distributed energy resources (DER) systems

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IEC TR 61850-90-7 has been prepared by IEC technical committee 57: Power systems management and associated information exchange. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2013. This edition is primarily an editorial revision in order to be consistent with the publication of Edition 2 of IEC 61850-7-420:2021.

This edition includes the following significant changes with respect to the previous edition:

- a) Clause 3 has been updated.
- b) Clause 8 (IEC 61850 information models for power converter-based functions) has been deleted. This clause defined data models with the transitional namespace “(Tr) IEC 61850-90-7:2012”. The data models are now defined in IEC 61850-7-420.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
57/2558/DTR	57/2610/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at [www.iec.ch/members\\_experts/refdocs](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/publications](http://www.iec.ch/publications).

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# COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

## Part 90-7: Object models for power converters in distributed energy resources (DER) systems

### 1 Scope

This part of IEC 61850, which is a Technical Report, describes functions for power converter-based distributed energy resources (DER) systems, focused on DC-to-AC and AC-to-AC conversions and including photovoltaic systems (PV), battery storage systems, electric vehicle (EV) charging systems, and any other DER systems with a controllable power converter.

The functions defined in this document were used to help define the IEC 61850 information models to described in IEC 61850-7-420 and which can be used in the exchange of information between these power converter-based DER systems and the utilities, energy service providers (ESPs), or other entities which are tasked with managing the volt, var, and watt capabilities of these power converter-based systems.

These power converter-based DER systems can range from very small grid-connected systems at residential customer sites, to medium-sized systems configured as microgrids on campuses or communities, to very large systems in utility-operated power plants, and to many other configurations and ownership models. They may or may not combine different types of DER systems behind the power converter, such as a power converter-based DER system and a battery that are connected at the DC level.

~~The namespace of this document is:~~

~~"(TR) IEC 61850-90-7:2012"~~

~~The namespace "IEC 61850-90-7" is considered as "transitional" since the models are expected to be included in IEC 61850-7-420. Potential extensions/modifications may happen if/when the models are moved to International Standard status.~~

~~Only the new data objects and CDCs which are represented in **bold-italic font** will be tagged with this namespace name. The others should still refer to the namespace where they are primarily defined.~~

NOTE The term power converter is being used in place of "inverter" since it covers more types of conversion from input to output power:

- AC to DC (rectifier)
- DC to AC (inverter)
- DC to DC (DC-to-DC converter)
- AC to AC (AC-to-AC converter)

### 2 Normative references

~~The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.~~

~~IEC 61850-7-2, Communication networks and systems for power utility automation—Part 7-2: Basic communication structure—Abstract communication service interface (ACSI)~~

~~IEC 61850-7-3, Communication networks and systems for power utility automation—Part 7-3: Basic communication structure—Common data classes~~

~~IEC 61850-7-4, Communication networks and systems for power utility automation—Part 7-4: Basic communication structure—Compatible logical node classes and data object classes~~

~~IEC 61850-7-410, Communication networks and systems for power utility automation—Part 7-410: Hydroelectric power plants—Communication for monitoring and control~~

~~IEC 61850-7-420, Communication networks and systems for power utility automation—Part 7-420: Basic communication structure—Distributed energy resources logical nodes~~

~~IEC 61850-8-1, Communication networks and systems for power utility automation—Part 8-1: Specific communication service mapping (SCSM)—Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3~~

~~ISO 4217, Codes for the representation of currencies and funds~~

~~EI Handbook for Electricity Metering, 10<sup>th</sup> Edition (2002), Edison Electric Institute, Washington, D.C.~~

There are no normative references in this document.

### 3 Terms, definitions, acronyms and abbreviated terms

For the purposes of the present document, the following terms, definitions, acronyms and abbreviated terms apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

#### 3.1 Terms and definitions

##### 3.1.1

##### **autonomous automatic operation**

~~responding, reacting, or developing independently of the whole; not controlled by others or by outside forces; independent~~

~~[SOURCE: Merriam-Webster dictionary]~~

operating mode in which all functions of the control equipment are performed without action of a human operator

[SOURCE: IEC 60050-351:2013, 351-55-03]

##### 3.1.2

##### **common data class CDC**

~~classes of commonly used data structures which are mostly defined in IEC 61850-7-3, but are sometimes initially defined in other IEC 61850 documents until they can be updated in IEC 61850-7-3~~

### 3.1.3

#### **device**

~~material element or assembly of such elements intended to perform a required function~~

~~Note 1 to entry: A device may form part of a larger device.~~

~~[SOURCE: IEC 60050-151:2001, 151-11-20]~~

### 3.1.2

#### **distributed energy resource**

##### **DER**

energy resource comprised of generation and/or storage and/or controllable load connected at the low or medium voltage distribution level

Note 1 to entry: DER may include associated protection, control, and monitoring capabilities, and may consist of aggregated DER units.

Note 2 to entry: DER may interact with the area and/or local electric power systems (EPS) by providing energy through the EPSs, by adapting their behaviour based on EPS conditions, and/or by providing other EPS-related services for regulatory, contractual, or market reasons.

[SOURCE: IEC 61850-7-420:2021, 3.1.13]

### 3.1.3

#### **electrical connection point**

##### **ECP**

point of electrical connection between the DER ~~source of energy (generation or storage)~~ and any electric power system (EPS)

Note 1 to entry: Each DER (generation or storage) unit has an ECP connecting it to its local power system; groups of DER units have an ECP where they interconnect to the power system at a specific site or plant; a group of DER units plus local loads have an ECP where they are interconnected to the utility power system.

Note 2 to entry: For those ECPs between a utility EPS and a plant or site EPS, this point is identical to the point of common coupling (PCC) in the IEEE 1547, *Standard for Interconnecting Distributed Resources with Electric Power Systems*.

~~[SOURCE: IEC 61850-7-420:2009, modified by transforming second paragraph into Note 1 to entry 2021, 3.1.17]~~

### 3.1.4

#### **electric power system**

##### **EPS**

~~facilities that deliver electric power to a load~~

~~Note 1 to entry: This may include generation units.~~

~~[SOURCE: IEEE 1547:2003]~~

composite, comprised of one or more generating sources, and connecting transmission and distribution facilities, operated to supply electric energy

Note 1 to entry: A specific electric power system includes all installations and plant, within defined bounds, provided for the purpose of generating, transmitting and distributing electric energy.

[SOURCE IEC 60050-692:2017, 692-01-02]

### 3.1.5

#### **electric power system, area**

##### **area EPS**

~~electric power system (EPS) that serves Local EPSs~~

~~Note 1 to entry: Typically, an Area EPS has primary access to public rights-of-way, priority crossing of property boundaries, etc. and is subject to regulatory oversight.~~

~~[SOURCE: IEEE 1547:2003]~~

electric power system that serves multiple local electric power systems

Note 1 to entry: A typical area EPS is a MV/LV distribution network.

[SOURCE: IEEE 1547:2018, modified - addition of Note 1 to entry]

### ~~3.1.7~~

~~**electric power system, local  
local EPS**~~

~~EPS contained entirely within a single premises or group of premises~~

~~[SOURCE: IEEE 1547:2003]~~

### ~~3.1.8~~

#### ~~3.1.8.1~~

~~**event**~~

~~**event information**~~

~~something that happens in time~~

~~Note 1 to entry: In power system operations, an event is typically state information and/or state transition (status, alarm, or command) reflecting power system conditions.~~

~~[SOURCE: IEC 60050-113:2005, 113-01-04, modified by removal of "subspace ... of space-time" and alteration of Note 1 to entry]~~

### **3.1.6**

**event**

**event information**

monitored information on the change of state of operational equipment

Note 1 to entry: In power system operations, an event is typically state information and/or state transition (status, alarm, or command) reflecting power system conditions.

[SOURCE: IEC 60050-371:1984, 371-02-04, modified – addition of term "event" and Note 1 to entry]

### ~~3.1.9~~

~~**function**~~

~~computer subroutine; specifically: one that performs a calculation with variables provided by a program and supplies the program with a single result~~

~~Note 1 to entry: This term is very general and can often be used to mean different ideas in different contexts. However, in the context of computer-based technologies, it is used to imply software or computer hardware tasks.~~

~~[SOURCE: Merriam-Webster dictionary]~~

### **3.1.7**

**process control function**

function to work on process variable quantities, which is composed of basic functions of process control, specific to particular functional units of the plant

[SOURCE: IEC 60050-351:2013, 351-55-16, modified - deletion of Note 1 to entry]

### **3.1.8**

**generator**

energy transducer that transforms non-electric energy into electric energy

Note 1 to entry: The reverse conversion of electrical energy into mechanical energy is done by an electric motor, and motors and generators have many similarities. The ~~prime mover~~ source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a hydropower turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, or any other source of mechanical energy.

[SOURCE: IEC 60050-151:2001, 151-13-35, modified - addition of Note 1 to entry]

### **3.1.10.2**

#### **generator**

~~device that converts kinetic energy to electrical energy, generally using electromagnetic induction.~~

~~Note 1 to entry:—The reverse conversion of electrical energy into mechanical energy is done by an electric motor, and motors and generators have many similarities. The prime mover source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a hydropower turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, or any other source of mechanical energy.~~

~~[SOURCE: Wikipedia 2007-12]~~

### **3.1.11**

#### **3.1.11.1**

##### **information**

~~intelligence or knowledge capable of being represented in forms suitable for communication, storage or processing~~

~~Note 1 to entry:—Information may be represented for example by signs, symbols, pictures, or sounds.~~

~~[SOURCE: IEC 60050-701:1988, 701-01-01]~~

#### **3.1.11.2**

##### **information**

~~knowledge concerning objects, such as facts, events, things, processes, or ideas, including concepts, that within a certain context has a particular meaning~~

~~Note 1 to entry:—Information may be represented for example by signs, symbols, pictures, or sounds.~~

~~[SOURCE: ISO/IEC 2382-1:1993, 01.01.01, modified by addition of Note 1 to entry]~~

### **3.1.12**

#### **information exchange**

~~communication process between two or more computer-based systems in order to transmit and receive information~~

~~Note 1 to entry:—The exchange of information between systems requires interoperable communication services.~~

### **3.1.9**

#### **inverter**

~~static power converter (SPC)~~

~~device that converts DC electricity into AC electricity. Equipment that converts direct current from the array field to alternating current. The electric equipment used to convert electrical power into a form or forms of electrical power suitable for subsequent use by the electric utility~~

~~Note 1 to entry:—Any static power converter with control, protection, and filtering functions used to interface an electric energy source with an electric utility system. Sometimes referred to as power conditioning subsystems, power conversion systems, solid-state converters, or power conditioning units.~~

~~[SOURCE: IEC 61727:2004, 3.8, modified by deletion of Note 2 to entry]~~

electric energy converter that changes direct electric current to single-phase or polyphase alternating currents

[SOURCE: IEC 60050-151:2001, 151-13-46]

### **3.1.10**

#### **monitor**

~~to check at regular intervals selected values regarding their compliance to specified values, ranges of values or switching conditions~~

acquire a quantity value continuously or sequentially in order to check whether it is within normal operating limits and, where appropriate, to signal if it passes its tolerance boundaries

[SOURCE: IEC 60050-351:2006,2013, 351-2243-03]

### 3.1.11 point of common coupling PCC

~~the point of a power supply network, electrically nearest to a particular load, at which other loads are, or may be, connected~~

~~Note 1 to entry:— These loads can be either devices, equipment or systems, or distinct customer's installations.~~

~~Note 2 to entry:— In some applications, the term "point of common coupling" is restricted to public networks.~~

~~Note 3 to entry:— The point where a local EPS is connected to an area EPS [IEEE 1547]. The local EPS may include distributed energy resources as well as load (see IEC definition which only includes load).~~

~~[SOURCE: IEC 60050-161:1990,161-07-15, modified by replacement of "consumer's installation" by "load" and by addition of Notes 1 to 3 to entry]~~

electrical connection point (ECP) in an electric power system, electrically nearest to a particular load or generator, at which other loads or generators are, or may be, connected

Note 1 to entry: These loads can be either devices, equipment or systems, or distinct network users' installations.

Note 2 to entry: The point where a local EPS is connected to an area EPS [IEEE 1547]. The local EPS may include distributed energy resources.

[SOURCE: IEC 61850-7-420:2021, modified – addition of "connection"]

### 3.1.12 power converter

electronic equipment that converts:

- AC to DC (rectifier)
- DC to AC (inverter)
- DC to DC (DC-to-DC converter)
- AC to AC (AC-to-AC converter)

### 3.1.17 prime mover

~~equipment acting as the energy source for the generation of electricity~~

~~Note 1 to entry:— Examples include diesel engine, solar panels, gas turbines, wind turbines, hydro turbines, battery storage, water storage, air storage, etc.~~

### 3.1.18 set point

~~target value that an automatic control system will aim to reach~~

[SOURCE: Wikipedia 2012-3]

### 3.1.19 set point command

~~a command in which the value for the required state of operational equipment is transmitted to a controlled station where it is stored~~

~~Note 1 to entry:— A setpoint is usually an analogue value which sets the controllable target for a process or sets limits or other parameters used for managing the process.~~

[SOURCE: IEC 60050-371:1984,371-03-11, modified by addition of Note 1 to entry]

### 3.2 Acronyms

<del>CDC:</del>	<del>Common Data Class</del>
<del>GIM:</del>	<del>Common Information Model</del>
DER:	Distributed Energy Resource
<del>DR:</del>	<del>Demand Response</del>
ECP:	Electrical Connection Point
EI:	Edison Electric Institute
EMS:	Energy Management System
EPS:	Electric Power System
ESP:	Energy Service Provider
<del>EV:</del>	<del>Electric Vehicle</del>
<del>EVSE:</del>	<del>Electric Vehicle Service Element</del>
<del>GPRS:</del>	<del>General packet radio service</del>
ISO:	Independent System Operator
L/HRVT:	Low/High Voltage Ride-Through
<del>LN:</del>	<del>Logical Node</del>
MMS:	Manufacturing Message Specification
PCC:	Point of Common Coupling
PF:	Power Factor
PV:	Photovoltaic
RTO:	Regional Transmission Operator
TSO:	Transmission System Operator

### 3.3 Abbreviated terms

Clause 4 of IEC 61850-7-4 defines abbreviated terms for building concatenated data names. Additional abbreviated terms used in this document are:

Ar	Amperes reactive
Array	Array of ...
Aval	Available
Db	Deadband
Dec	Decrease
Del	Delta
Dept	Dependent
Dsct	Disconnect
Gra	Gradient
Hold	Hold
Hys	Hysteresis
Inc	Increase
<del>Indp</del>	<del>Independent</del>
<del>Long</del>	<del>Long</del>
<del>Pair</del>	<del>Paired</del>
Rcnt	Reconnect
<del>Rvrt</del>	<del>Revert</del>

Sag	Sag
<del>Shrt</del>	<del>Short</del>
Snpt	Snapshot
Swell	Swell
<del>Win</del>	<del>Window</del>

## 4 Overview of power converter-based DER functions

### 4.1 General

The advent of decentralized electric power production is a reality in the majority of the power systems of the world, driven by the need for new types of energy converters to mitigate the heavy reliance on non-renewable fossil fuels, by the increased demand for electrical energy, by the development of new technologies of small power production, by the deregulation of energy markets, and by increasing environmental constraints.

The numbers of interconnected DER systems are increasing rapidly. The advent of decentralized electric power production is a reality in the majority of power systems all over the world, driven by many factors:

- The need for new sources of energy to mitigate the heavy reliance on externally-produced fossil fuels.
- The requirements in many countries for renewable portfolios that have spurred the movement toward renewable energy sources such as solar and wind, including tax breaks and other incentives for utilities and their customers.
- The development of new technologies of small power production that have made, and are continuing to improve, the cost-effectiveness of small energy devices.
- The trend in deregulation down to the retail level, thus incentivizing energy service providers to combine load management with generation and energy storage management.
- The increased demand for electrical energy, particularly in developing countries, but also in developed countries for new requirements such as Electric Vehicles (EVs).
- The constraints on building new transmission facilities and increasing environmental concerns that make urban-based generation more attractive.

These pressures have greatly increased the demand for Distributed Energy Resource (DER) systems that consist of both generation and energy storage systems which are interconnected with the distribution power systems.

DER systems challenge traditional power system management. These increasing numbers of DER systems are also leading to pockets of high penetrations of these variable and often unmanaged sources of power which impact the stability, reliability, and efficiency of the power grid. DER systems can be no longer viewed only as “negative load” and therefore insignificant in power system planning and operations. Their unplanned locations, their variable sizes and capabilities, and their fluctuating responses to both environmental and power situations make them difficult to manage, particularly as greater efficiency and reliability of the power system is being demanded.

At the same time, DER systems could become very powerful tools in managing the power system for reliability and efficiency. The majority of DER systems use power converters to convert their primary electrical form (often direct current (DC) or non-standard frequency) to the utility power grid standard electrical interconnection requirements of 60 Hz or 50 Hz and alternating current (AC). ~~Not only can power converters provide~~ In addition to these basic conversions, ~~but power converters are also very powerful devices that~~ can readily modify many of their electrical characteristics through software settings and commands, so long as they remain within the capabilities of the DER system that they are managing and within the standard requirements for interconnecting the DER to the power system.

DER systems are becoming quite “smart” and can perform “autonomously”<sup>1</sup> most of the time according to pre-established settings or “operating modes”, while still responding to occasional commands to override or modify their autonomous actions by utilities and/or energy service providers (ESPs). DER systems can “sense” local conditions of voltage levels, frequency deviations, and temperature, and can receive emergency commands and pricing signals, which allow them to modify their power and reactive power output. These autonomous settings can be updated as needed. To better coordinate these DER autonomous capabilities while minimizing the need for constant communications, utilities and ESPs can also send schedules of modes and commands for the DER systems to follow on daily, weekly, and/or seasonal timeframes.

Given these ~~ever more~~ sophisticated capabilities, utilities and energy service providers (ESPs) are increasingly desirous (and even mandated by some regulations) to make use of these capabilities to improve power system reliability and efficiency. Several countries are using the concept of “operating envelopes” that define upper and lower limits on the import or export power in a given time interval for specific connection points. The DER systems are then responsible for applying appropriate limits to individual energy resources.

None of the functions described in this document are necessarily “mandatory” from an implementation perspective – actually requiring certain functions to be implemented is the purview of regulators and of the purchasers of systems. ~~What this document states is “if a function is to be implemented, then it must be implemented according to these specifications”.~~

#### 4.2 Power converter configurations and interactions

Bulk power generation is generally managed directly, one-on-one, by utilities. This approach is not feasible for managing thousands if not millions of DER systems.

DER systems cannot and should not be managed in the same way as bulk power generation. New methods for handling these dispersed sources of generation and storage must be developed, including both new power system functions and new communication capabilities. In particular, the “smart” capabilities of power converter-based DER systems must be utilized to allow this power system management to take place at the lowest levels possible, while still being coordinated from region-wide and system-wide utility perspectives.

This “dispersed, but coordinated intelligence” approach permits far greater efficiencies, reliability, and safety through rapid, autonomous DER responses to local conditions, while still allowing the necessary coordination as broader requirements can be addressed through communications on an as-needed basis.

Communications, therefore, play an integral role in managing the power system, but are not expected or capable of continuous monitoring and control. Therefore the role of communications must be modified to reflect this reality.

Power converter-based DER functions range from the simple (turn on/off, limit maximum output) to the quite sophisticated (volt-var control, frequency/watt control, and low-voltage ride-through). They also can utilize varying degrees of autonomous capabilities to help cope with the sophistication.

At least three levels of information exchanges are envisioned:

- a) Autonomous DER behaviour responding to local conditions with controllers focused on direct and rapid monitoring and control of the DER systems: This autonomous behaviour would use one or more of the pre-set modes and/or schedules to direct their actions, thus

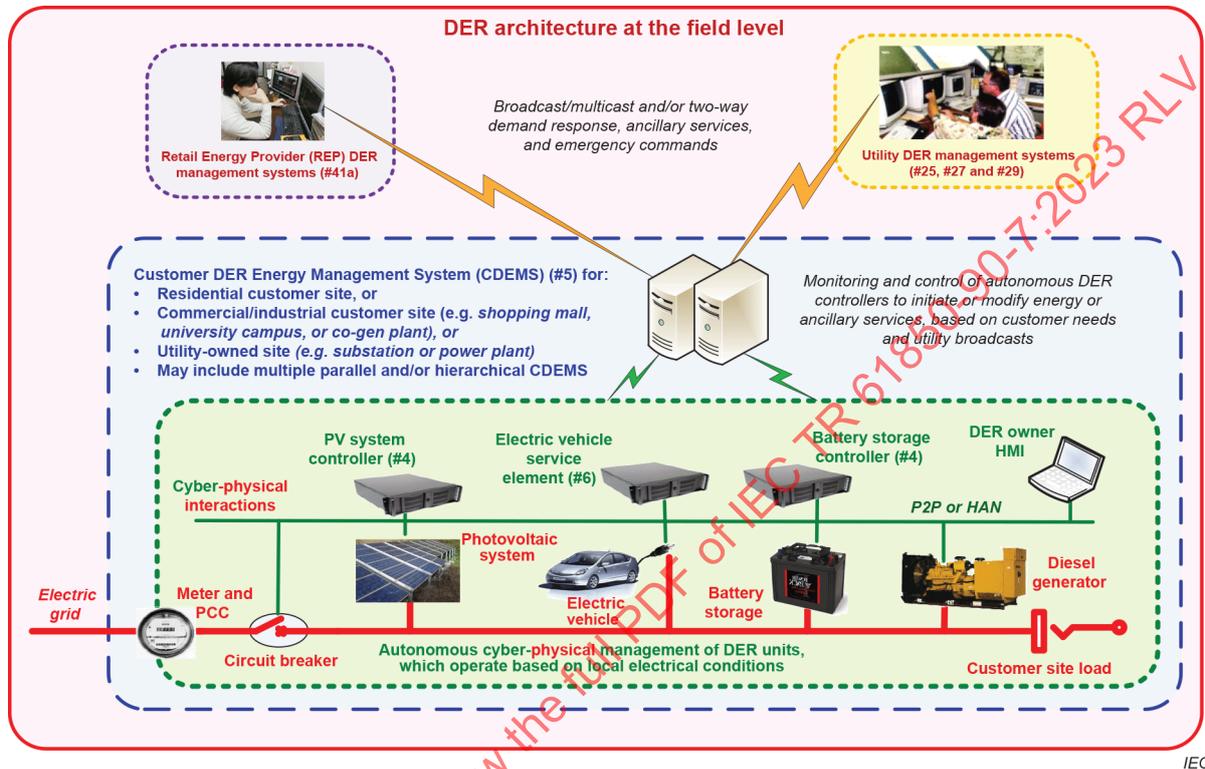
<sup>1</sup> Not controlled by others or by outside forces; independent. This word is used in the definition of “distributed process computer system” as a “set of spatial distributed process computer systems for the monitoring and control of basically autonomous sub-processes” (IEC 60050-351:2006, 351-30-05).

not needing remote communications except occasionally to modify which modes or schedules to use.

- Autonomous behaviour is defined as DER systems utilizing pre-set modes and schedules that respond to locally sensed conditions, such as voltage, frequency, and/or temperature, or to broadcast information, such as pricing signals or requests for using specific modes. These pre-settings are updated as needed (not in real-time), possibly through the Internet or through other communication methods.
  - The DER systems would utilize its detailed knowledge of the status and capabilities of the DER equipment as well as the status of the local electric power grid, such as voltage and frequency, to determine the output from the DER system.
  - Common types of autonomous DER systems consist of the controllers that directly manage one or more power converters, such as a small PV system, a battery storage system, an electric vehicle service element (EVSE), and each of the individual DER systems within an office building, a wind farm, or a microgrid.
  - Interaction times are millisecond to seconds.
- b) DER management system interactions with multiple DER systems in which the DER management system has a more global vision of all the DER systems under its control. It understands the overall capabilities of the DER systems under its management but may not have (or need) detailed data.
- DER management systems can issue direct commands but they primarily establish the autonomous settings for each DER system.
  - On start-up, the DER management system may provide various possible autonomous mode settings to each of the DER systems, and then over time modify which of these autonomous mode settings are active, possibly in response to utility requests or pricing signals.
  - Common scenarios include a campus DER management system coordinating many DER systems on different buildings or an energy service provider managing disparate DER systems within a community.
  - Additional scenarios include an ISO/RTO/TSO managing a large storage device through Automatic Generation Control (AGC) or requesting a specific power factor at the PCC of a wind farm.
  - A microgrid scenario would include a microgrid management system managing the intentional islanding of the microgrid and then coordinating the generation, storage, and load elements to maintain microgrid stability through the combination of setting autonomous modes for some DER systems and issuing direct commands to other DER systems.
  - Interaction frequency may be seconds to minutes, hours, or even weeks.
- c) Broadcast/multicast consist essentially of one-way notifications without one-to-one communications with large numbers of DER systems. These notifications could be emergency signals, pricing signals, or requests for specific DER modes. Typically these would come from utilities and/or Energy Service Provider (ESP).
- No direct responses from the DER systems would be expected. If there were power system changes expected, these would be monitored elsewhere, such as on the feeder or in a substation. If there were financial implications to the broadcast/multicast request, the DER system responses would be determined during the billing and settlements process.
  - These broadcast or multicast requests may be to DER management systems or to individual DER systems.
  - These broadcast/multicast requests would be interpreted by the DER systems as possible modifications of their current autonomous behaviour or could be direct commands for response to emergency situations.
  - Since broadcast/multicast can be used to request actions without necessarily knowing which DER systems can or will respond, the expectation could be that only a certain percentage will respond.

- Common scenarios include an energy service provider broadcasting a pricing signal, which is then reacted to by the individual DER systems, or a utility multicasting a reduction in generation to all DER systems on a constrained feeder that cannot handle reverse power flows.
- Broadcast/multicast frequency may be hours, weeks, or seasons.

These hierarchical DER management interactions are shown in Figure 1.



**Figure 1 – DER management hierarchical interactions: autonomous, loosely-coupled, broadcast/multicast**

#### 4.3 Power converter methods

DER power converters and their controllers can perform many autonomous functions, based on their intrinsic capabilities, various parameter settings, and locally measured conditions, such as voltage levels, frequency, rates of changes in voltage and frequency, temperature, and other information.

The methods for power converters to manage their autonomous behaviour include the following:

- “Modes” consist of pre-established groups of settings that can enable autonomous DER behaviour, where the DER senses local conditions, and, using those mode settings, responds appropriately. This approach minimizes the communications requirements and permits more rapid responses. “Modes” can be established for volt-var control, frequency-watt control, charging/discharging storage, and some other complex actions, where the arrays and parameters for each mode are sent ahead of time – maybe once a year or season, and then “go to mode” commands/requests can be broadcast/multicast.
- Schedules can also be established, which can operate for a specific time period or indefinitely (once initiated) completely autonomously. For instance, a schedule can establish what modes to use during weekday mornings, versus mid-afternoon, versus weekends.
- Temperature-based curves and pricing-signal curves provides settings for what actions to take based on the current temperature or pricing signal. A pricing signal curve can indicate which mode(s) to go to, based on the pricing signal level (can be \$\$, but can also be tiers,

or H-M-L, or other signal). When a new pricing signal is broadcast, the DERs can ramp to the specified modes. There can even be a schedule of pricing signals so that they do not need to be broadcast, unless an emergency calls for a different level.

- c) Ramp rates and parameters based on "% of capability" (rather than absolute amounts) are also included. In addition there is a time-window randomization that requires DERs to respond to commands using a random number within the time window to actually initiate the command. This prevents sharp jumps whenever a new command/request/pricing signal is broadcast. (Obviously the time window can be set to zero if immediate emergency action is required.)

Although the DER generator and storage power converter functions do not directly cover loads, the same mechanisms of modes, schedules, graphic curves, arrays, timing constraints, etc. could be very readily applied to loads. The actual modes would be different (lighting cannot create vars, but could dim slightly), but the mechanisms would be the same.

#### 4.4 Power converter functions

Power converter functions range from the simple to the complex. Most power converter functions are based on settings or curves that allow them to respond autonomously to local conditions, while some require direct control commands.

This document covers many of these key power converter functions, including:

- a) Immediate control functions for power converters
  - Function INV1: connect / disconnect from grid
  - Function INV2: adjust maximum generation level up/down
  - Function INV3: adjust power factor
  - Function INV4: request active power (charge or discharge storage)
  - Function INV5: pricing signal for charge/discharge action
- b) Volt-var management modes
  - Volt-var mode VV11: available vars support mode with no impact on watts
  - Volt-var mode VV12: maximum var support mode based on WMax
  - Volt-var mode VV13: static power converter mode based on settings
  - Volt-var mode VV14: passive mode with no var support
- c) Frequency-watt management modes
  - Frequency-watt mode FW21: high frequency reduces active power
  - Frequency-watt mode FW22: constraining generating/charging by frequency
- d) Dynamic reactive current support during abnormally high or low voltage levels
  - Dynamic reactive current support TV31: support during abnormally high or low voltage levels
- e) Functions for “must disconnect” and “must remain connected”
  - “Must disconnect” MD curve
  - “Must remain connected” MRC curve
- f) Watt-triggered behaviour modes
  - Watt-power factor WP41: feed-in power controls power factor
  - Alternative Watt-power factor WP42: feed-in power controls power factor
- g) Voltage-watt management modes
  - Voltage-watt mode VW51: volt-watt management: generating by voltage
  - Voltage-watt mode VW52: volt-watt management: charging by voltage

- h) Non-power-related modes
  - Temperature-function mode TMP: ambient temperature indicates function
  - Pricing signal-function mode PS: pricing signal indicates function to execute
- i) Parameter setting and reporting
  - Function DS91: modify power converter-based DER settings
  - Function DS92: event/history logging
  - Function DS93: status reporting
  - ~~Function DS94: time synchronization~~
- j) Scheduled commands, in which a schedule is sent to the power converter with commands scheduled for particular times. These commands can also invoke pre-established parameters. Examples include:
  - Week-day schedule for volt-var actions
  - Weekly schedule for frequency-watt actions

It is expected that functions will be added in the future, for instance for handling intentional and unintentional islanding.

These different mechanisms can be intermingled, or only a specific type used, depending upon the requirements of implementations and configurations.

## 4.5 Differing DER architectures

### 4.5.1 Conceptual architecture: electrical coupling point (ECP)

Some power converter-based DER systems may be directly connected to the utility grid, while others may be part of a site microgrid. In either case, the power converter-based DER systems will have a point of electrical connection, which is defined as:

“The electrical coupling point (ECP) is the point of electrical connection between the DER source of energy (generation or storage) and any electric power system (EPS). Each DER (generation or storage) unit has an ECP connecting it to its local power system; groups of DER units have an ECP where they interconnect to the power system at a specific site or plant; a group of DER units plus local loads have an ECP where they are interconnected to the utility power system.”<sup>2</sup>

### 4.5.2 Conceptual architecture: point of common coupling (PCC)

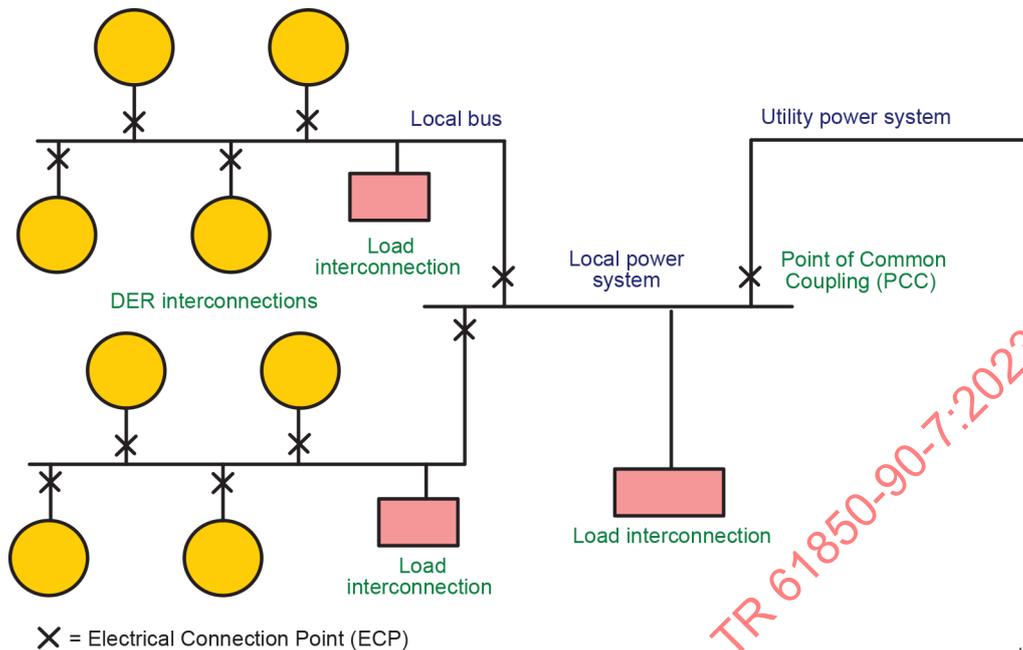
For those ECPs that demarcate the point between a utility EPS and a plant or site EPS, this point is identical to the point of common coupling (PCC) defined as “the point where a Local EPS is connected to an Area EPS” in IEEE 1547, *Standard for Interconnecting Distributed Resources with Electric Power Systems* (see 3.1 for additional definitions).

Many functions reflect conditions at the DER’s ECP. For instance, the measured voltage levels used for volt-var management are those at the DER’s ECP.

ECPs are also hierarchical, such as in a university campus environment where the PCC is between the campus and the utility, but where multiple ECPs exist for the different DER systems located in different university buildings. Requests for DER actions can be made at the highest level, say for volt-var settings at the PCC. The university DER energy management system would then allocate different volt-var settings for each of the DER ECPs to reflect their DER capabilities, the needs/desires of the university buildings (people), and the overall campus reliability and efficiency requirements.

<sup>2</sup> ~~Clause 3.1.5 of IEC 61850-7-420:2009.~~

This hierarchical concept is illustrated in Figure 2.



**Figure 2 – Electrical Connection Points (ECP) and Point of Common Coupling (PCC)**

#### 4.5.3 Utility interactions directly with power converters or indirectly via a customer EMS

Utilities/ESPs can interact with power converter-based DER systems using different architectures. They may issue requests or commands directly to the DER systems either one-on-one or via broadcast/multicast communications.

Alternatively, a customer energy management system (EMS) can help manage power converter-based DER system responses to the broadcast utility request, ~~with the idea that~~. This customer EMS ~~will possibly~~ may be managing multiple power converter-based DER systems, customer appliances, other types of distributed generators and storage devices, and plug-in electric vehicles.

For instance, if the utility broadcasts a specific mode request for power converter-based DER system actions, then these can be passed directly or indirectly (through explicit commands) to the power converter-based DER systems. If the utility broadcasts Demand Response (DR) signals or more generic volt-var requests, then the customer EMS could use other devices in addition to power converter-based DER systems to meet these requests. With this approach, the customer EMS could manage responses locally to meet the requests with the most effective mix of devices.

#### 4.5.4 Communication profiles

The communication profiles between the utility and the customer EMS, will consist of different technologies at different layers, for example:

- a) Data object models: IEC 61850-7-420
- b) Application protocols: Mapping of IEC 61850 data objects to web services, IEC 61850-8-1 Mapping to MMS (ISO 9506), IEC 60870-5, ModBus, ~~and/or~~ IEEE 1815 (DNP3), IEEE 2030.5
- c) Transport protocols: TCP/IP, UDP/IP, ModBus, IEC 60870-5-101, IEEE 1815 (DNP3) serial

- d) Media layers: Public Internet, ~~GPRS cellphone~~ cellular (mobile) network, AMI network, utility private network, leased services from telecommunication providers

#### 4.6 General sequence of information exchange interactions

The (generic) sequence for interactions between a utility/ESP and power converter-based DER systems is:

- a) The DER systems operate autonomously by default, based on pre-established settings and curves. Multiple groups of these settings/curves may be available to be triggered by a remote command, and may be updated as needed through local or remote communications.
- b) The utility determines what types of services are desired from power converter-based DER systems within a region, on a feeder, or in some other area. This determination will be based on assessments of the power system status, abilities of other equipment to perform the required actions (e.g. capacitor banks for var control), market considerations, etc.
- c) The utility broadcasts a general request that power converter-based DER systems (within a region or feeder or other area) go into a specific mode or that certain parameters are set. This request may be sent either to individual power converter-based DER system controllers, or to more general “customer EMSs” that know how to interpret such requests for the power converter-based DER system controllers that they are managing. In either case, the utility does not necessarily need to know anything about the power converter-based DER system capabilities, current PV status, market or tariff agreements on using the power converter-based DER system, or desires of the PV owner.
- d) At each customer site or other facility, the power converter-based DER system controller OR a customer EMS receives and interprets this broadcast utility request.

If a customer EMS is used:

- a) The customer EMS interprets the utility request. It determines whether it will take any action, and what the command(s) will be to the power converter-based DER system controller(s) under its control, including responding to any customer overrides or changes. These actions could be explicit commands to each power converter-based DER system it is managing, or could be a schedule of commands if the power converter-based DER system has the ability to handle schedules.
- b) The customer EMS then issues specific commands to the power converter-based DER system(s): First it requests (or already has) the current status of the power converter-based DER system(s), modifies the command if necessary to reflect the status, and then issues the appropriate command.
- c) The power converter-based DER system(s) respond to the customer EMS command, indicating success or rejection, as well as any error codes. In addition, the current status of the power converter-based DER system could be sent if either explicitly requested by the customer EMS or if it is “automatically” sent as part of the sequence.
- d) The customer EMS may or may not be required to respond to the utility request.
  - If the utility does not expect a direct response, it may both monitor conditions to determine if enough power system changes have occurred and/or read the meter (or meter event log) to determine if the power converter-based DER system responded appropriately.
  - If it does respond, it will acknowledge receipt of the command and returning the appropriate information.

If a power converter-based DER system controller directly receives the broadcast request from the utility:

- a) The power converter-based DER system controller determines internally how best to respond, and performs those actions.
- b) The power converter-based DER system controller may or may not respond to the command from the utility with an acknowledgement and any appropriate information.

- c) If the utility does not expect a direct response, it may both monitor conditions to determine if enough power system changes have occurred and/or read the meter (or meter event log) to determine if the power converter-based DER system responded appropriately.
- d) If it does respond, it will acknowledge receipt of the command and returning the appropriate information.
- e) The power converter-based DER system(s) are metered either individually or via net metering, with their output (in response to the command) captured as part of the metering data. If electric storage is part of the power converter-based DER system, then it could be metered separately or the power converter-based DER system as a whole could just be metered. (Metering is out of scope for this document).
- f) If communications are lost, the power converter-based DER system goes to a default mode, possibly after a timeout period. The default mode, the timeout period, and other parameters for this situation would be established ahead of time.
- g) Customers can override or modify commands at any time if they desire.

## **5 Concepts and constructs for managing power converter functions**

### **5.1 Basic settings of power converters**

#### **5.1.1 Nameplate values versus basic settings**

Nameplate values are expected to be fixed, based on the type, model, and capabilities of the power converter. However, installation-specific requirements may require modifications to the nameplate values, so long as these basic settings remain within the constraints of the nameplate values. These basic settings are usually established upon installation and start-up, and are usually due to varying power converter configurations, power grid environments, desired power converter capabilities, and DER owner preferences.

Basic power converter settings are needed for several functions and include power and voltage settings. These basic settings will be applied to power adjusting functions. At the beginning of this clause the power settings will be described and afterwards voltage settings. The basic setting functions assume a tightly coupled interaction between the power converter-based DER systems and a controlling entity (utility, energy service provider, or customer EMS).

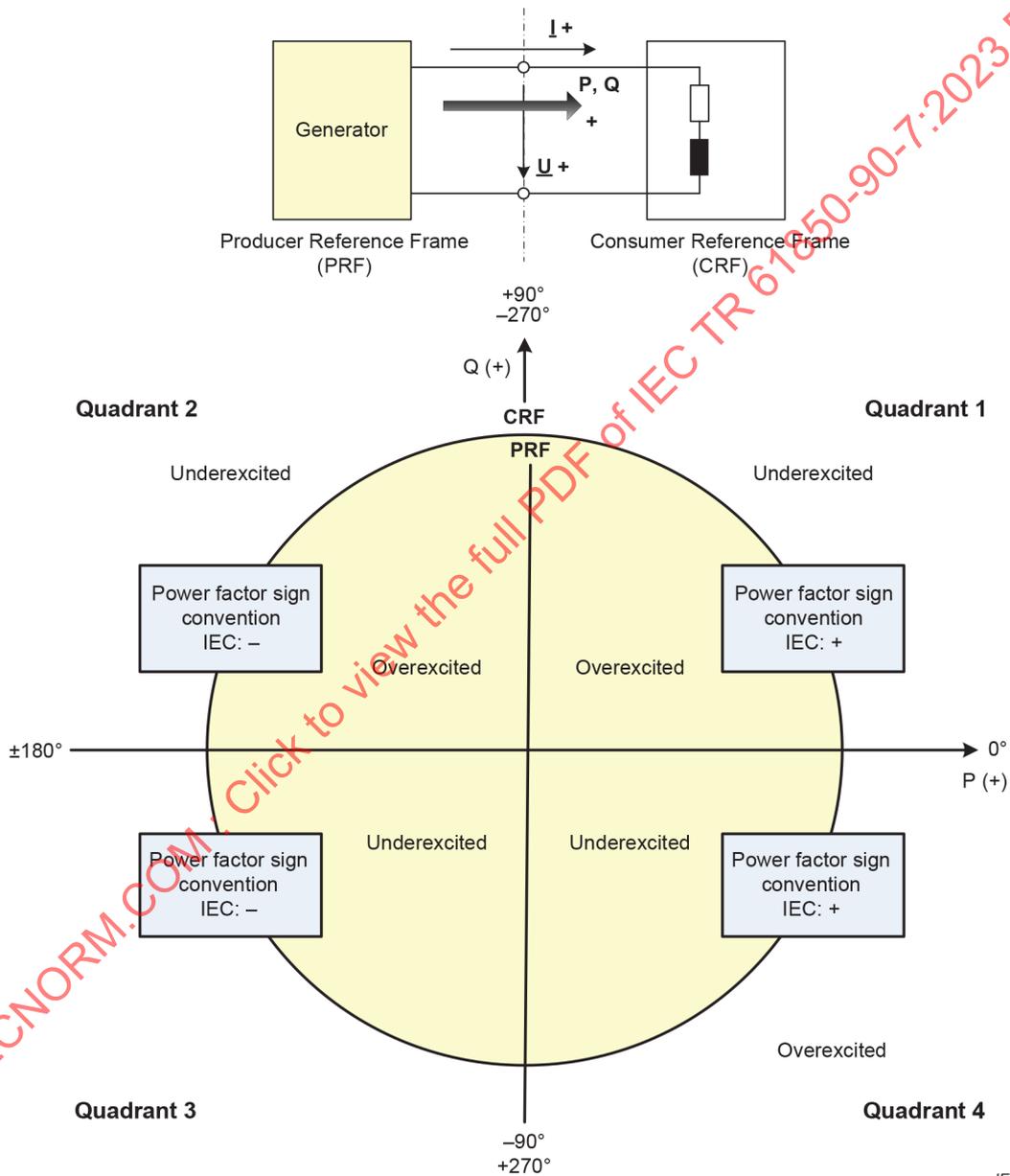
#### **5.1.2 Power factor and power converter quadrants**

Figure 3 shows the possible working areas of a DER power converter from both a Producer Reference Frame (PRF) and from a Consumer Reference Frame (CRF). In general for DER systems, the PRF is used, in which the 1<sup>st</sup> and 4<sup>th</sup> quadrants are for delivering power to the grid (vars either overexcited or underexcited, respectively), while the 2<sup>nd</sup> and 3<sup>rd</sup> quadrants are for receiving power from the grid (vars either overexcited or underexcited, respectively).

DER power converters can work in any of these four quadrants, depending upon their capabilities and the desired functions. Historically, there are two conventions, IEC and EEI (Edison Electric Institute), which are reflected in the two PFSign conventions. These conventions are illustrated in Figure 3 and Figure 4, and are shown in Table 1 from the point of view of the Producer Reference Frame:

**Table 1 – Producer Reference Frame (PRF) conventions**

Quadrant	Excitation	PFSign Active Power (usually IEC)	PFSign (usually EEI)
I	Overexcited	+	-
II	Overexcited	-	+
III	Underexcited	-	-
IV	Underexcited	+	+



**Figure 3 – Producer and Consumer Reference Frame conventions**

Therefore, all commands that affect the power factor (PF) must include three elements in order to specify which quadrant is being referenced:

- a) The signed power factor value
- b) PFEExt identification of “overexcited” or “underexcited”

- c) PFsign convention indicator (which may be set as either nameplate or basic setting for an implementation)

If the power converter does spontaneously change between charging and discharging without an explicit command, it can continue to maintain the vars according to what it was previously doing, either providing vars or absorbing vars, or the reverse. The spontaneous change action (reversing or maintaining var direction) is set either as nameplate or basic setting (VArAct).

The EEI power factor sign convention is based on the power triangle acc. handbook for electricity metering (EEI) and IEC 61557-12 (2007).

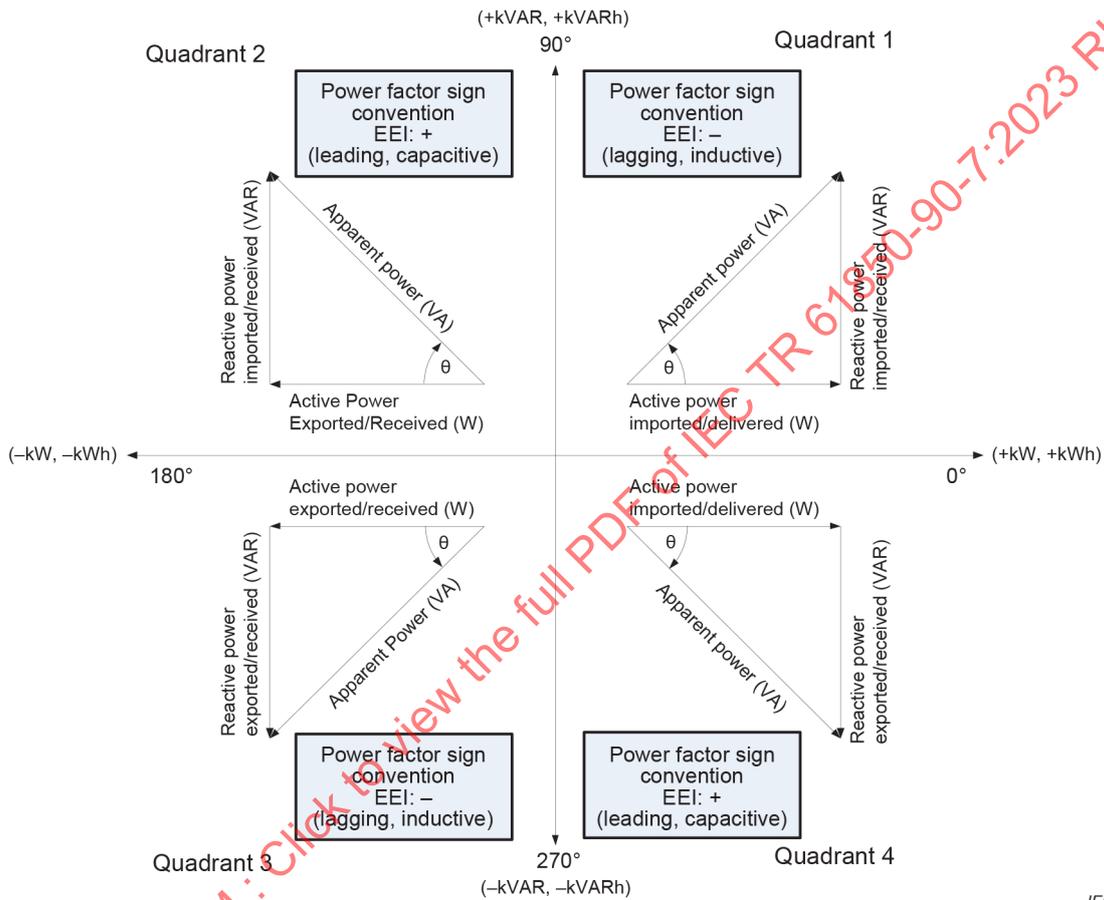


Figure 4 – EEI power factor sign convention

### 5.1.3 Maximum watts, vars, and volt-amp settings

Each power converter's power connection to its local grid is called its electrical connection point (ECP). If there are multiple power converters within a site, they may all contribute to the interconnection of the site to the main grid at the point of common coupling (PCC).

The power converter quadrant areas can be constrained in order to meet specified limits at its ECP or at the PCC. In order to determine the limits at the PCC, all power converters must have three parameters, called WMax (for active power), VAMax (for apparent power), and VArMax (for reactive power) that establish their limits at the ECP of each power converter. Collectively, these ECP limits provide the limits at the PCC.

WMax, VAMax, and VArMax are these settable limits that may be the same as the nameplate values, or may be (typically) lower values reflecting actual implementation limits. They would normally be set at the initial deployment time, although they could be modified occasionally to reflect changes to the implementation.

The parameter  $W_{Max}$  is the most critical value: it is used as the reference value for power requests.  $VAr_{Max}$  may be the same as  $W_{Max}$ , such that a single process can set the limits for both real and reactive power functions, but these settings may also be set separately. Active power control commands can then be issued as a percentage of  $W_{Max}$ : each power converter can then calculate its own actual values from its own  $W_{Max}$  value. This approach allows the reduction of a DER's power level by relative values in an unlimited range.

For a facility with multiple power converters, the maximum continuous active power output capability of the facility is given by the sum of parameter  $W_{Max}$  of all power converters. Likewise, the maximum continuous reactive power output capability is given by summing the  $VAr_{Max}$  parameters of all power converters. Furthermore, in some cases it can be an advantage to set the maximum continuous reactive power output capability in same manner as  $W_{Max}$ . However, the basic settings for power do not intend to limit the energy flow to be one directional.

An example is shown in Figure 5 for the 1<sup>st</sup> and 4<sup>th</sup> quadrant (assuming the arrows indicate a producer reference frame).

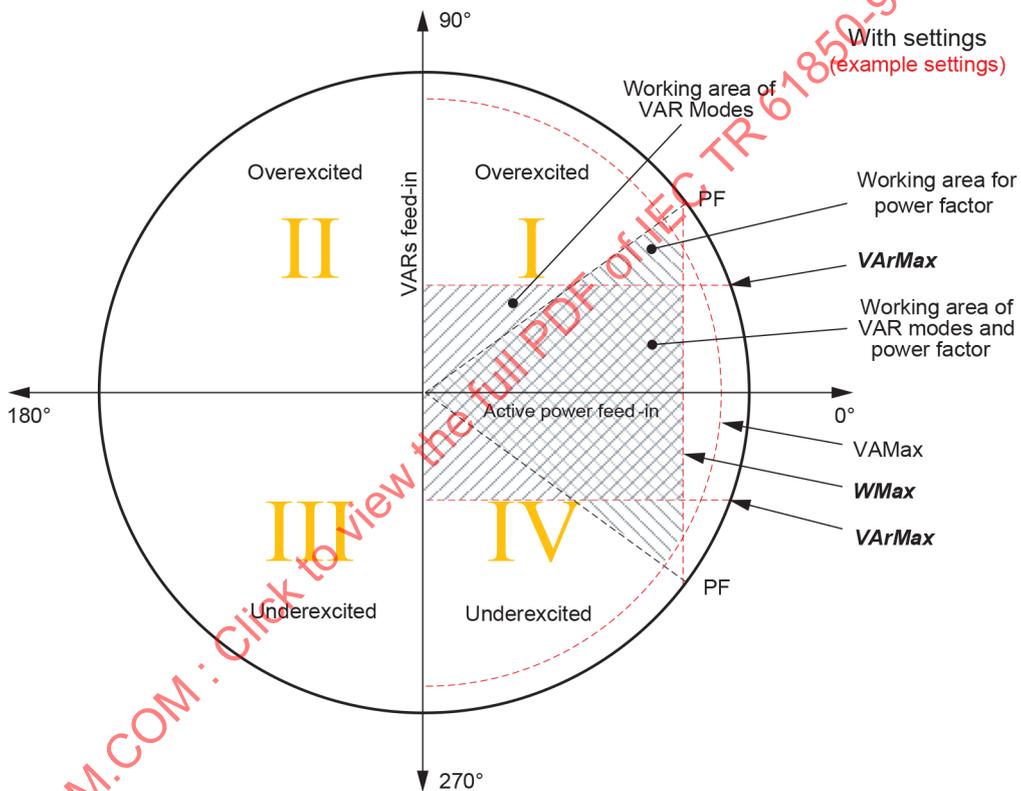


Figure 5 – Working areas for different modes

The different hatched areas show the different working areas and working area limits. The red hatched lines show the maximum values for active power  $W_{Max}$ , reactive power  $VAr_{Max}$  and apparent power  $VAMax$ .

Possible power factor settings may range from a minimum PF ( $OutPFSet$ ) (underexcited) in quadrant 4, going through the maximum value of 1 to a minimum power factor (overexcited) in quadrant 1. Possible var settings (see function  $INV2$  below) are limited by  $VAr_{Max}$ .

Since some possible settings are limited by regulations or device capabilities, more than one boundary may apply to a selected DER management function for power converters, resulting in zones limited by more than one hatching type.

### 5.1.4 Active power ramp rate settings

The default ramp rate of change of active power is provided by the parameter WGra. This parameter sets the change of active power due to either a change by a command or by an internal action such as the release of power reduction by use of the hysteresis in the function Active Power Reduction by Frequency. This ramp rate (gradient) is not intended to replace the specific ramp rates that are set by the commands or schedules, but acts as the default if no specific ramp rate is specified. WGra is defined as a percentage of WMax per second.

### 5.1.5 Voltage phase and correction settings

In the case of single phase power converters, the voltage value used in the power converter functions is based on whichever phase circuit (A, B, or C) the power converter is connected to. The identity of the phase can be set in the power converter as a basic setting. In the case of three-phase power converters that do not act independently, the mean value of A, B, and C is to be used, unless abnormally high or low voltage levels of individual phases are measured in unbalanced systems, in which case the voltage levels of those individual phases may be used.

For functions using voltage parameters (like the volt-var modes, volt-watt modes, and dynamic reactive current support), a reference voltage (VRef) and a correction voltage (VRefOfs) are additionally introduced to the previously mentioned parameters, WMax, VAMax and WGra. All power converters behind one PCC have a common reference voltage, but differ in the voltage between their own ECP and the PCC due to configuration differences within a plant. These differences can be corrected by the parameter VRefOfs that will be applied to each power converter, as can be seen in Figure 6, where a positive value means that voltage at the ECP is higher than the voltage at the PCC. This correction voltage will be applied to the voltage-based modes and will allow a homogenous setting and broadcasts for the plant.

The equation for the effective percent voltage is:

$$\text{Effective Percent Voltage} = 100 \times (\text{local voltage} - V_{\text{RefOfs}}) / (V_{\text{Ref}})$$

#### Example settings

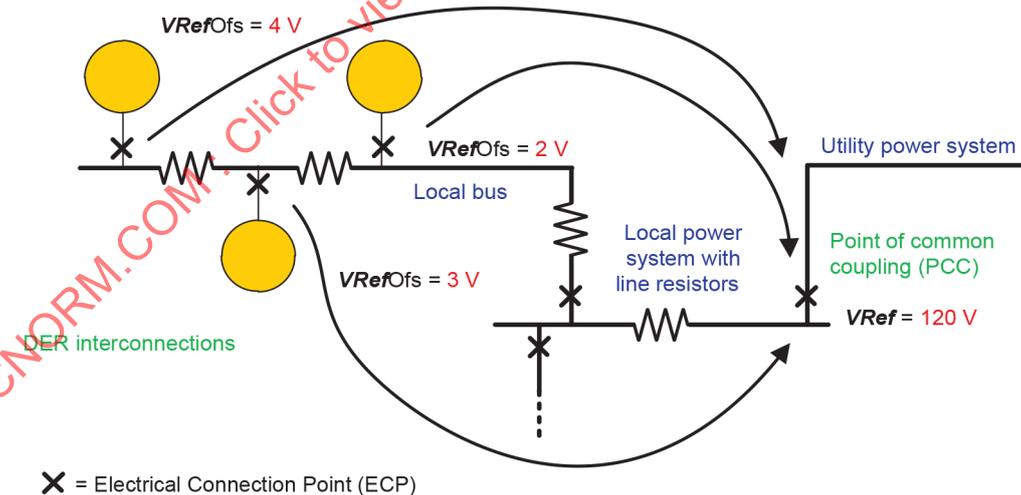


Figure 6 – Example of voltage offsets ( $V_{\text{RefOfs}}$ ) with respect to the reference voltage ( $V_{\text{Ref}}$ )

### 5.1.6 Charging settings

For those power converters that manage storage DER units that can both deliver power (discharging in quadrants 1 and 4) and absorb power (charging in quadrants 2 and 3), additional

parameters<sup>3</sup> are needed if the maximum discharge limits are different from the maximum charge limits: WchaMax, VACHaMax, and WChaGra.

### 5.1.7 Example of basic settings

An example of settings for a power converter is shown in Table 2.

**Table 2 – Example basic settings for a storage DER unit**

Parameter	Example Values
PFsign	1 = IEC; 2 = EEI;
PFExt	Underexcited = True; Overexcited = False
VArAct	1 = reverse var underexcited/overexcited characterization when changing between charging and discharging) 2 = maintain var characterization
WMax, delivered	14 500 W
WChaMax, received	–14 500 W
VAMax	16 000 VA
VACHaMax	16 000 VA
VArMax	12 000 VAR
VRef	120 V
VRefOfs	2 V
WGra	20 % WMax/second
WChaGra	15 % WChaMax/second

### 5.1.8 Basic setting process

The settings described above are expected to only be set once or infrequently over the life time of the system. The utility/ESP or the customer EMS would take the following actions:

- a) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- b) Issue command or mode to modify power converter-based DER settings:
  - Data element to be modified (e.g. WMax, VAMax, VArMax, VRef, VRefOfs, WGra, mode)
  - New value for that data element
- c) Receive response to the command:
  - Successful (plus new value of data element)
  - Rejected (plus reason: equipment not available, message error, overridden, security error)

## 5.2 Modes for managing autonomous behaviour

### 5.2.1 Benefits of modes to manage DER at ECPs

Modes are methods for managing DER systems by pre-setting desired parameters and curves that describe desired behaviour in response to local conditions (e.g. voltage, frequency, power factor, temperature, and pricing signal). Many different mode settings can be defined once and

<sup>3</sup> Additional details on storage parameters are described in IEC TR 61850-90-9.

updated only infrequently. Utilities and/or ESPs can then invoke a specific mode by a single command whenever they wish the DER to follow the behaviour defined by that mode.

The use of modes allows the DER to act autonomously without moment-by-moment commands, thus both simplifying the tasks of the utilities/ESPs, as well as minimizing the necessary communications burden. Utilities and ESPs can either monitor the behaviour of the DERs or can simply monitor the power system to determine how well their mode requests are affecting the power system.

Generally, modes will be applied to one power converter or groups of power converters that are connected at different levels of ECPs (see Figure 7 for examples).

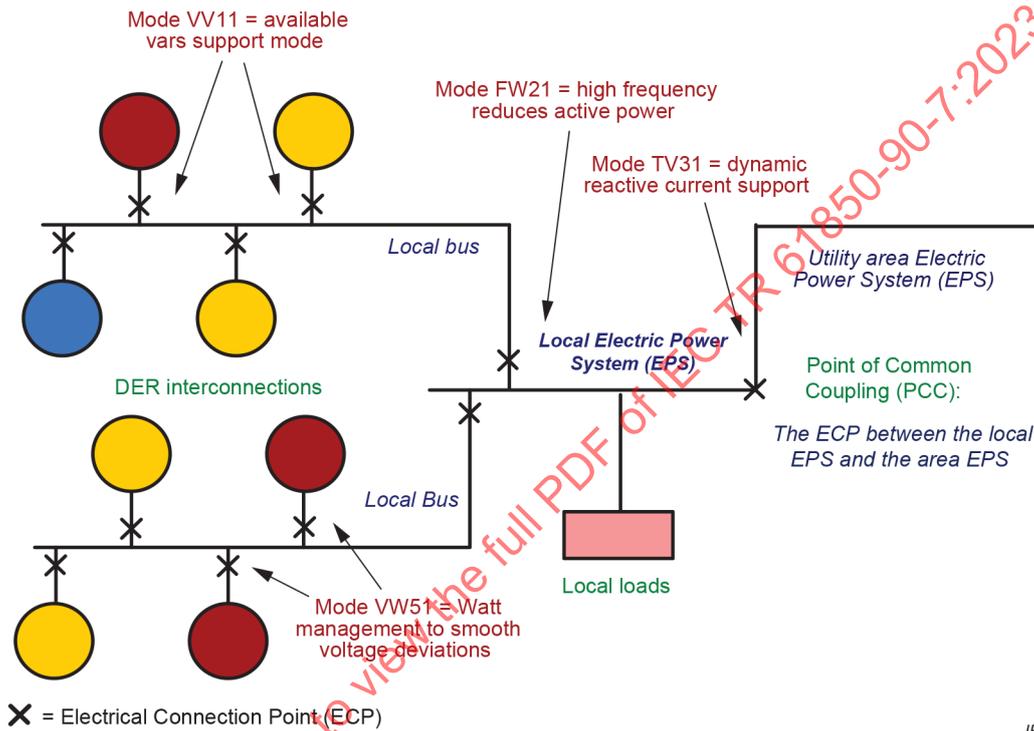


Figure 7 – Example of modes associated with different ECPs

### 5.2.2 Modes using curves to describe behaviour

Modes are defined as using curves to describe autonomous behaviour. These curves correlate a measured or triggering value (the independent variable) with a requested response by the DER (dependent variable).

In order to generate a curve, two-column arrays are used, with the first column containing monotonically increasing triggering values (x-axis) and the second column containing the response values (y-axis). These arrays are combined into a piecewise linear curve by interpolating each response values to correspond with each triggering value.

When an operational mode is invoked, the real-time measured value or stipulated external value of the triggering parameter is used to derive the interpolated response value.

Examples include the following modes, although others could be added. The first four modes are power-related modes, while the last two modes utilize non-power-related triggering values:

- a) Volt-Var Mode: Voltage values to determine what vars the power converter should produce at each voltage level.

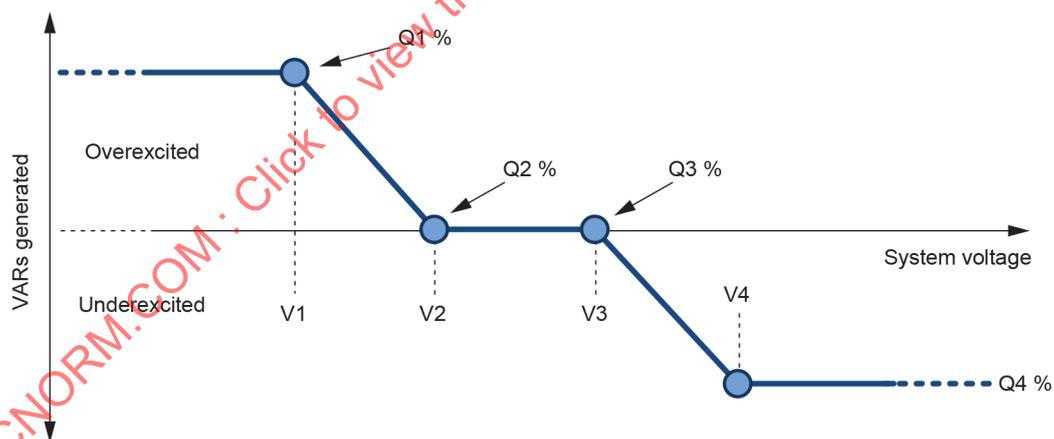
- b) Frequency-Watt Mode: Frequency values to determine what watts the power converter should produce for each frequency value.
- c) Dynamic reactive current support Mode: Apply volt-var management during short times of abnormally low or high voltage values to support the grid until either the voltage returns within its normal range or the power converter must disconnect.
- d) Volt-Watt Mode: Voltage values to determine what watts the power converter should produce as a function of the voltage level.
- e) Temperature-var Mode: Temperature values to determine what vars or what volt-var mode the power converter should produce within each temperature range.
- f) Pricing Signal Mode: Pricing signal values to determine what watts, vars, power-related mode, or other ancillary service the power converter should produce for each range of pricing signals.

In most of these modes, the real-time triggering values (voltage, frequency, etc.) are measured locally. In some modes, the triggering value might be received from external sources, such as regional average temperature or energy pricing signal.

Unlike direct control commands, modes indicate behaviour that the power converter should follow autonomously without further intervention. This approach alleviates the need for continuous control commands being sent out to large numbers of power converters.

Because autonomous behaviour must take into account the current capabilities of the DER system, these power converter modes are designed to request DER systems to provide the needed mode support as best as their capabilities allow them. For this reason, the curve settings are generally in percentages of nominal or nameplate values, rather than absolute values. That approach permits both small and large power converter-based DER systems to respond within their limits.

An example of a curve used in a volt-var mode is shown in Figure 8.



**Figure 8 – Example of a volt-var mode curve**

### 5.2.3 Paired arrays to describe mode curves

Each mode curve is described by a two-column array of pairs of values: the first column in the array contains the breakpoints of the independent variable values, while the second column contains the dependent variable values at those breakpoints. These two columns of values can be used to derive a piece-wise linear curve.

The independent variables are typically values which may be measured locally or calculated from locally available measurements or values. For instance, when a DER controller receives a mode curve which uses voltage as the independent variable, the DER may determine its

current location along the curve by averaging the three voltage phase values at the ECP and applying the appropriate voltage offset. The independent variable may be an absolute value (e.g. frequency value) or may be a percentage of nominal (e.g. percentage of nominal voltage).

The dependent variables are typically (but not exclusively) percentages of a nominal value. These dependent variables are used to calculate what behaviour the DER is being requested to follow. For instance, if the dependent variable is the percentage of the maximum watts (WMax) and the independent variable is percentage of nominal voltage, the DER controller can determine its desired watts based on its measured voltage.

The paired arrays therefore consist of the breakpoints of the independent variables, the breakpoints of the dependent variables, and the units (either SI units or percentage of SI units).

#### 5.2.4 Percentages as size-neutral parameters: voltage and var calculations

As noted previously, because broadcast/multicast commands cannot necessarily know the size or capabilities of a power converter, the curve settings are generally in percentages of nominal or nameplate values, rather than absolute values. That approach permits both small and large power converter-based DER systems to respond within their limits.

In particular, given this size-neutral and connection-point-neutral approach, power converters will need to calculate an effective percent value for the locally measured voltage as follows:

$$EffectiveLocalVoltage = \left( \frac{LocallyMeasuredVoltage - VRefOffset}{VRef} \right) \times 100$$

A power converter would then compare this *EffectiveLocalVoltage* to the voltage percentages (X-Values) in the configuration curve, so the X-Values of the curve points would be calculated as follows:

$$PercentVoltage = \left( \frac{DesiredVoltageValue}{VRef} \right) \times 100$$

These definitions allow the same *PercentVoltage* values to be used in the configuration curves of many different power converters without adjusting for local conditions at each power converter. Such adjustments can be made by setting the global Reference Voltage (VRef) or Reference Voltage Offset (VRefOfs) when the device is first commissioned or occasionally thereafter, without affecting the curve settings.

In similar fashion, the requested var (y-values) to be written for each curve point would be a percentage calculated in one of three ways, as indicated by the y-value type specified in the curve:

- a) VArS based on %WMax

$$PercentVArS = \left( \frac{DesiredVArValue}{WMax} \right) \times 100$$

- b) VArS based on %VArMax

$$PercentVArS = \left( \frac{DesiredVArValue}{VArMax} \right) \times 100$$

- c) VArS based on available vars as measured and calculated by the DER system

$$\text{PercentVARs} = \left( \frac{\text{DesiredVARValue}}{\text{AvailableVARs}} \right) \times 100$$

The percentage of VARs is a signed value, so that it can represent VARs generated (positive) or absorbed (negative).

### 5.2.5 Hysteresis as values cycle within mode curves

Although the simplest curve is a piece-wise linear curve, hysteresis can be added to provide different return routes. This hysteresis adds stability to the power converter responses to possibly fluctuating primary curve values by not following the minor fluctuations, but by maintaining a constant level until the trend of the primary curve value stabilizes.

There are two modes available (parameter names are shown in the example in Figure 9):

- by specifying a hysteresis path, or
- via a deadband path to simulate hysteresis.

A ramp rate can be configured by RmpTmsPT1 for getting of system voltage to this function. This parameter is configured in seconds. This is the time this function requires reaching 95 % of the grid voltage change (3 times the RC time constant).

Examples of volt-var curves with hysteresis are shown in Figure 9 and Figure 10.

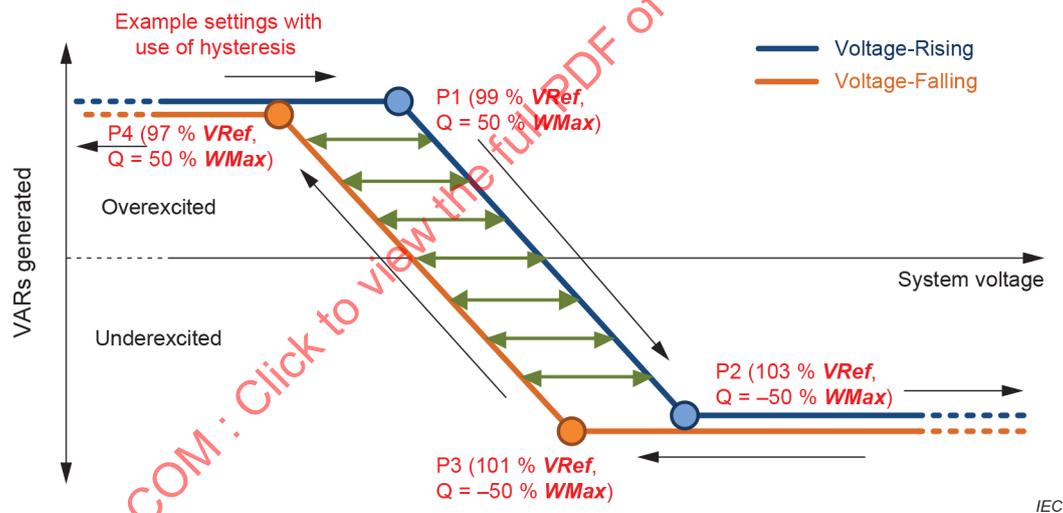


Figure 9 – Example of hysteresis in volt-var curves

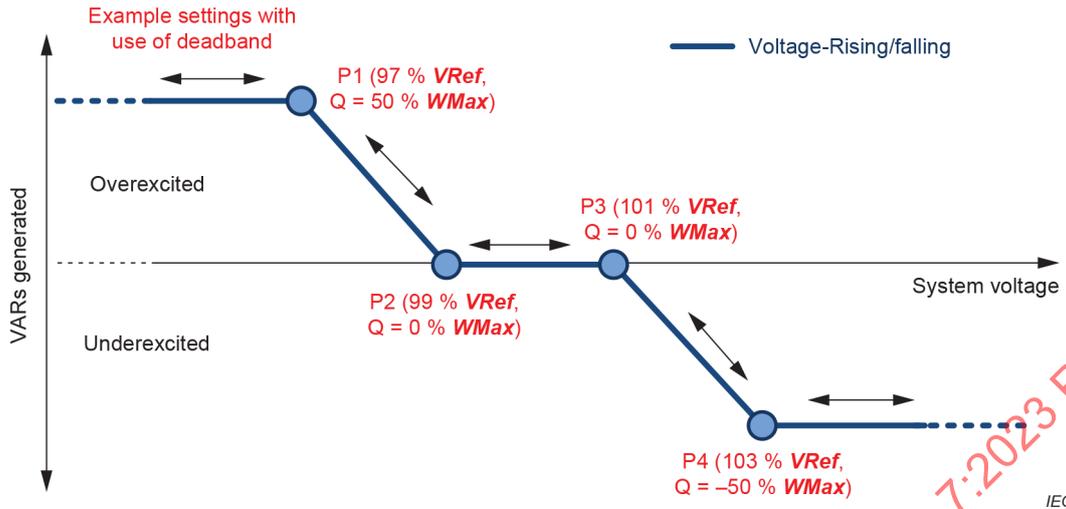


Figure 10 – Example of deadband in volt-var curves

### 5.2.6 Low pass exponential time rate

The local function block diagram in Figure 11 shows the topology for low pass, utility defined curve shapes and linear gradient (ramp rates). The utility defined curve shape can be assumed to be the any function defined by paired arrays.

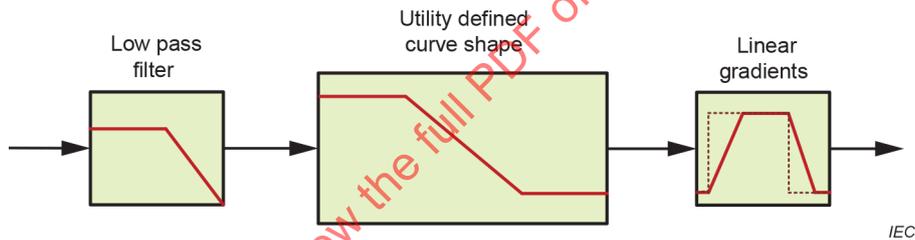


Figure 11 – Local function block diagram

The Low-Pass filter is a simple first-order filter with a frequency response magnitude given by:

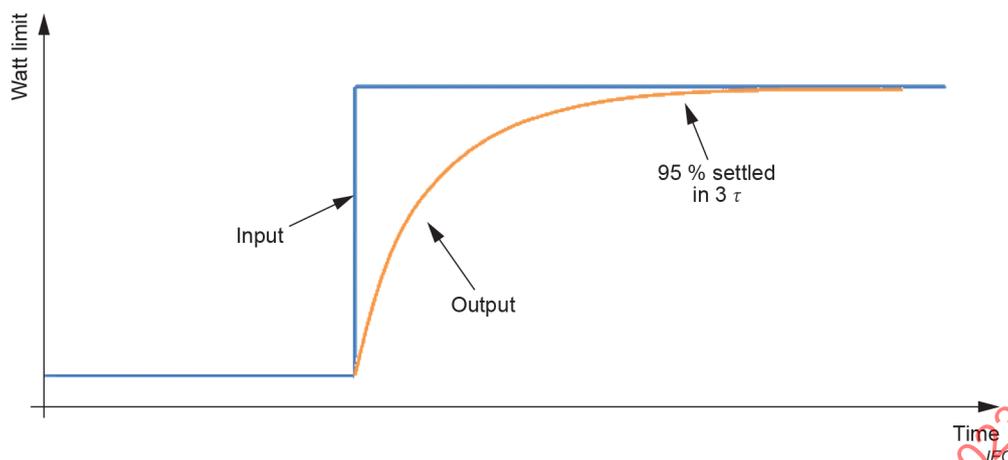
$$\left| \frac{Output}{Input} \right| = \frac{1}{\sqrt{1 + (\omega\tau)^2}}$$

where

$\omega = 2\pi \times \text{frequency}$ ;

$\tau$  is the time constant of the filter

The time-response of such a filter to a step change in the input is as illustrated in Figure 4.



**Figure 12 – Time domain response of first order low pass filter**

The configuration parameter for this filter is a time, in seconds, in which the filter will settle to 95 % of a step change in the input value. This is equivalent to  $3\tau$ .

### 5.2.7 Ramp rates

To avoid sharp shifts at the breakpoints of the piecewise linear curve, a ramp rate is included for each transition in order to smooth and stabilize the responses of large numbers of power converter-based DER systems. In order to distinguish the decrease and increase of the independent output value two ramp rates are in use, called RmpTmmDec and RmpTmmInc.

### 5.2.8 Randomized response times

Since mode requests will (most likely) be broadcast or multicast to large numbers of DER systems at the same time, it may be beneficial to stagger the responses. This is achieved by providing a time window within which a random “start” time actually triggers the execution of the mode.

### 5.2.9 Timeout period

A timeout period is available for reverting to a default state of the DER system, to ensure that a missed or lost command does not impact normal operations beyond that timeout period. If the mode is the default state, then the timeout period would be set to infinite.

### 5.2.10 Multiple curves for a mode

Each type of operational mode could have multiple curves with different settings. For instance, a volt-var mode could have different curves that could be invoked during colder days or hotter days. The pricing signal mode could have different curves for weekdays and for weekends. The low-voltage-ride-through mode could have different curves for different situations.

### 5.2.11 Multiple modes

Multiple modes may be in effect at any one time, so long as they are not mutually exclusive. Modes may also be overridden by immediate control commands, such as for emergency situations. For instance, DER systems that are executing a volt-var mode under normal circumstances could be triggered by a high temperature to execute a temperature-var mode to provide or absorb more vars.

Multiple pricing signal modes could be effect. For instance there could be different pricing signal modes for energy, for vars, for frequency response, or for other ancillary services. When actual pricing signals are received for each type, then an assessment would be performed to determine which may be mutually exclusive, which of those may be the preferred mode, and which modes

might co-exist at the same time. For instance, a high pricing signal for vars might out-weigh a lower pricing signal for watts, while frequency-watt mode might co-exist with either.

### 5.2.12 Use of modes for loosely coupled, autonomous actions

Power converter mode requests to power converter-based DER systems are examples of decentralized coordination of generation or loosely-coupled generation control. Loosely-coupled interactions also cannot expect complete compliance from all DER systems. For instance, power converter-based DER systems may not be able to respond completely for any number of reasons: the sun is behind a cloud, the customer has overridden the mode setting, local situations are impacting what response the power converter-based DER system can provide, etc.

Therefore the expectation for issuing mode requests is that an aggregated response will be gotten from many or most power converter-based DER systems, but not necessarily all. Any financial ramifications will be determined by the metering results.

Since these mode requests maybe broadcast (multicast) to specific groups of power converter-based DER systems and since the responses from the power converter-based DER systems will generally not be explicit, the utility may not know what the actual responses will end up being, and could require subsequent interactions not only with these power converter-based DER systems but possibly with distribution grid capacitor controllers, load tap changers, voltage regulators, storage devices, and other types of DER.

## 5.3 Schedules for establishing time-based behaviour

### 5.3.1 Purpose of schedules

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

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

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

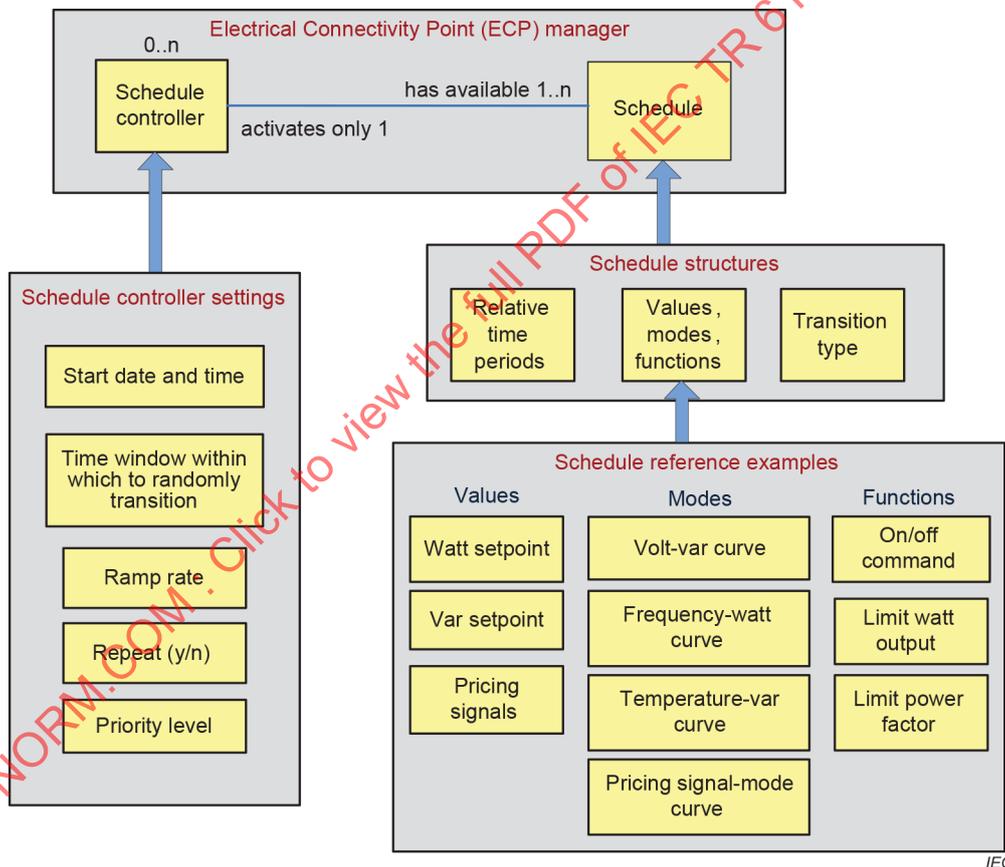
Schedules can be used to allow even more autonomous control of the behaviour of DER equipment. They may be sent ahead of time, and then activated at the appropriate time.

### 5.3.2 Schedule components

The interrelationship of schedule controllers, schedules, and schedule references, along with some example settings are shown in Figure 13. These components are described as:

- a) Electrical Connectivity Point (ECP) manager: An ECP manager handles one or more DER unit controllers that provide energy through that ECP. It is expected that the ECP manager will handle the schedule controllers for its interconnected DER units.

- b) Schedule controllers: One or more schedule coordinators may be available at the ECP. Each schedule controller can control multiple schedules so long as they are not running at the same time. The schedule controller indicates which schedule is currently ready-to-run or running. For one schedule controller, only one schedule can be running.
- c) Schedules: Each schedule must have a non-zero identifier that is a unique schedule identity within the ECP. A schedule consists of time periods of arbitrary length that reference delta time from the initial entry.
- d) Schedule references: Each entry in a schedule references a specific value, a mode, or a function. Configuration parameters indicate the units and other characteristics of the entries.
  - Values are direct settings, such as maximum watt output. These are absolute values or a percentage, to be used primarily where specific values are needed.
  - Modes are the settings and arrays of independent and dependent variables that manage output through algorithmic calculations, such as the volt-var modes.
  - Functions are the combination of settings for immediate control commands, such as INV3, adjust power factor. These usually involve percentages of maximum to allow power converters with different capabilities to respond appropriately.



**Figure 13 – Interrelationships of schedule controllers, schedules, and schedule references**

~~The details of scheduling are described in IEC 61850-90-10.~~

## 6 DER management functions for power converters

### 6.1 Immediate control functions for power converters

#### 6.1.1 General

Immediate control functions assume a tightly coupled interaction between the power converter-based DER systems and a controlling entity (utility, energy service provider, or customer EMS). This implies that the controlling entity has knowledge about the capabilities of the power converter-based DER systems, can request updates on their current status, can expect the power converter-based DER system to follow the command to the best of their capabilities, and will receive a direct response from the power converter-based DER systems on the results from following the command.

Basic commands will supersede each other and any power converter mode commands in effect, based on the time they were issued by the controlling entity.

Basic commands also imply communication channels with high availability between the controlling entity and the power converter-based DER systems, since the controlling entity must maintain direct knowledge of the power converter-based DER system status and capabilities. Nonetheless, it is expected that power converter-based DER systems will revert to “default” states if communications are unavailable for some pre-specified length of time (implementation dependent).

It is expected that, in general, utilities will use direct controls with larger, utility-owned power converter-based DER systems, while ESPs could use direct commands with groups of power converter-based DER systems, and customer EMSs could use direct controls with those power converter-based DER systems belonging to the customer. However, other interactions are possible, depending upon business decisions and specific implementations.

#### 6.1.2 Function INV1: connect / disconnect from grid

This function causes the power converter-based DER system to immediately physically connect or disconnect from the grid via a disconnect switch at the power converter-based DER system's ECP to the grid.

The utility/ESP or the customer EMS takes the following actions:

- a) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- b) Issue connect/disconnect command to power converter-based DER system:
  - Binary command to open or close a switch.
  - Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately (optional – if not included, then default time window for this function will be used). The connection may be delayed due to necessary safety functions.
  - Timeout period, after which the power converter-based DER system will revert to its default status, such as closing the switch to reconnect to the grid (optional – if not included, then default timeout period for this function will be used).
- c) Receive response to the command:
  - Successful (plus resulting switch position).
  - Rejected (plus reason: equipment not available, message error, overridden, security error).

### 6.1.3 Function INV2: adjust maximum generation level up/down

This function sets the maximum generation level at the electrical coupling point (ECP) as a percentage of set capacity (WMax). This limitation could be met by limiting PV output or by using the excess PV output to charge associated storage.

In addition, a ramp rate (power versus time) and a time window within which to randomly start will be included so that not all power converter-based DER systems change state abruptly at the same time.

A timeout period is included for reverting to the default state of the power converter-based DER system, to ensure that a missed or lost command does not impact normal operations beyond that timeout period.

The utility/ESP or the customer EMS takes the following actions:

- 1) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- 2) Issue command to adjust power setpoint:
  - Command to adjust the power setpoint to the requested generation level
  - Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint if either it is now being constrained or it is now being released from a constraint (optional – if not included, then use previously established default ramp rate: WGr)
  - Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
  - Timeout period, after which the power converter-based DER system will revert to its default status, such as resetting the maximum power setpoint to its default value (optional – if not included, then default timeout period for this function will be used)
- 3) Receive response to the command:
  - Successful (plus actual maximum power setpoint)
  - Rejected (plus reason: equipment not available, message error, overridden, security error).

### 6.1.4 Function INV3: adjust power factor

Fixed power factor will be managed through issuing a power factor value and corresponding excitation. In addition, a ramp rate (change versus time) and a time window within which to randomly start will be included so that not all power converter-based DER systems change state abruptly or at the same time.

A timeout period is included for reverting to the default state of the power converter-based DER system, to ensure that a missed or lost command does not impact normal operations beyond that timeout period.

The utility/ESP or the customer EMS takes the following actions:

- 1) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- 2) Issue command to adjust power factor setpoint:
  - Command to adjust the power factor
  - Command to adjust power factor excitation

- Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint (optional – if not included, then use previously established default ramp rate)
- Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
- Timeout period, after which the power converter-based DER system will revert to its default status, such as resetting the power factor setpoint to its default value (optional – if not included, then default timeout period for this function will be used)

3) Receive response to the command:

- Successful (plus actual output power factor value)
- Rejected (plus reason: equipment not available, message error, overridden, security error)

### 6.1.5 Function INV4: request active power (charge or discharge storage)

Power converter-based DER systems which can manage energy production through additional generation reserve and/or storage capabilities can also respond to requests to increase or decrease this energy production, although it is understood that they will always be in ultimate control of what actions they take and that these functions are “requests” to perform certain actions if feasible within pre-specified constraints. For example, a storage system cannot charge when the storage element is full nor can it discharge if at the storage reserve limit.

This function requests the storage system to charge or discharge at a specific rate (% of max charging or discharging rate). A controller might use this command frequently, in conjunction with reads of the battery charge level, to achieve a desired daily charge / dump characteristic.

To account for diversity in the size of storage systems, the function requests a percentage quantity based on the capacity of the system. For active power out requests (storage discharging), the percent is relative to the present maximum discharge rate (WMax, delivered). For active power in requests (storage charging), the percent is relative to the present maximum charging rate (WMax, received). It is acknowledged that the discharging capacity of the power converter and the charging capacity of the charger may differ.

A timeout period is included for reverting to the default state of the power converter-based DER system, to ensure that a missed or lost command does not impact normal operations beyond that timeout period.

The power converter-based DER system may also determine if only power converter-based DER system output is used for charging or whether grid power can be used.

The utility/ESP or the customer EMS takes the following actions:

- 1) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- 2) Issue command to request active power (charge/discharge) setpoint for the storage system:
  - Command to adjust the active power charge/discharge setpoint for the storage system
  - Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint (optional – if not included, then use previously established default ramp rate)
  - Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)

- Timeout period, after which the power converter-based DER system will revert to its default status (optional – if not included, then default timeout period for this function will be used)
- Storage charge from grid setting (yes/no)

3) Receive response to the command:

- Successful (plus actual active power setpoint)
- Rejected (plus reason: equipment not available, message error, overridden, security error)

### 6.1.6 Function INV5: pricing signal for charge/discharge action

This function provides a pricing signal (actual price or some relative pricing indication) from which the power converter-based DER system may decide whether to charge the storage or discharge the storage, and what rate to charge or discharge.

The utility/ESP or the customer EMS takes the following actions:

1) Issue pricing signal (the actual form or content of the pricing signal will be established by the utility/ESP and is outside the scope of this specification):

- Pricing signal
- Requested ramp time for the power converter-based DER system to move from its current output to any new output (optional – if not included, then use previously established default ramp rate)
- Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
- Timeout period, after which the power converter-based DER system will revert to its default status (optional – if not included, then default timeout period for this function will be used)

2) Receive response to the command:

- Successful (plus actual active power setpoint)
- Rejected (plus reason: equipment not available, message error, overridden, security error)

## 6.2 Modes for volt-var management

### 6.2.1 VAR management modes using volt-var arrays

#### 6.2.1.1 Purpose of volt-var modes

Since utilities (and/or other energy service providers) will be requesting var support from many different power converter-based DER systems with different capabilities, different ranges, and different local conditions, it would be very demanding of the communications systems, unnecessary, and ultimately impossible for the utilities to issue explicit settings to each power converter-based DER system every time a change is desired.

Therefore, volt-var behaviours can be configured into a power converter using arrays that establish a volt-var relationship or curve for use during normal power system. Each volt-var behaviour is associated with a volt-var mode, and requests can be made to change modes by simply specifying the desired mode. This allows DER power converters to be addressed in groups, with each having tailored volt-var behaviours, and yet all able to be switched from one mode to another with minimal communication overhead.

Key power converter modes are described below, with the understanding that additional modes may be defined at a later date. In any of these modes, the power converter-based DER system would still be limited to what it can safely or physically provide, and will log its actions. It is also

expected that any of these mode may be overridden by dynamic reactive current support modes as described in 6.4.

### 6.2.1.2 Volt-var modes

A number of examples of power converter modes have been defined (see Modes VV11 to VV14) for typical types of var support requests. For each power converter mode, one to a few volt-var arrays of settings can be associated (the maximum number that may be configured into a power converter is limited only by the device itself). Controlling entities (utility or other) may choose what kind of volt-var behaviour is desired for each mode and may configure power converters accordingly.

Each volt-var array consists of volt-var pairs: a set of voltage levels and their corresponding var levels that will be treated as a piecewise linear function. These arrays can be of variable length, depending upon the number of volt-var pairs. Utilities can issue these volt-var arrays initially and update them when necessary. For uniform vars across all voltage levels, parameters may be used to set the fixed percent of vars.

Disabling all volt-var modes permits the power converter to revert to its default var behaviour.

### 6.2.1.3 Invoking volt-var modes

There are three ways a utility can invoke a volt-var mode:

- a) Direct requests to specific power converter-based DER systems.
- b) Broadcasts or multicasts to all power converter-based DER systems in a selected area (region, feeder, substation) to use a particular volt-var array.
- c) Scheduling volt-var modes using different criteria.

Multiple volt-var modes may be ready-to-run at any one time. The most recently activated mode will take precedence over other modes. If the most recent mode is deactivated, the next most recent will take effect.

### 6.2.2 Example setting volt-var mode VV11: available var support mode with no impact on watts

As one example of volt-var modes, the available vars mode reflects the calculation of the most efficient and reliable var levels for power converter-based DER systems at specific distribution points of common coupling (PCC) without impacting the watts output. This mode could also help compensate for local high voltage due to PV kW back flow on the circuit.

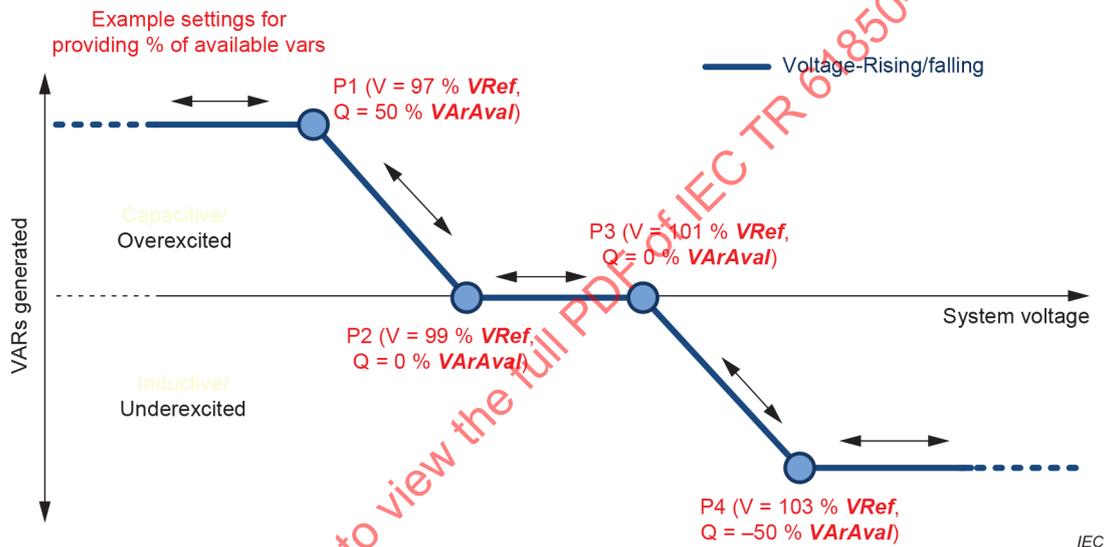
In this mode, power converter-based DER systems will be provided with a double array of setpoints: a set of voltage levels and their corresponding var levels as % of available vars. The voltage levels will range between  $V_1$  and  $V_x$  in increasing voltage values (decreasing for hysteresis if used). Values between these setpoints will be interpolated to create a piecewise linear volt-var function. The corresponding var levels define the percent of  $VAr_{Aval}$  (available vars) requested for the voltage level.

Figure 14 provides one example of volt-var settings for this mode. It is assumed that the var value between  $V_{Min}$  and  $V_1$  is the same as for  $V_1$  (shown as 50 %  $VAr_{Aval}$ , in this example). The equivalent is true for the var value between  $V_4$  and  $V_{Max}$  (which is assumed to be 50 %  $VAr_{Aval}$  in this example). PT1 is the low-pass exponential time rate filter described in 5.2.6.

**Example Settings**

Voltage Array (% $V_{Ref}$ )		VAr Array (% $V_{ArAval}$ )	
V1	97	Q1	50
V2	99	Q2	0
V3	101	Q3	0
V4	103	Q4	-50

VAr Ramp Rate Limit – fastest allowed decrease in VAR output in response to either power or voltage changes	50 [% $V_{ArAval}$ /s]
VAr Ramp Rate Limit – fastest allowed increase in VAR output in response to either power or voltage changes	50 [% $V_{ArAval}$ /s]
The time of the PT1 in seconds (time to accomplish a change of 95 %)	10 s
Randomization Interval – time window over which mode or setting changes are to be made effective	60 s



**Figure 14 – Volt-var mode VV11 – available vars mode**

The steps to invoke the VV11 available vars mode are as follows:

1) Issue request to go into VV11 Mode:

- Request to go into VV11 Mode
- Array of volt-var of setpoints identifying the y-value type as the percent vars of available vars rather than of maximum vars (optional – if not included, then use previously established default array)
- Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint if either it is now being constrained or it is now being released from a constraint (optional – if not included, then use previously established default ramp rate)
- Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
- Timeout period, after which the power converter-based DER system will revert to its default status, such as resetting the maximum power setpoint to its default value (optional – if not included, then default timeout period for this function will be used)

- 2) Receive response to the command:
  - Successful
  - Rejected

**6.2.3 Example setting volt-var mode VV12: maximum var support mode based on WMax**

As another volt-var example, power converter-based DER systems provide the maximum vars without exceeding 100 % WMax. This mode would typically be invoked by the utility to support transmission emergencies or other var emergencies.

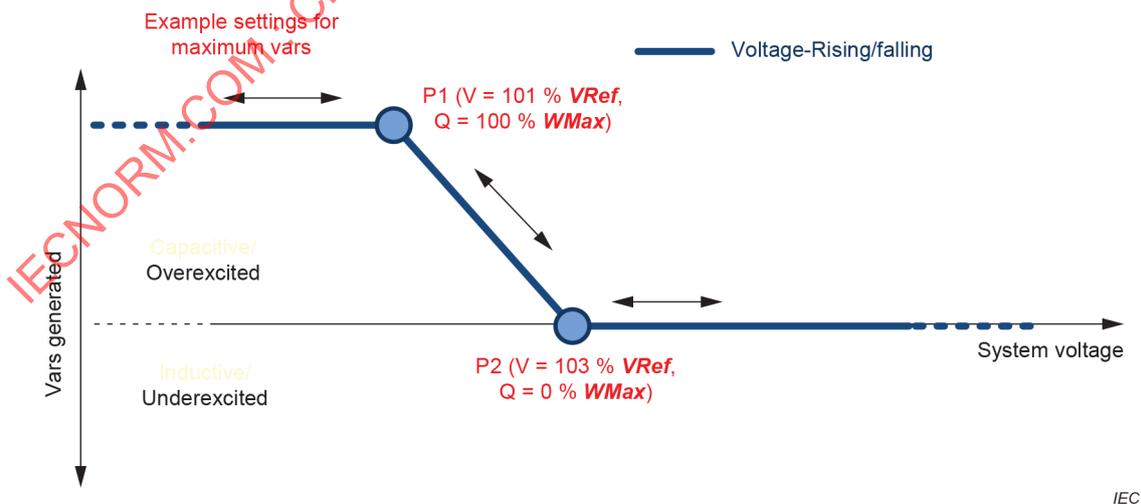
This function would essentially be represented as a straight horizontal line at y-values in the curve = 100 % and the y-value type set to “maximum vars”, until the regulated limits or the power converter protective limits are hit.

Figure 15 provides one example of how a VV12 mode may be configured. In this example, the power converter generates maximum capacitive vars for reduced voltages down to the cut-off limit VMin. As voltage increases above configuration point V1, var generation is ramped down, reaching zero at V2, so as not to drive the local system voltage too high.

The ramp rates and/or the randomized time-constant settings are also required.

**Example Settings**

Voltage Array (%VRef)		VAr Array (%WMax)			
V1	101	Q1	100	VAr Ramp Rate Limit – fastest allowed decrease in var output in response to either power or voltage changes	50 [%WMax/s]
V2	103	Q2	0	VAr Ramp Rate Limit – fastest allowed increase in var output in response to either power or voltage changes	50 [%WMax/s]
				The time of the PT1 in seconds (time to accomplish a change of 95 %).	10 s
				Randomization Interval – time window over which mode or setting changes are to be made effective	60 s



**Figure 15 – Power converter mode VV12 – Maximum var support mode based on WMax**

The steps to invoke the VV12 maximum var support mode are as follows:

- 1) Issue request to go into VV12 Mode:

- Request to go into VV12 Mode
- Array of volt-var of setpoints identifying the y-value type as the percent vars of maximum watts rather than of available vars (optional – if not included, then use previously established default array)
- Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint if either it is now being constrained or it is now being released from a constraint (optional – if not included, then use previously established default ramp rate)
- Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
- Timeout period, after which the power converter-based DER system will revert to its default status, such as resetting the maximum power setpoint to its default value (optional – if not included, then default timeout period for this function will be used)

2) Receive response to the command:

- Successful
- Rejected

#### **6.2.4 Example setting volt-var mode VV13: static power converter mode based on settings**

Another example mode, VV13, establishes fixed var settings for power converters as illustrated in Figure 16. This mode does not use curves but only settings.

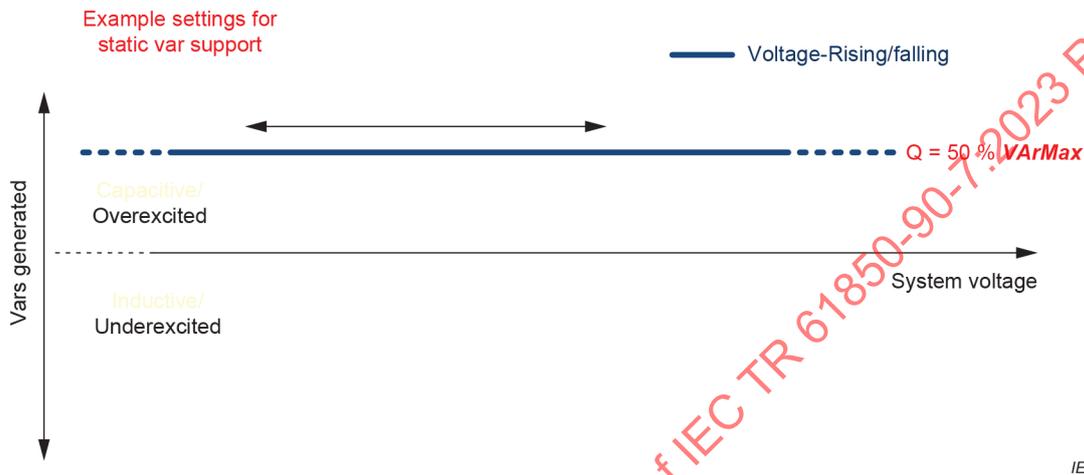
This function can be typically represented as a straight horizontal line at a Q percentage value between  $\pm 100\%$  until the regulatory VMin/**VMax** levels or the power converter protective limits are reached. The percentage can be one of three options: percent available vars (no impact on watts output) or percent maximum watts (watts output may be impacted) or percent maximum vars.

This mode is likely to be of interest in cases where a separate power converter-based DER system controller is managing the PV site. In such a case, the controller would be the point of intelligence, monitoring system voltage and communicating with the utility, then managing the local power converters moment by moment to achieve the desired results.

The ramp rates and/or the randomized time-constant settings are also required.

**Example Settings**

VArWMaxPct	50 % of max watts
VArMaxPct	50 % of max vars
VArAvalPct	50 % of max available vars
Randomization Interval – time window over which mode or setting changes are to be made effective	60 s



**Figure 16 – Power converter mode VV13 – Example: static var support mode based on VArMax**

The steps to invoke the VV13 static var support mode are as follows:

- 1) Issue request to go into VV13 Mode:
  - Set the constant percent of vars for the appropriate type of vars (percent available vars, percent maximum watts, or percent maximum vars)
  - Request to go into VV13 Mode via the constant VAr Mode of Operation
  - Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint if either it is now being constrained or it is now being released from a constraint (optional – if not included, then use previously established default ramp rate)
  - Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
  - Timeout period, after which the power converter-based DER system will revert to its default status, such as resetting the maximum power setpoint to its default value (optional – if not included, then default timeout period for this function will be used)
- 2) Receive response to the command:
  - Successful
  - Rejected

**6.2.5 Example setting volt-var mode VV14: passive mode with no var support**

This example mode is the same as mode VV13 above, except that the var levels are zero. In this mode, power converters will follow the system voltage levels within their capability range, presumably at their most efficient settings.

This mode will serve as the default mode for power converter-based DER systems upon power up, if all other volt-var modes are disabled, when schedules expire, or if no communications

have been received within a defined period (e.g. if no additional signals have been received over x hours or if the schedule has run out without further updates).

Utilities could switch some or all power converters to this mode if other modes presented unexpected difficulties.

The steps to invoke the VV14 Mode are as follows:

1) Issue request to go into VV14 Mode:

- Set the percent of vars to zero (0) for the appropriate type of vars
- Request to go into VV14 Mode via the constant VAR Mode of Operation
- Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint if either it is now being constrained or it is now being released from a constraint (optional – if not included, then use previously established default ramp rate)
- Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)
- Timeout period, after which the power converter-based DER system will revert to its default status, such as resetting the maximum power setpoint to its default value (optional – if not included, then default timeout period for this function will be used)

2) Receive response to the command:

- Successful
- Rejected

### **6.3 Modes for frequency-related behaviours**

#### **6.3.1 Frequency management modes**

Frequency management modes are used to mitigate frequency deviations by countering them with reduced or increased power. These modes can be used for emergency situations involving very large frequency deviations, but can also be used continuously to smooth minor frequency changes. These modes also include the addition of hysteresis.

The curve shapes shown in Figure 17 provide a generic example of the operating areas that could be specified. The vertical axis would be percent of WMax, and the horizontal axis is frequency, with nominal frequency (ECPNomHz) shown in the middle.

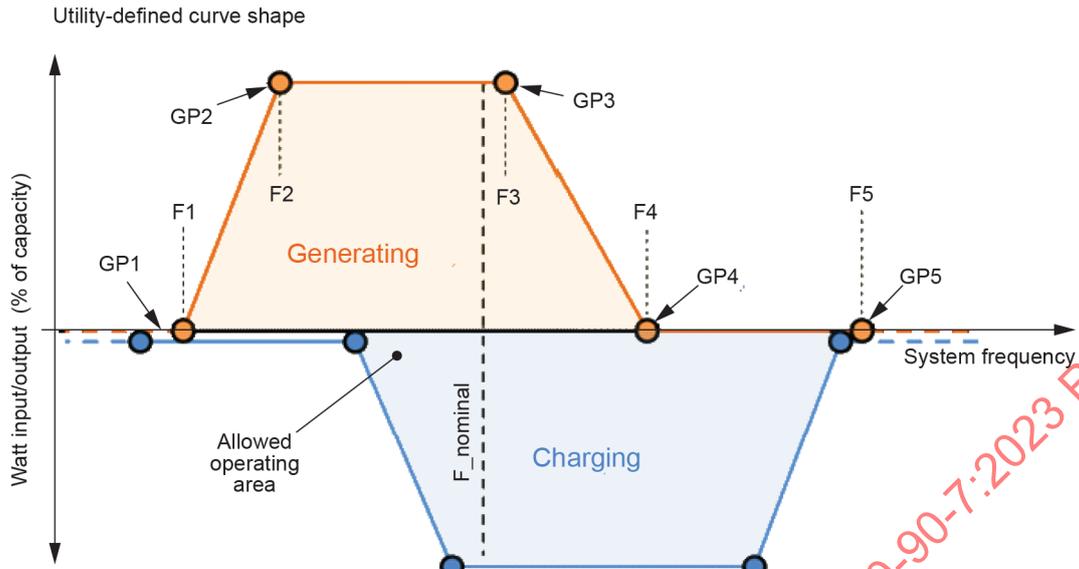


Figure 17 – Frequency-watt mode curves

### 6.3.2 Frequency-watt mode FW21: high frequency reduces active power

This frequency-watt mode addresses the issue that high frequency often is a sign of too much power in the grid, and vice versa. These extreme deviations from nominal frequency can cause grid instability, particularly if they cause significant amounts of generating equipment to trip off-line.

One method for countering this over-power problem is to reduce power in response to rising frequency (and vice versa if storage is available). Adding hysteresis provides additional flexibility for determining the active power as frequency returns toward nominal. Figure 18 shows the necessary settings for the active power reduction by frequency.

The parameters for frequency are relative to nominal grid frequency (ECPNomHz). The parameter HzStr establishes the frequency above nominal at which power reduction will commence. If the delta grid frequency is equal or higher than this frequency, the actual active power will be “capped” at its current output level, shown as  $P_M$ . If the grid frequency continues to increase, the power cap will be reduced by following the gradient parameter (WGra), defined as percent of  $P_M$  per Hertz.

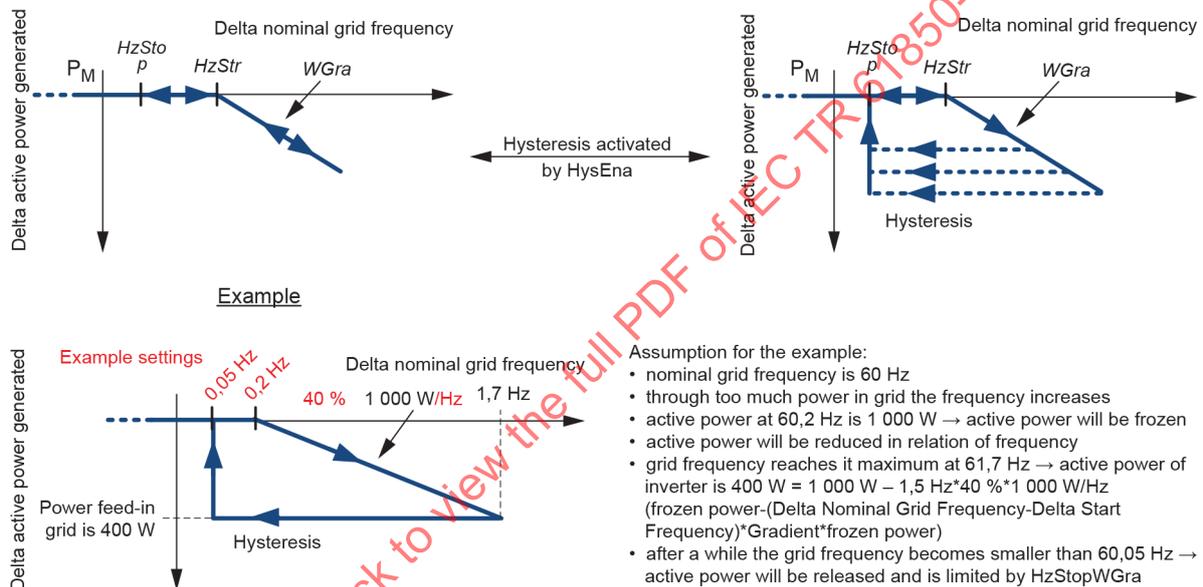
The parameter HysEna can be configured to activate or deactivate hysteresis. Without hysteresis (HysEna is deactivated), the power curve follows the same gradient back up as frequency is reduced (see top left graph in Figure 18). With hysteresis (HysEna is activated), the power curve remains capped at the lowest power level reached until the delta grid frequency reaches the delta stop frequency, HzStop (see top right graph and example in Figure 18).

For generation, the output power could be decreased to zero; for combinations of generation and storage, the output power may shift from decreasing generation to absorbing power (charging).

Whether or not hysteresis is active, the actual power will be uncapped when the delta grid frequency becomes smaller than or equal to the parameter HzStop. In order to prevent abrupt power increases after this uncapping of the actual power, an active power gradient is used as a time-based recovery ramp rate. This power gradient parameter, HzStopWGra, is defined in WMax/minute. The default could be around 10 % WMax/minute.

### Example Settings

Name	Description	Example settings
WGra	The slope of the reduction in the maximum allowed watts output as a function of frequency	40 % $P_M/\text{Hz}$
HzStr	The frequency deviation from nominal frequency (ECPNomHz) at which a snapshot of the instantaneous power output is taken to act as the “capped” power level (PM) and above which reduction in power output occurs	0,2 Hz
HzStop	The frequency deviation from nominal frequency (ECPNomHz) at which curtailed power output may return to normal and the cap on the power level value is removed.	0,05 Hz
HysEna	A Boolean indicating whether or not hysteresis is enabled	On
HzStopWGra	The maximum time-based rate of change at which power output returns to normal after having been capped by an over frequency event.	10 % $W_{\text{Max}}/\text{minute}$



IEC

**Figure 18 – Frequency-based active power reduction**

This frequency-watt mode is specifically designed for emergency situations involving grid stability concerns, and thus is expected to be rarely invoked. However, like all modes, it could be activated in conjunction with other modes, including frequency-watt modes that respond to minor frequency deviations, such as FW22.

The frequency-watt mode settings can be pre-specified at installation to act in all high/low frequency situations or can be modified and activated at a later time via the following actions:

- Issue command to modify frequency-watt settings:
  - Frequency-watt mode
  - Triggering settings for frequency
  - Hysteresis activation setting
  - Gradient values
  - Recovery ramp rate

- 2) Receive response to the command:
  - Successful (plus new value of data element)
  - Rejected (plus reason: equipment not available, message error, overridden, security error)

### 6.3.3 Frequency-watt mode FW22: constraining generating/charging by frequency

#### 6.3.3.1 General

If more general response to minor frequency deviations is desired, particularly if both generation and charging of storage is included, then frequency-watt arrays need to be used, rather than the individual parameters defined in the FW21 mode.

There can be multiple frequency-watt modes configured into a power converter. For example, the desired frequency-watt settings might be different on-peak versus off-peak, or different when islanded (in isochronous mode) versus grid connected. A simple mode change broadcast could move the power converters from one pre-configured frequency-watt mode to another mode.

The settings for this mode would include a frequency-watts-delivered curve (generation) and/or a frequency-watts received curve (storage), ramps for changing power, time of the input filter, and as with other functions, a time window, ramp rate, and timeout.

As another example, Figure 19 shows an equivalent approach to frequency-watt mode FW21, but using frequency-watt curves instead of individual parameters.

#### Example Settings

RmpTms for P1	10 s
RmpTmmDec	100 % WMax/minute
RmpTmmInc	40 % WMax/minute
RmpRsUp	10 % WMax/minute

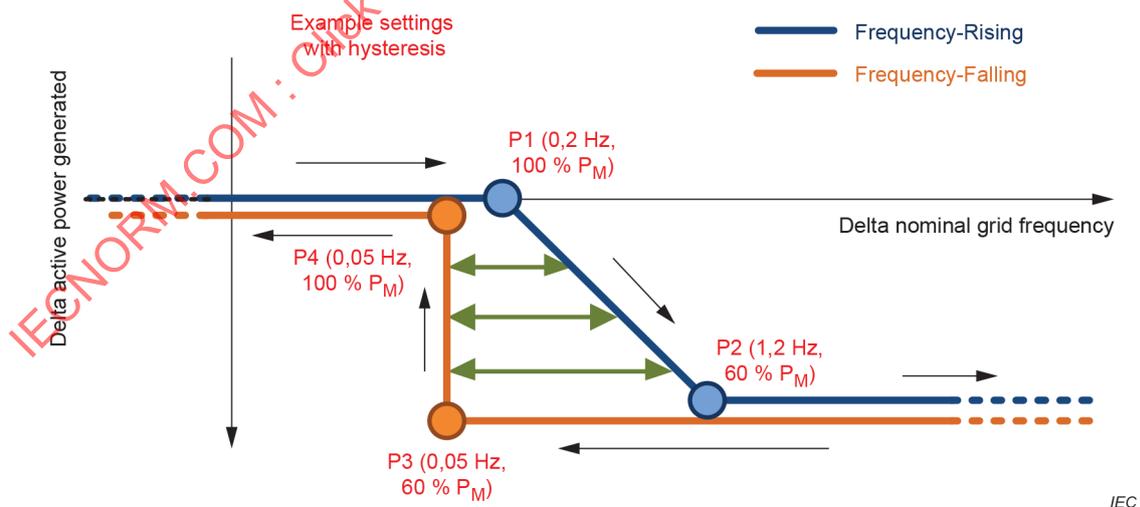


Figure 19 – Frequency-based active power modification with the use of an array

#### 6.3.3.2 Modes

As with the volt-var modes, there could be multiple frequency-watt modes configured into a power converter. For example, the desired frequency-watt settings might be different on-peak vs. off-peak or different when islanded vs. grid connected. A simple mode change broadcast

could move the power converters from one pre-configured frequency-watt mode to another mode.

### 6.3.3.3 Basic Concept

The basic idea is illustrated in Figure 20.

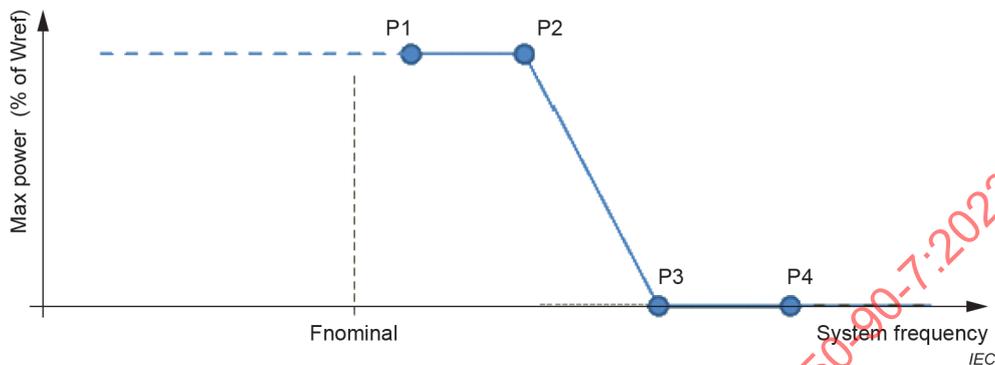


Figure 20 – Example of a basic frequency-watt mode configuration

The desired frequency-watt behaviour is established by writing a variable-length array of frequency-watt pairs. Each pair in the array establishes a point on the desired curve such as those labelled in Figure 20 as P1-P4. The curve is assumed to extend horizontally to the left below the lowest point and to the right above the highest point in the array. The horizontal X-axis values are defined in terms of actual frequency (Hz). The vertical Y-axis values are defined in terms of a percentage of a reference power level ( $W_{Ref}$ ) which is, by default, the maximum Watt capability of the system,  $W_{Max}$  (defined in prior work, which may differ from the nameplate value). As will be explained later in this document, these Y-axis values are signed, ranging from +100 % to -100 %, with positive values indicating active power produced (delivered to the grid) and negative values indicating power absorbed.

### 6.3.3.4 Setting a Snap Shot Power Reference ( $W_{Ref}$ ) Value

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

**Snapshot Enable (DeptRef):** An enumeration which when set to watts as percent of frozen active power  $W_{Ref}$ , instructs the power converter that the  $W_{Ref}$  value is to be set to a snapshot of the instantaneous output power  $DeptSnptRef$  at a certain point. When Snapshot is enabled, no reduction in output power occurs prior to reaching the  $W_{Ref}$  Capture Frequency ( $W_{Ref}Hz$ ).

**$W_{Ref}$  Capture Frequency:** The frequency deviation from nominal frequency, in hertz, at which the  $W_{Ref}$  value is established at the instantaneous output of the system at that moment. This parameter is only valid if Snapshot Enable is true.

**$W_{Ref}$  Release Frequency:** The frequency deviation from nominal frequency, in hertz, at which the  $W_{Ref}$  value is released, and system output power is no longer limited by this function. This parameter is only valid if Snapshot Enable is true.

### 6.3.3.5 Optional Use of Hysteresis

Hysteresis can be enabled for this frequency-watt function in the same way as with the volt-var function defined previously. Rather than the configuration array containing only points incrementing from left to right (low frequency to high frequency), as indicated in Figure 2, hysteresis is enabled by additional points in the configuration array which progress back to the left. Figure 21 illustrates this concept.

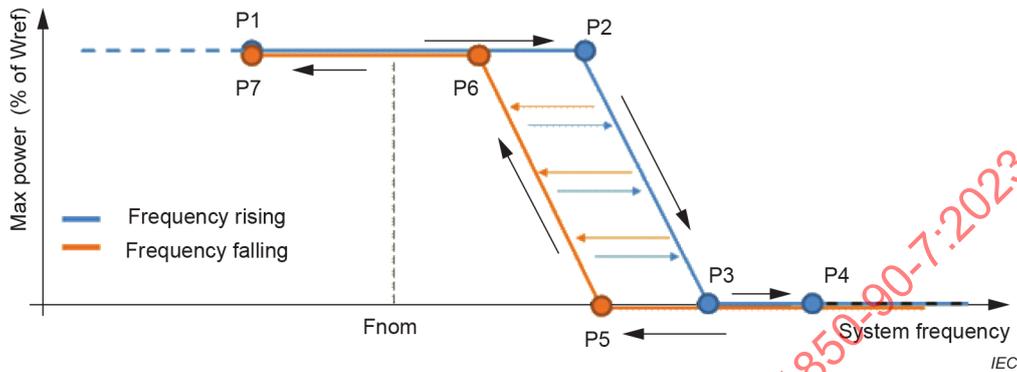


Figure 21 – Example array settings with hysteresis

In this case, the points in the configuration array can be thought-of as the coordinates for an X-Y plotter. The pen goes down on the paper at the first point, then steps through the array to the last point, tracing out the resulting curve. As with any configuration (including those without hysteresis), power converters must inspect the configuration when received and verify its validity before accepting it. The hysteresis provides a sort of dead-band, inside which the maximum power limit does not change as frequency varies. For example, in Figure 22, if frequency rises until the max power output is being reduced (somewhere between points P2 and P3), but then the frequency begins to fall, the maximum power setting would follow the light orange arrows horizontally back to the left, until the lower bound is reached on the line between points P5 and P6.

The return hysteresis curve does not have to follow the same shape as the rising curve. Figure 22 illustrates an example of such a case.

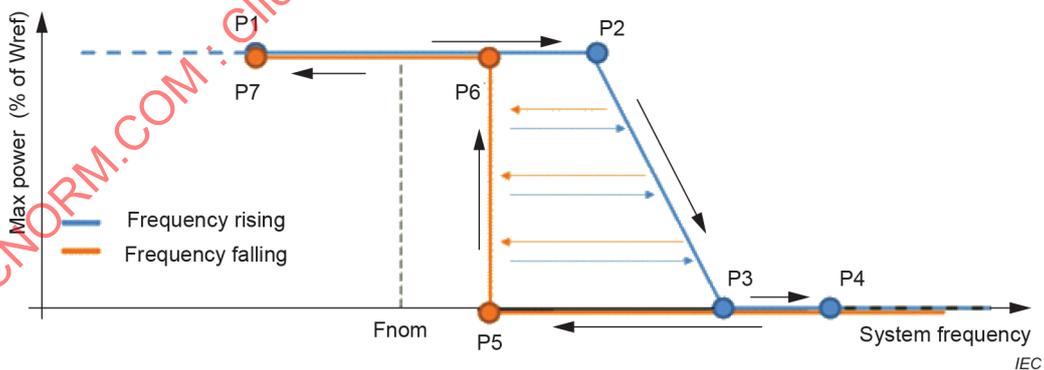


Figure 22 – Example of an asymmetrical hysteresis configuration

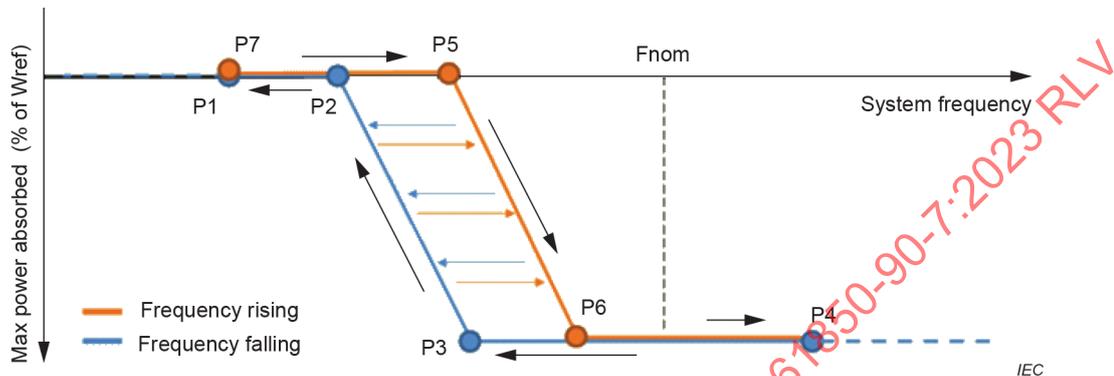
### 6.3.3.6 Controlling Ramp Time

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

Ramp Time Increasing and Ramp Time Decreasing: The maximum rates at which the maximum power limit established by this function can rise or fall, in units of % WMax/second.

### 6.3.3.7 Supporting Two-Way Power Flows

Some systems, such as battery storage systems, may involve both the production and the absorption of Watts. To support these systems, a separate control function is defined, which is identical to that described above, except the vertical axis is defined as maximum watts absorbed rather than maximum watts delivered. This allows for battery storage systems to back-off on charging when grid frequency drops, in the same way that photovoltaic systems back-off on delivering power when grid frequency rises. Figure 23 illustrates an example setting.



**Figure 23 – Example array configuration for absorbed watts vs. frequency**

A further characteristic of systems capable of two-way power flows is that the maximum power curtailment illustrated in Figure 20 through Figure 23 need not stop at 0 %. It may pass through zero, changing signs, and indicating that power must flow in the opposite direction (unless prevented from doing so by some other hard limitation).

For example, a battery storage system may be in the process of discharging, delivering power to the grid. If the grid frequency then rises above normal, the maximum delivered power level may begin to be curtailed. Once it has been curtailed to zero, if the frequency keeps rising, the system could be required to absorb watts, taking power out of the grid. Likewise, a battery storage system could curtail charging if the grid frequency drops too low, and begin discharging if frequency continues to drop further. These array configurations would utilize the signed nature of the array Y-values, as mentioned above.

## 6.4 Dynamic reactive current support during abnormally high or low voltage levels

### 6.4.1 Purpose of dynamic reactive current support

The dynamic reactive current support function defines the requirements for power converters to support the grid during short periods of abnormally high or low voltage levels by feeding reactive current to the grid until the voltage either returns within its normal range or the power converter is forced to disconnect. This function is required in some regions in order to meet international laws and regulations<sup>4</sup>.

### 6.4.2 Dynamic reactive current support mode TV31: support during abnormally high or low voltage levels

#### 6.4.2.1 Basic concepts of dynamic reactive current support

During abnormally high and low voltage levels, dynamic reactive current support by power converter-based DER systems may and/or must be taken to counter these abnormal conditions. These dynamic support actions are based on a combination of the rate of change of the voltage levels and the duration of these abnormal voltage dips/spikes. The basic concept is shown in Figure 24, where ArGraSag and ArGraSwell identify the additional reactive current as a percent

<sup>4</sup> The function may contain a description of the relevant European Standard EN 50549 law that is being met. Event logging will show when a law and its parameters have been changed.

of the rated current, based on the delta voltage ( $\Delta V$ ) from the moving average of voltage (voltage averaged across a window of time). A deadband, defined by  $DbV_{Min}$  and  $DbV_{Max}$ , can be used to limit this function to be activated only when the delta voltage exceeds some limit.

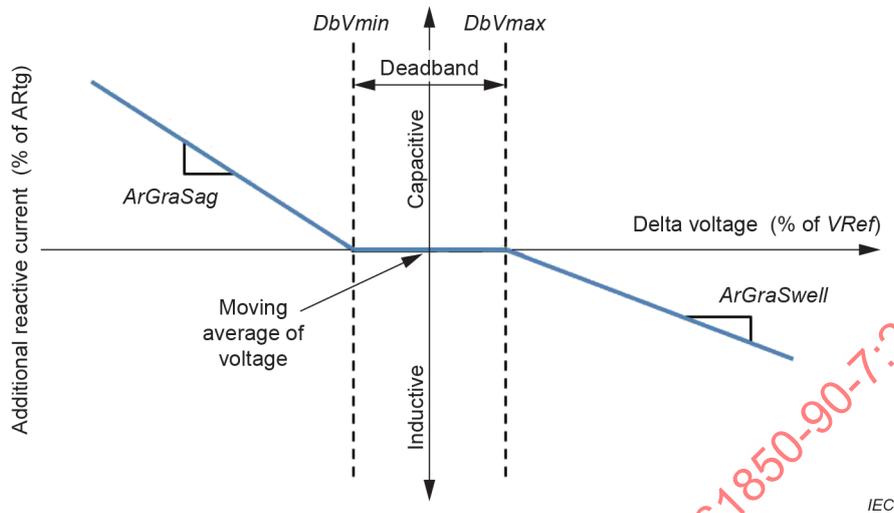


Figure 24 – Basic concepts of the dynamic reactive current support function

#### 6.4.2.2 Calculation of delta voltage

More precisely, the delta voltage  $\Delta V$  is calculated as the difference between the present measured voltage and the moving average of voltage (VA<sub>v</sub>). This moving average voltage is calculated using a sliding linear filtering over a preceding window of time specified as  $FilterTms$  (shown as  $FilterTms$ ). The calculation of delta voltage (delta voltage = present voltage – moving average voltage, expressed as a percentage of  $V_{Ref}$ ) is illustrated at time = “Present” in Figure 25.

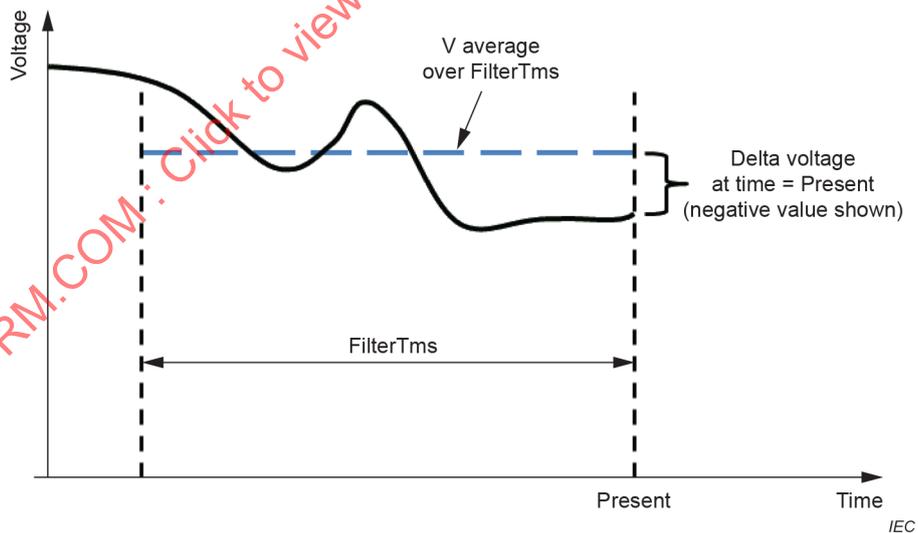


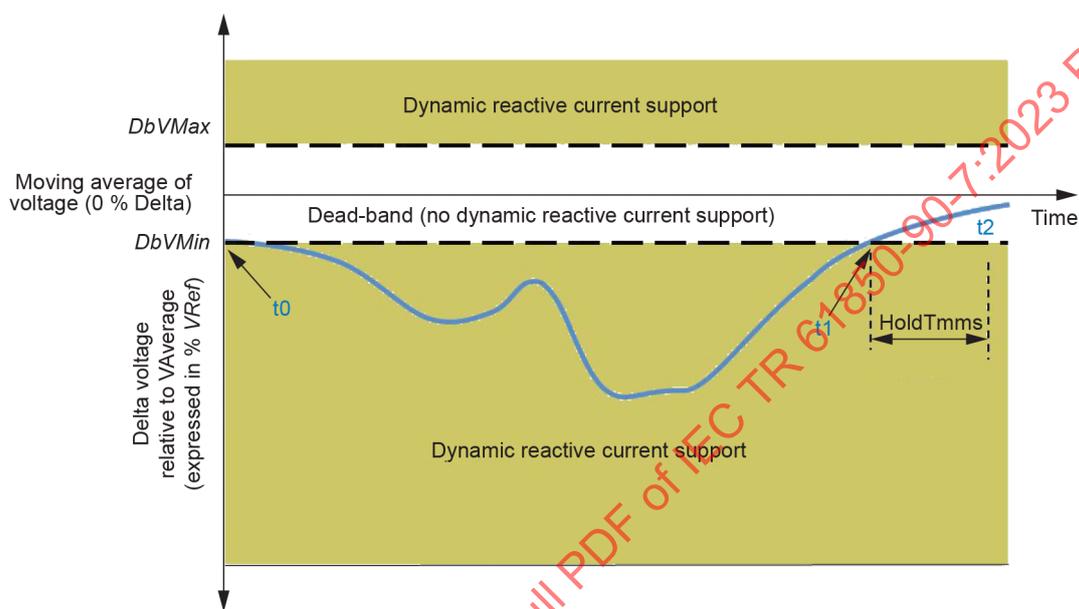
Figure 25 – Calculation of delta voltage over the filter time window

#### 6.4.2.3 Activation of dynamic support

The use of the deadband between  $DbV_{Max}$  and  $DbV_{Min}$  allows the activation of this behaviour for a voltage sag or swell to be thought of as an “event”. The event begins when the present measured voltage moves above the moving average voltage by  $DbV_{Max}$  or below by  $DbV_{Min}$ , as shown by the blue line in Figure 26 and labelled as  $t_0$ .

In the example shown, reactive current support continues until a time  $\text{HoldTmms}$  after the voltage returns above  $\text{DbVMin}$  as shown. In this example, this occurs at time  $t_1$ , and this event continues to be considered active until time  $t_2$  (which is  $t_1 + \text{HoldTmms}$ ).

When this behaviour is activated, the moving average voltage (VA<sub>v</sub>) and any reactive current levels that might exist due to other functions (such as the static volt-var function) are frozen at  $t_0$  when the “event” begins and are not free to change again until  $t_2$  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.



IEC

Figure 26 – Activation zones for dynamic reactive current support

#### 6.4.2.4 Deactivation of dynamic support

Dynamic support may be effectively deactivated by setting  $\text{ArGraSag}$  and  $\text{ArGraSwell}$  to zero (0), so that the function does not modify any reactive current output.

#### 6.4.2.5 Alternative gradient shape

This function includes the option of an alternative behaviour to that shown in Figure 24.  $\text{ArGraMod}$  selects between that behaviour where gradients trend toward zero at the deadband edges, and that of Figure 27 where the gradients trend toward zero at the centre. In this alternative mode of behaviour, the additional reactive current support begins with a step change when the “event” begins (at  $\text{DbVMin}$  for example), but then follows a gradient through the centre until the event expires,  $\text{HoldTmms}$  after the voltage returns above the  $\text{DbVMin}$  level.

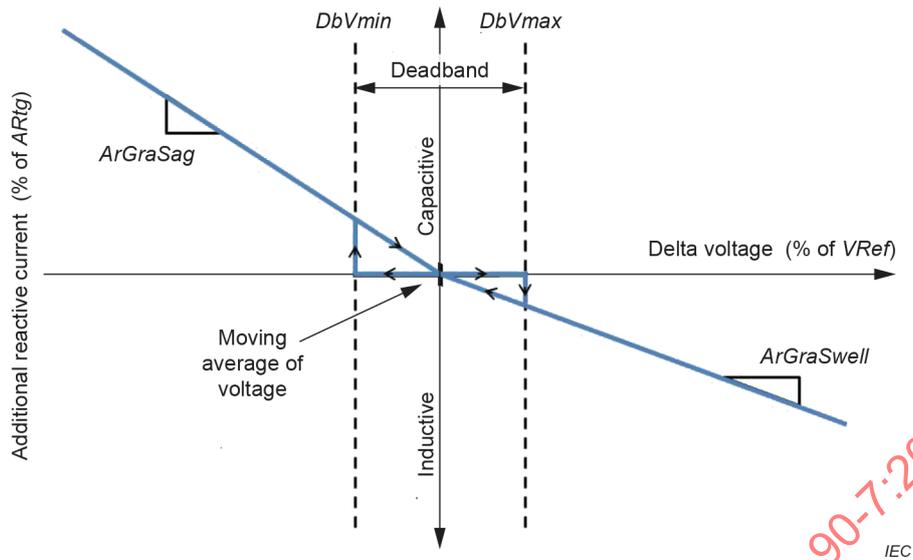


Figure 27 – Alternative gradient behaviour, selected by ArGraMod

6.4.2.6 Blocking zones

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

As illustrated in Figure 28, at t0 the voltage at the ECP falls to the level indicated by the BlkZnV setting and dynamic reactive current support stops. Current support does not resume until the voltage rises above BlkZnV + HysBlkZnV as shown at t1. BlkZnTmms provides a time, in milliseconds, before which dynamic reactive current support continues, regardless of how low voltage may sag. BlkZnTmms is measured from the beginning of any sag “event” as described previously.

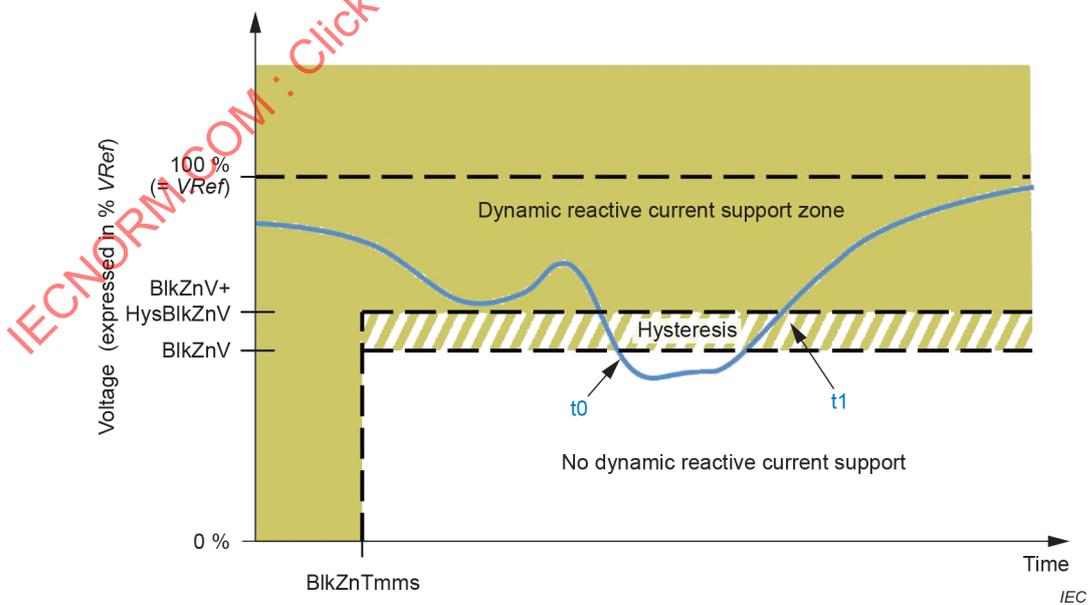


Figure 28 – Settings to define a blocking zone

## **6.5 Low/high voltage ride-through curves for “must disconnect” and “must remain connected” zones**

### **6.5.1 Purpose of L/HVRT**

A flexible mechanism is needed through which general Low/High Voltage Ride-Through (L/HVRT) behaviour may be configured, if so desired. In this context, L/HVRT refers only to the connect/disconnect behaviour of the DER, essentially defining the voltage conditions under which the DER may and must connect and disconnect.

This function defines only the mechanism through which the L/HVRT settings may be made and does not define the settings that would be used. Various countries, states, or other organizations such as the IEEE may issue specific L/HVRT requirements. The intention is that this function will be sufficiently flexible to support all such requirements.

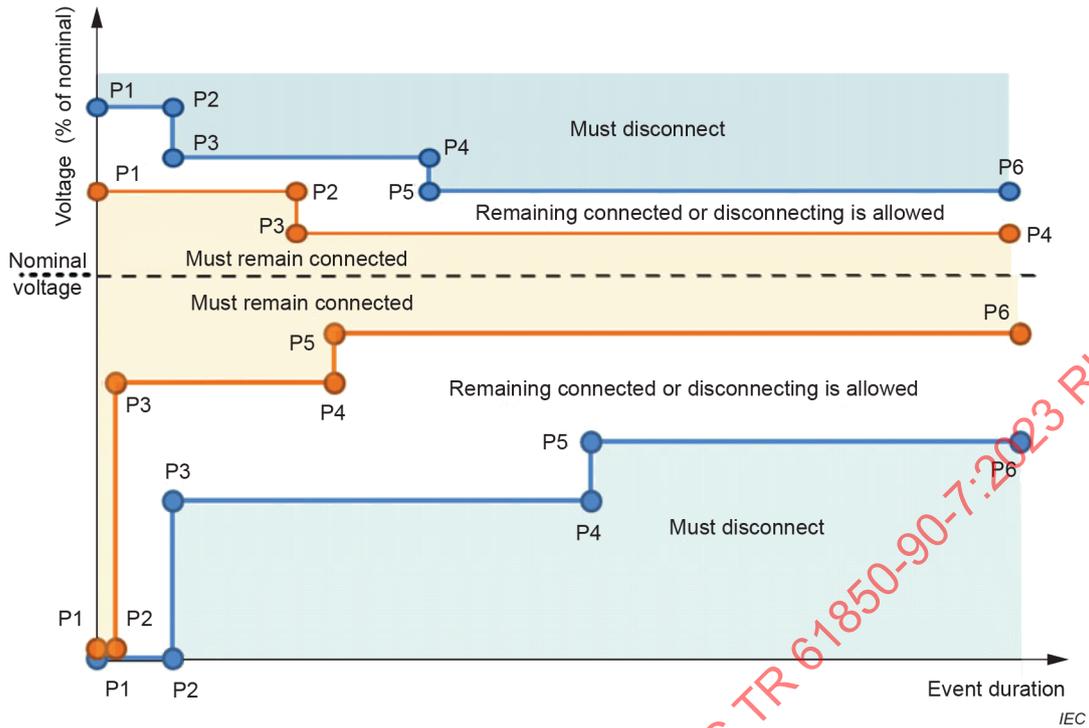
For low/high voltage ride through situations, either parameters or curves can be used to define the “must disconnect” and “must remain connected” zones, where the option for either remaining connected or disconnecting lies between these two zones:

- a) “Must disconnect” zone of voltage levels versus time. This zone is defined by a combination of the power converter safety constraints, local regulatory requirements, and any specific operational situations (anti-islanding requirement).
- b) “Remaining connected or disconnecting is allowed” zone of voltage levels versus time. This zone is defined by the area (if any) between the “must disconnect” and the “must remain connected” curves.
- c) “Must remain connected” zone of voltage levels versus time. This curve is also defined by a combination of the power converter safety constraints, local regulatory requirements, and any specific operational situations (e.g. microgrid creation requirement).

### **6.5.2 “Must disconnect” (MD) and “must remain connected” (MRC) curves**

Some “must disconnect” curves are defined in standards like IEEE 1547/IEC PAS 63547. In addition, power converters have their own must-disconnect settings for safety reasons and/or to prevent possible damage to the equipment. This can be modelled by the existing over and under voltage protection functions.

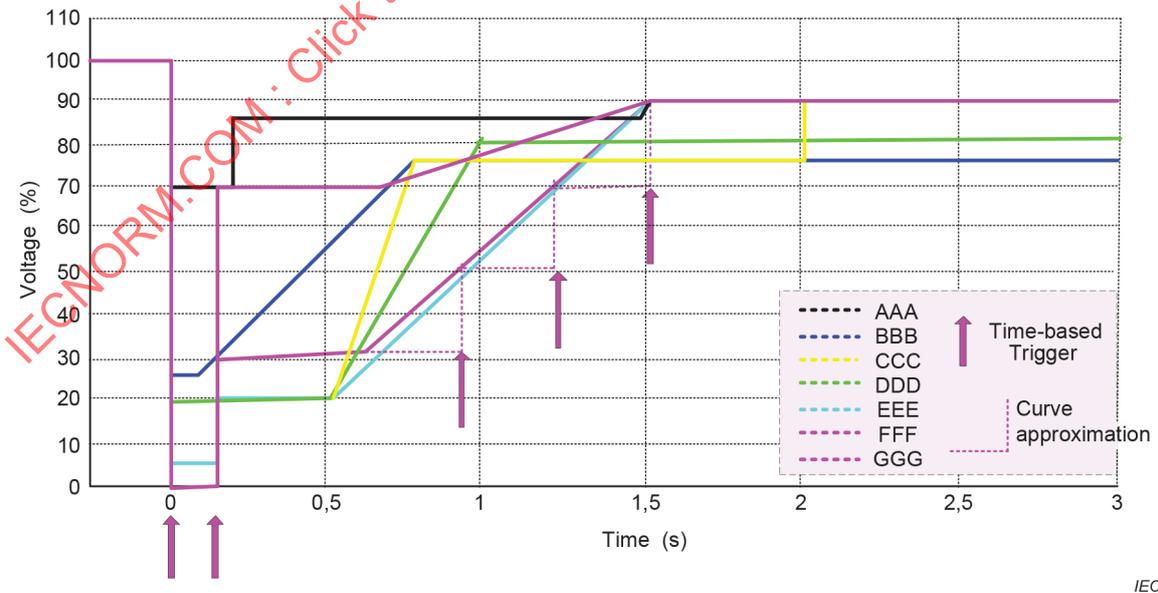
Increasingly regulations are also requesting DER systems to remain connected during voltage anomalies, so long as they are not too long in duration or the voltage levels are not too high or low. These “must disconnect” and “must remain connected” zones are illustrated in Figure 29.



**Figure 29 – Must disconnect and must remain connected zones**

As described in the TV31 function, these “must remain connected” curves may be the same as those defined by regulations for that function, but may also be different. For instance, these curves may be modified by individual power converter sensitivities, since the safety of the equipment overrides any general regulations.

Examples of different “must remain connected” curves are shown in Figure 30. For implementation purposes in order to allow precise time-based triggers, any curve segments that are not parallel to the x or y axes may be approximated by steps.



**Figure 30 – Examples of “must remain connected” requirements for different regions**

## 6.6 Modes for watt-triggered behaviours

### 6.6.1 Watt-power factor mode WP41: feed-in power controls power factor

The amount of watts provided at the ECP can be set to gradually modify the power factor. This watt-power factor mode WP41 is shown in Figure 31. The power factor will be set in relation to the feed-in power, in this example ranging from 0,85 overexcited to 0,90 underexcited. These settings are not expected to be updated very often over the life time of the system.

#### Example Settings

Power (% WMax)		Power Factor		Power Factor with convention defined by PFsign and PFExt	
WStr	20	PFStr	0,9	PFExtStr	Overexcited → False
WStop	40	PFStop	0,85	PFExtStop	Underexcited → True

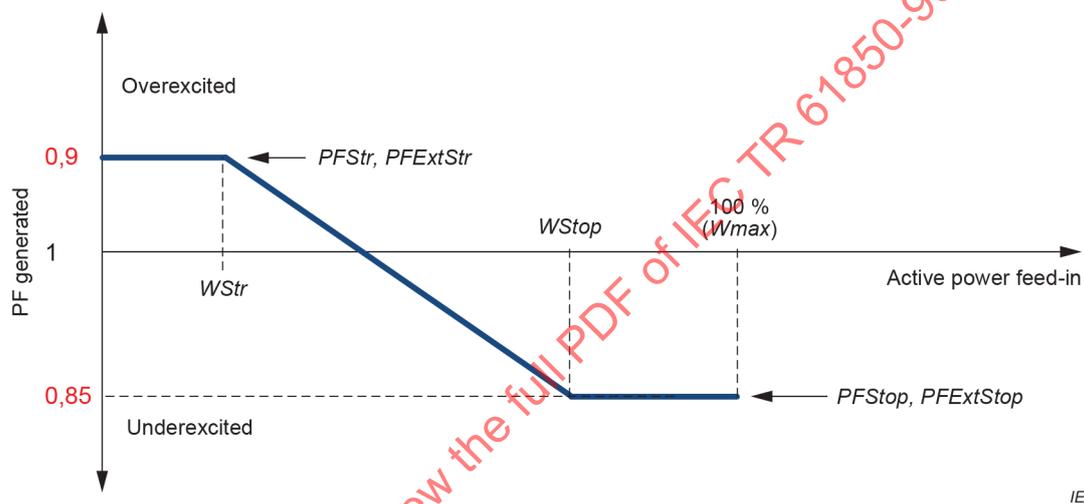


Figure 31 – Power factor controlled by feed-in power

The six parameters can be set with the power converter defining the curve via the parameters.

### 6.6.2 Alternative watt-power factor mode WP42: feed-in power controls power factor

Alternatively, the curves can be defined using arrays, as is done for other modes.

The utility/ESP or the customer EMS takes the following actions:

- 1) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- 2) Issue command to modify watt-PF settings:
  - Watt-PF paired array to create the curve
  - Requested ramp time for the power converter-based DER system to move from the current setpoint to the new setpoint if either it is now being constrained or it is now being released from a constraint (optional – if not included, then use previously established default ramp rate)
  - Time window within which to randomly execute the command. If the time window is zero, the command will be executed immediately, (optional – if not included, then default time window for this function will be used)

- Timeout period, after which the power converter-based DER system will revert to its default status, such as resetting the maximum power setpoint to its default value (optional – if not included, then default timeout period for this function will be used)

3) Receive response to the command:

- Successful (plus new value of data element)
- Rejected (plus reason: equipment not available, message error, overridden, security error)

## 6.7 Modes for voltage-watt management

### 6.7.1 Voltage-watt mode VW51: voltage-watt management: generating by voltage

Similar to the frequency-watt mode FW22 a voltage-watt management can be used for smoothing voltage deviations.

There can be multiple voltage-watt modes configured into a power converter. For example, the desired frequency-watt settings might be different on-peak versus off-peak, or different when islanded versus grid connected. A simple mode change broadcast could move the power converters from one pre-configured voltage-watt mode to another mode.

Figure 32 shows one example for maximum watts generated versus voltage.

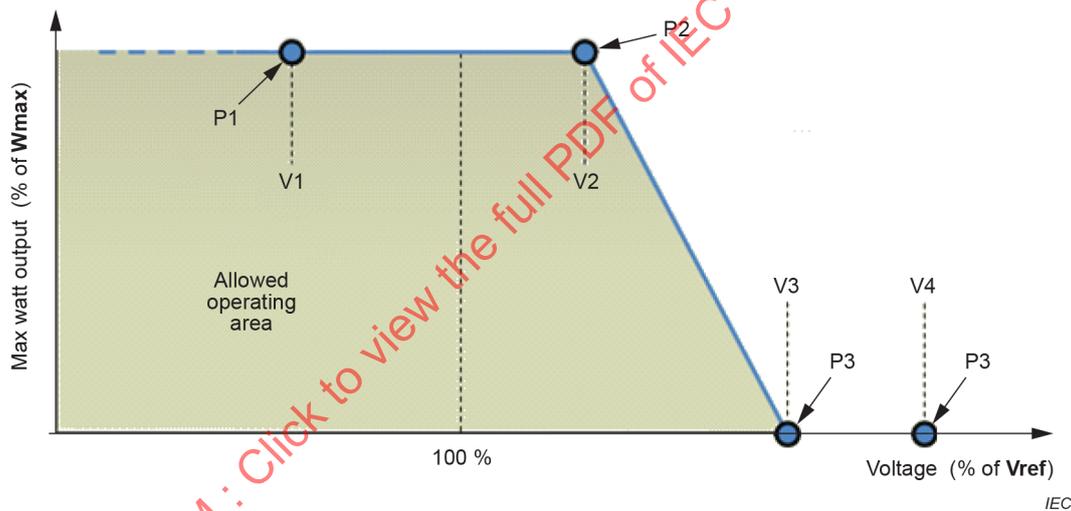
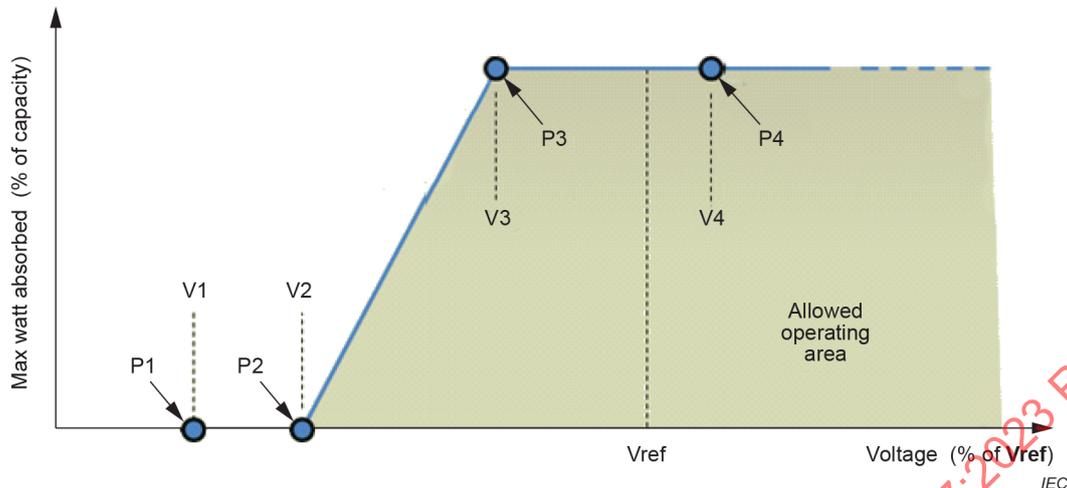


Figure 32 – Example configuration curve for maximum watts vs. voltage

### 6.7.2 Voltage-watt mode VW52: voltage-watt management: charging by voltage

In addition to voltage-based management of generation, charging of storage units also can be affected by voltage-watt management. Figure 33 illustrates maximum watts absorbed by a storage device versus voltage.



**Figure 33 – Example configuration curve for maximum watts absorbed vs. voltage**

The settings for this mode would include a voltage-watts-delivered curve (generation) and/or a voltage -watts received curve (storage), ramps for changing power, time of the input filter, and as with other functions, a time window, ramp rate, and timeout.

The curve shapes shown in Figure 33 above are one example. The vertical axis would be percent of WMax, and the horizontal axis is voltage, with reference voltage (VRef) shown in the middle.

## 6.8 Modes for behaviours triggered by non-power parameters

### 6.8.1 Temperature mode TMP

The temperature mode invokes the temperature curve. In the temperature curve, the temperature is the primary value of the curve, while the secondary value identifies the action to take. Actions to take when the temperature is within one of the specified ranges can include functions, such as adjust power factor (INV3), or other modes, such as maximum var support mode (VV12).

A typical use would be for the power converter to respond with additional vars during very high temperatures, similar to a feeder's capacitor bank that is set to respond to temperature.

### 6.8.2 Pricing signal mode PS

The pricing signal mode invokes the pricing signal curve. In the pricing signal curve, the pricing signal is the independent variable of the curve, while the dependent variable identifies the action to take. Actions can include functions, such as adjust maximum generation level (INV2), or other modes, such as frequency-watt mode (FW21).

Multiple pricing signal curves can be established to reflect different energy and ancillary services. For instance, one pricing signal curve could be for watts, another for var support, and a third for frequency support. So long as they are not contradictory (e.g. two curves for watts), these modes can be activated for the same time periods.

The actual pricing signal would be received from an external source (e.g. broadcast by the utility/ESP) or from a schedule (e.g. pricing signal between 6 am and 2 pm, between 2 pm and 4:30 pm, and between 4:30 pm and 6 am). This pricing signal would be used with the activated curve to determine the DER response.

## 6.9 Setting and reporting functions

### 6.9.1 Purpose of setting and reporting functions

In addition to functions which directly control functions, many individual parameters can be set to different values in order to change the power converter's behaviour. Some of these settings are described below.

### 6.9.2 Establishing settings DS91: modify power converter-based DER settings

This function permits the utility, energy service provider, customer EMS, and/or other authorized entities to dynamically modify or update various parameters for power converter-based DER systems. This list of parameters may be expanded, but will include:

- **Intermittency Ramp Rate Limit.** This setting will limit the rate that watts delivery to the grid can increase or decrease in response to intermittent PV generation. The configuration will be in units of "percent of WMax per minute". A single setting will be applied to both increasing and decreasing power output. This ramp rate limit does not apply to output power changes in response to commands that are received. Such commands contain their own ramp limits. Power converter-based DER systems must manage the details of their battery charging such that the rate of change in power delivery to and from the grid remains below this limit – even when the PV generation is intermittent.
- **Storage Reserve** (Minimum energy charge level allowed, % of maximum charge level). This level may be set by the vendor, asset owner, or system operator for a variety of purposes. In some cases, depth of discharge may be limited in order to extend battery service life. In other cases, a minimum reserve may be desired to provide some carryover during outage. It is intended that reserve settings be maintained even while managing intermittency ramp rate limits as described above. For example, a system with a 20 % minimum reserve setting may charge up to 40 % before beginning to generate to the grid so that a sudden loss of the PV source can be covered by a controlled ramp-down of generation, and yet without dropping below 20 % charge.
- **Maximum Storage Charge and Discharge Levels.** These settings establish the maximum charge and discharge rates for storage elements that might be part of the DER. These settings are expressed in terms of a percentage of WMax, delivered and WMax, received, and by default are equal to 100 % of these settings. Charge/Discharge commands, as described in INV4, are expressed in terms of a percentage of these settings.

The utility/ESP or the customer EMS takes the following actions:

- 1) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- 2) Issue command to modify power converter-based DER settings:
  - Data element to be modified
  - New value for that data element
- 3) Receive response to the command:
  - Successful (plus new value of data element)
  - Rejected (plus reason: equipment not available, message error, overridden, security error)

### 6.9.3 Event logging DS92: log alarms and events, retrieve logs

#### 6.9.3.1 Event log concepts

Event/history logs are maintained by the power converter-based DER systems to record key time-stamped events. The event log can be queried by selecting time ranges.

Different users of power converter-based DER systems will need varying timeframes for retrieving event log information and different types of information from these event logs:

- a) Utility operations will typically only need key operations-related information, possibly infrequently or only under special circumstances.
- b) Owners/managers (including utility owners) will want more detailed information, probably periodically or after certain types of events.
- c) Energy management systems with tightly-coupled interactions will need complete event logs relatively frequently.
- d) Larger PV plants are different from large numbers of small power converter-based DER systems: more types of event data may be collected from these larger plants, while only basic event data may be collected from the smaller power converter-based DER systems. Larger plants may also aggregate and/or amalgamate events from multiple individual power converter-based DER systems.

In general the following types of events will be logged, but decisions on exactly which ones are logged or which ones are retrieved by any specific user, will be determined on an implementation basis by DataSets, Logs, and LogControlBlocks:

- a) All errors or failures (service tracking and logging)
- b) All startup and shutdown actions (logging)
- c) All control actions (service tracking and logging)
- d) All responses to control actions (service tracking and logging)
- e) All limit violations, including returns within limits (logging)

~~NOTE—Service tracking is a new service defined in IEC 61850-7-2.~~

### 6.9.3.2 Event Log Fields

All event logs will contain the following fields at a minimum:

- a) Date and time stamp: The accuracy of this timestamp will be determined by the frequency of time synchronization and the innate precision in keeping time of the power converter-based DER system, and is therefore outside the scope of this specification. Zeros can be used to pad any timestamp if the accuracy does not match the format.
- b) Data reference: the reference to the data item that triggered the event log entry. For instance, if it is a voltage-related event, the Data reference will be to that data object. If it is a power converter mode event, the Data Reference will be to the power converter mode data object.
- c) Value: Value field of the Data reference field that is triggering the event, including commands, state changes of monitored values, quality code changes, mode setting, etc. For instance, the request to go into a specific power converter mode will be logged with the Value containing the power converter mode identity.

To enable the filtering of events so that different users can select different types of events to retrieve, different logs can be used. These different logs may be set up to differentiate different types of events, such as:

- a) Communications (for communication-related events)
- b) Grid power (for power system events)
- c) Device asset (for time and asset-related events)
- d) Security (for security-related events)
- e) Power converter-based DER system (for power converter-based DER system events, as well as other PV events)
- f) Storage system (for storage power converter events, as well as other storage events)

Table 3 shows some examples of events that are logged.

**Table 3 – Events**

Domain	Part	Type	Attribute	Description
Communications	Messaging	Status	Success	Request received successfully. Value field identifies the request as a “demand response”
	Messaging	Status	Success	Command received successfully. Value field identifies the command as a “Direct command”
	Messaging	Status	Acknowledged	Response – acknowledgment sent
	Messaging	Alarm	Message failed	Response – alarm invalid message. Value field contains type of error
	Network interface	Alarm	Comm. failed	Alarm communications error. Value field contains type of error.
PV System	Power converter	Command	Success	Action taken successfully (details are provided in Mode and Command events)
	Power converter	Command	Failed	Requested action failed. Value field contains type of error.
	Power converter	Command	Deviation	Action taken is a deviation from the requested action. Data Reference and Value fields contain indication of this deviation
	Mode	Status	Power converter mode	Power converter is in one of the power converter modes, as indicated in the Value field
	Power converter	Command	INV Command	Power converter responded to one of the INV commands, as indicated in the Value field
	Power converter	Status	Limit exceeded	Power converter status changed due to internal control threshold exceeded. Data Reference and Value fields provide details
	Schedule	Schedule change	Success	Action was successfully taken in response to the scheduled requirement
	Schedule	Schedule change	Failed	Action failed in response to the scheduled requirement. Value field indicates the type of error
	Power	Status	Power out	Power converter power turned off
	Power	Status	Power on	Power converter power turned on
	Power	Alarm	Power out	Power tripped off due to internal situation
	Power	Alarm	DC voltage	Inadequate DC bus voltage, Value field provide measured value
	Power	End alarm	DC voltage	DC bus voltage within limits. Value field provide measured value
	Temperature	Alarm	Limit exceeded	Temperature limit exceeded. Value field contains type of error.
	Temperature	End alarm	Limit exceeded	Returned within temperature limit. Value field contains type of error.

Domain	Part	Type	Attribute	Description
Grid Power	ECP Switch	Status	Connected	Switch at the ECP between power converter and the grid is connected
	ECP Switch	Status	Disconnected	Switch at the ECP between power converter and the grid is disconnected
	Voltage	Alarm	Limit exceeded	Voltage limit exceeded. Value field contains voltage measurement.
	Voltage	End alarm	Limit exceeded	Returned within voltage limit. Value field contains voltage measurement.
	Voltage	Alarm	Limit exceeded	Voltage distortion limit exceeded. Value field contains voltage distortion.
	Voltage	End alarm	Limit exceeded	Returned within voltage distortion limit. Value field contains voltage distortion.
	Current	Alarm	Limit exceeded	Current limit exceeded. Value field contains current measurement.
	Current	End alarm	Limit exceeded	Returned within current limit. Value field contains current measurement.
	Power quality	Alarm	Limit exceeded	Harmonic limit exceeded. Value field contains harmonic measurement.
	Power quality	End alarm	Limit exceeded	Returned within harmonic limit. Value field contains harmonic measurement.
	Other 1547 parameters	Alarm	Limit exceeded	High/low limit exceeded
	Other 1547 parameters	End alarm	Limit exceeded	Returned within high/low limit
Device asset	Logs	Status	Almost full	Log is almost full. Value contains percentage full.
	Logs	Alarm	Full	Log full: new events to overwrite unread events
	Time	Alarm	Clock failed	Clock failure. Value contains error information.
	Time	Alarm	Synch failed	Synchronization failed. Value contains error information
	Time	Setting	Synchronized	Synchronized. Value contains delta between new time and old time
	Time	Setting	Daylight adjust	Daylight time or Standard time adjustment. Value indicates Daylight of Standard
	Firmware	Alarm	Data error	Data error detected in firmware. Value indicates type of error

The retrieval of the event log consists of the following command and response:

1) Retrieve event log

- Event log retrieval command
- Start time/ stop time (start time = 0 means start from beginning of log; stop time = 0 means include through the final log entry)

2) Receive response to the command:

- Requested log entries
- Success/Failure (plus reason: no log event fulfils the retrieval criteria, log not available, message error, security error, request type not supported, etc.)

Additional event log interactions can include:

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

b) Notification of an event log error

#### 6.9.4 Reporting status DS93: selecting status points, establishing reporting mechanisms

Many functions require the status of the power converter-based DER system either periodically, on significant change of a value, or upon request.

Examples of status information that is standardized in the corresponding Logical Nodes are listed in Table 4. These status information points and any other information (standardized and extended Logical Nodes and Data Objects) can be used to configure DataSets that are used by ReportControlBlocks. The ControlBlocks can be configured to get the required reporting behaviour (periodic, sequence of events, or general interrogation).

**Table 4 – Examples of status points**

Status Point	Description
<i>Primary information</i>	
Connect status	Whether or not the device is currently connected at its ECP.
PV output available	Yes/No
Storage output available	Yes/No
Status of var capability	Yes/No
Power converter active power output	Present active power output level (Watts). This is an instantaneous (minimum averaging) reading.
Power converter reactive output	Present reactive power output level (VAr). This is a signed quantity.
Current power converter mode	Identity of mode or function that the power converter-based DER is in, including "owner mode" (Enumeration with range left open for proprietary vendor)
<i>Detailed information</i>	
Power converter status	Power converter is switched on (operating), off (not able to operate), or in stand-by mode (capable of operating but currently not operating)
DC Current level available for operation	Indicates whether or not there is sufficient DC current to allow operation. – Value, not yes/no
Power converter active power output	Present active power output level (Watts). This is an instantaneous (minimum averaging) reading.
DC power converter input power	Use for determining efficiency of power converter
Local/Remote control mode	Power converter is under local control or can be remotely controlled
Active power setpoint	Value of the active power setpoint
Reactive power setpoint	Value of the output reactive power setpoint
Power factor setpoint	Value of the power factor setpoint
<i>Power measurements</i>	
Active power	Active power value, plus high and low limits
Reactive power	Reactive power value, plus high and low limits
Phase to ground voltages	Voltage values per phase, plus high and low limits
Power factor	Power factor value, plus high and low limits
<i>Battery storage status (if storage is included in power converter-based DER system)</i>	
Capacity rating	The useable capacity of the battery, maximum charge minus minimum charge from a technology capability perspective (Watt-hours)
State of charge	Currently available energy, as a percent of the capacity rating (percentage)
Available energy	State of charge times capacity rating minus storage reserve (Watt-hours) See storage settings section for definition of "storage reserve"

Status Point	Description
Maximum battery charge rate	Set using DS91. The maximum rate of energy transfer into the storage device. (Watts). This establishes the reference for the charge percentage settings in function INV4.
Maximum battery discharge rate	Set using DS91. The maximum rate of energy transfer out of the storage device (Watts). This establishes the reference for the discharge percentage settings in function INV4.
Internal battery voltage	Internal battery voltage
DC power converter power input	Used for determining efficiency of power converter
<i>Nameplate and Settings Information</i>	
Manufacturer name	Text string
Model	Text string
Serial number	Text string
Power converter power rating	The continuous power output capability of the power converter (Watts)
Power converter VA rating	The continuous Volt-Amp capability of the power converter (VA)
Power converter var rating	Maximum continuous var capability of the power converter (var)
Maximum battery charge rate	The maximum rate of energy transfer into the storage device. (Watts). This establishes the reference for the charge percentage settings in function INV4.
Maximum battery discharge rate	The maximum rate of energy transfer out of the storage device. (Watts) This establishes the reference for the discharge percentage settings in function INV4.
Storage present indicator	Indication of whether or not battery storage is part of this system.
PV present indicator	Indication of whether or not PV is part of this system.
Time resolution	Time resolution and precision
Source of time synchronization	Text string

The retrieval of status items may be undertaken using one or all of the following methods:

a) Single status values:

- On-demand, request a single status value. That status value will then be returned to the requester.
- Upon a status value change or upon exceeding a deadband or upon exceeding a limit (depending upon the type of status point), that status value will be transmitted

b) Sets of status values:

- During initialization of the power converter-based DER system, sets of status values can be assigned to one or more “data sets”. These data sets can then be used in the following ways:
  - On-demand, request one of these data sets. All of the status values in the requested data set will be returned to the requester
  - Periodically, all of the status values in each data set will be transmitted
  - Upon change or upon exceeding a deadband or upon exceeding a limit of a status point in the data set, all of the status values in the affected data set will be transmitted
- After initialization, using the communications network, data sets can be created, modified, and/or deleted, and the reporting triggers can be established (e.g. upon demand, periodically, upon change).

The “on-demand” retrieval method for single status values and at least one data set are mandatory. The other retrieval methods may be optional or may be deemed mandatory for different implementations.

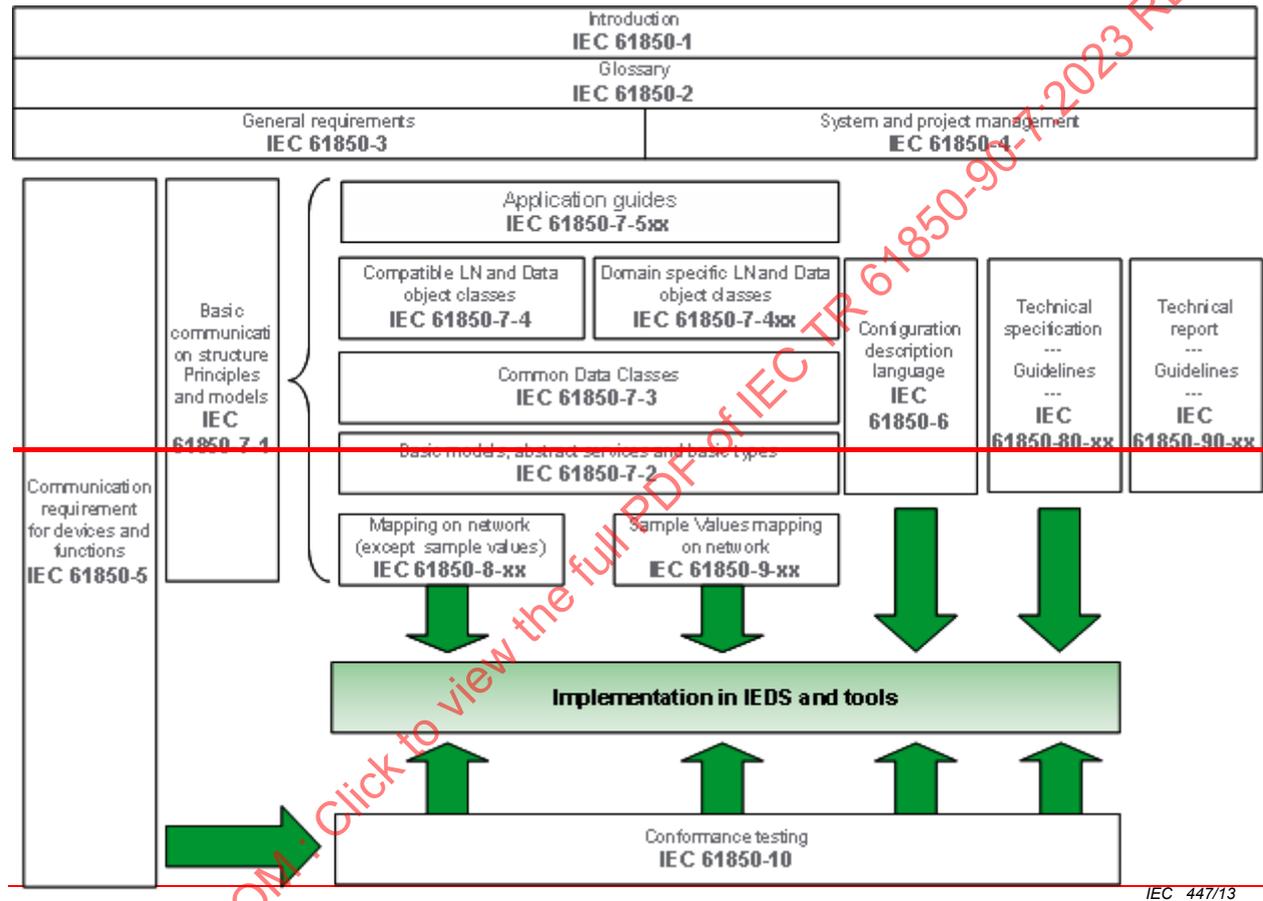
~~7.9.5 Time synchronization DS94: time synchronization requirements~~

~~The power converter-based DER system will use the time synchronization services specified in IEC 61850-8-1.~~

~~8 IEC 61850 information models for power converter-based functions~~

~~8.1 Overall structure of IEC 61850~~

~~Figure 34 describes the overall structure of the IEC 61850 series.~~



~~Figure 34 – Structure of the IEC 61850 Parts~~

~~This Technical Report provides the descriptions of power converter-based functions and informative versions of the proposed IEC 61850 models for these functions. It is expected that these models will be added to the next edition of IEC 61850-7-420:2009, after updates resulting from implementations and industry reviews.~~

~~**Note** – New data objects, logical nodes, and common data classes are shown *bold and italicized*; existing data objects, logical nodes, and common data classes are shown in normal type.~~

~~8.2 IEC 61850 system logical nodes~~

~~Certain Logical Nodes (LNs), described in full in IEC 61850-7-4<sup>5</sup>, provide basic information on the device hardware and software.~~

- ~~• Table 5 describes the meanings of LN tables.~~

<sup>5</sup> – If any discrepancies are found, the latest edition of IEC 61850-7-4 shall be the authoritative source.

- ~~Table 6, in particular PhyNam, is used for describing the device hardware/firmware and basic communications.~~
- ~~Table 7 (showing only the mandatory data objects) is used for describing communications software, including its health.~~
- ~~Table 8 (showing only some more relevant, but optional data objects) is used for describing aspects of a logical device~~

**Table 5 – Interpretation of logical node tables**

Column heading	Description
Data object name	Name of the data object
Common data class	Common data class that defines the structure of the data object. See IEC 61850-7-3. For common data classes regarding the service tracking logical node (LTRK), see IEC 61850-7-2.
Explanation	Short explanation of the data object and how it is used.
T	<p>Transient data objects – the status of data objects with this designation is momentary and must be logged or reported to provide evidence of their momentary state. Some T may be only valid on a modelling level. The TRANSIENT property of DATA OBJECTS only applies to BOOLEAN process data attributes (FC=ST) of that DATA OBJECTS. Transient DATA OBJECT is identical to normal DATA OBJECT, except that for the process state change from TRUE to FALSE no event may be generated for reporting and for logging.</p> <p>For transient data objects, the falling edge shall not be reported if the transient attribute is set to true in the SCL-ICD file.</p> <p>It is recommended to report both states (TRUE to FALSE, and FALSE to TRUE), i.e. not to set the transient attribute in the SCL-ICD file for these DOs, and that the client filter the transitions that are not "desired".</p>
M/O/C	<p>This column defines whether data objects are mandatory (M) or optional (O) or conditional (C) for the instantiation of a specific logical node.</p> <p>NOTE The attributes for data objects that are instantiated may also be mandatory or optional based on the CDC (attribute type) definition in IEC 61850-7-3.</p> <p>The entry C is an indication that a condition exists for this data object, given in a note under the LN table. The condition decides what conditional data objects get mandatory. C may have an index to handle multiple conditions.</p>

**Table 6 – LPHD class**

LPHD Class				
Data object name	Common data class	Explanation	T	M/O/C
LNName		Shall be inherited from logical-node class (see IEC 61850-7-2)		
Data objects				
Descriptions				
PhyNam	DPL	Physical device name plate		M
Status information				
PhyHealth	ENS	Physical device health		M
OutOv	SPS	Output communications buffer overflow		O
Proxy	SPS	Indicates if this LN is a proxy		M
InOv	SPS	Input communications buffer overflow		O
NumPwrUp	INS	Number of power ups		O
WrmStr	INS	Number of warm starts		O
WacTrg	INS	Number of watchdog device resets detected		O
PwrUp	SPS	Power up detected		O
PwrDn	SPS	Power down detected		O
PwrSupAlm	SPS	External power supply alarm		O

LPHD-Class			
Controls			
RsStat	SPC	Reset device statistics	O

**Table 7 – Common LN class**

Common LN Class				
Data-object name	Common data-class	Explanation	T	M/O/C
LNName		Shall be inherited from logical-node class (see IEC 61850-7-2)		
Data objects				
Descriptions				
NamPlt	LPL	Name plate		C1
Status information				
Mod	ENC	Mode		C
Beh	ENS	Behaviour		M
Health	ENS	Health		C1

**Table 8 – LLNO class**

LLNO Class				
Data-object name	Common data-class	Explanation	T	M/O/C
LNName		Shall be inherited from logical-node class (see IEC 61850-7-2)		
Data				
OpTmh	INS	Operation time		O
LocKey	SPS	Local operation for complete logical device		O
Loc	SPS	Local control behaviour		O
LocCtlBeh	SPS	SPS Local control behaviour		O
Controls				
Diag	SPC	Run diagnostics		O
Settings				
MitLev	SPG	Select mode of authority for local control (True — control from multiple levels above the selected one is allowed, False — no other control level above allowed)		O

### 8.3 Key components of IEC 61850 information modelling of power converter-based functions

#### 8.3.1 Subsets of 61850 models for power converter-based DER functions

The object modelling requirements in this report will use existing and extended IEC 61850-7-420 (DER) Logical Nodes, as well as existing IEC 61850-7-4 (basic) Logical Nodes, IEC 61850-7-3 Common Data Classes, and IEC 61850-7-2 Services. Some of the 61850-7-420 Logical Nodes will need new data objects. A few new Logical Nodes are defined.

The concepts for the power converter-based functions within the IEC 61850 information model are as follows:

High level or broadcast/multicast interactions are generally focused on the ECP of DER systems. Therefore most of those data objects are either already within or *added* to the Logical Nodes that are identified in IEC 61850-7-420 as part of the ECP Logical Device and the DER Unit Logical Device. These include:

- (1) ~~DCRP: Corporate characteristics~~
- (2) ~~DOPR: Operational characteristics~~
- (3) ~~DOPA: Operational control authority~~
- (4) ~~DOPM: Operational parameter-based mode commands~~
- (5) ~~**DGSM**: Operational curve-based mode commands~~
- (6) ~~**FMAR**: Array for defining mode curves~~
- (7) ~~**RDGS**: Dynamic reactive current support~~
- (8) ~~**FWHZ**: Frequency watt modes~~
- (9) ~~**FPFW**: Feed-in watt-triggered modes~~
- (10) ~~DPST: Status at ECP~~
- (11) ~~DCCT: Economic dispatch parameters~~
- (12) ~~DSCC: Schedule controllers for energy and ancillary services~~
- (13) ~~DSCH: Schedule for energy and/or ancillary services~~

For interactions between local DER management systems and the DER controllers, more direct interactions with controllers, power converters, generators, storage units, and other equipment are necessary. These logical nodes include the following:

- (1) ~~DRAT: Generator ratings~~
- (2) ~~DRCT: Controller Characteristics~~
- (3) ~~DRCS: Controller Status~~
- (4) ~~DRCC: Supervisory Control~~
- (5) ~~DGEN: Unit Generator~~
- (6) ~~ZINV: Power converter~~
- (7) ~~ZBAT: Battery system~~
- (8) ~~ZBTC: Charger for the battery system~~
- (9) ~~MMXU: Measurement values~~
- (10) ~~MMDC: Direct current measurement values~~
- (11) ~~CSWI: Switch~~

### ~~8.3.2 Types of interactions for settings, functions, and modes~~

The key types of interactions for settings, functions, and modes are:

- (1) ~~Settings: This step may be done by setting parameters one at a time, by setting a combination of parameters at one time, and/or by establishing these parameters at implementation time.~~
- (2) ~~Parameter-based Function: Issue a control command through the appropriate LN or enable the function via the appropriate mode of operation in LN-DOPM.~~
- (3) ~~Curve-based Mode: Enable an operational mode command using LN **DGSM** to initiate the mode and indicate which mode array to use.~~
- (4) ~~Response: (Optionally) receive a response from the command. If a message error is received, the ServiceError information will be included.~~

- (5) ~~Event Log: The function requesting event log information (DS92) will establish one or more logs associated with one or more Data Sets, as defined in 14.3 of IEC 61850-7-2:2010. For instance, one log could reflect only control commands, while another log could include not only the control commands but also the setting changes, while a third log might be more comprehensive, covering all key events. (This process is in lieu of the ability to select types of events, since this capability is not yet supported in IEC 61850.) At least three different logs must be supported. Although the actual contents of each of the logs will be determined on an implementation basis, the basic need is to provide different users with different types of events.~~
- (6) ~~Status: The function requesting status information (DS93) will use Data Sets that have either been pre-established or dynamically defined.~~
- (7) ~~Time synchronization: The function for time synchronization (DS94) will use the underlying protocol.~~

**8.3.3 Key common data classes (CDCs)**

**8.3.3.1 CDCs**

The common data classes (CDCs) shown in Tables 9 to 17 from IEC 61850-7-3:2010 and IEC 61850-7-420:2009 are the most frequently used CDCs in these DER functions. Key attributes are copied to this document just for informational purposes (see IEC 61850-7-3:2010 for details). Any additional attributes that are part of a CDC are optional, and are not expected to be necessary, but may, of course, be used.

**8.3.3.2 SPS – single point status CDC**

SPS – Single point status common data class definition (complete details are given in 7.3.2 of IEC 61850-7-3:2010). See Table 9.

**Table 9 – CDC SPS**

SPS class					
Data-object name	Attribute type	FC	TrgOp	Value/value-range	M/O/C
DataSource	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
status					
stVal	BOOLEAN	ST	dchg	TRUE FALSE	M
q	Quality	ST	qchg		M
t	Timestamp	ST			M
configuration, description and extension					
d	VISIBLE-STRING255	DC	Text		O

**8.3.3.3 SPC – single point control CDC**

SPC – Single point control common data class definition (complete details are given in 7.5.2 of IEC 61850-7-3:2010). See Table 10.

**Table 10 — CDC SPC**

SPC class					
Data object name	Attribute type	FC	TrgOp	Value/value range	M/O/C
DataName	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
Control and status					
ctNum	Int8U	CO			AG_CO_M
stVal	BOOLEAN	ST	dchg	TRUE FALSE	M
q	Quality	ST	qchg		M
t	Timestamp	ST			M
configuration, description and extension					
d	VISIBLE-STRING255	DC	Text		O

**8.3.3.4 — DPC — double point control CDC**

~~DPC — Double point control common data class definition (complete details are given in 7.5.3 of IEC 61850-7-3:2010). See Table 11.~~

**Table 11 — CDC DPC**

DPC class					
Data object name	Attribute type	FC	TrgOp	Value/value range	M/O/C
DataName	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
Control and status					
ctNum	Int8U	CO			AG_CO_M
stVal	CODED-ENUM	ST	dchg	intermediate-state off on bad-state	M
q	Quality	ST	qchg		M
t	Timestamp	ST			M
configuration, description and extension					
d	VISIBLE-STRING255	DC	Text		O

**8.3.3.5 — INC — integer point control CDC**

~~INC — Integer point control common data class definition (complete details are given in 7.5.4 of IEC 61850-7-3:2010). See Table 12.~~

**Table 12 — CDC INC**

INC class					
Data object name	Attribute type	FC	TrgOp	Value/value range	M/O/C
DataName	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
Control and status					
ctNum	Int8U	CO			AG_CO_M

INC class					
Data-object name	Attribute-type	FC	TrgOp	Value/value-range	M/O/C
DataSetName	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
stVal	INT32	ST	dchg		M
q	Quality	ST	qchg		M
t	Timestamp	ST			M
<i>configuration, description and extension</i>					
d	VISIBLE-STRING255	DC	Text		O

### 8.3.3.6 ~~ING – integer status setting CDC~~

~~ING – Integer status setting common data class definition (complete details are given in 7.6.3 of IEC 61850-7-3:2010). See Table 13.~~

**Table 13 – CDC ING**

ING class					
Data-object name	Attribute-type	FC	TrgOp	Value/value-range	M/O/C
DataSetName	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
<i>Control and status</i>					
setVal	INT32	SP			AC_NSQ_M
<i>configuration, description and extension</i>					
minVal	INT32	CF			O
maxVal	INT32	CF			O
d	VISIBLE-STRING255	DC	Text		O

### 8.3.3.7 ~~ASG – analogue setting~~

~~ASG – analogue setting common data class definition (complete details are given in 7.7.2 of IEC 61850-7-3:2010). See Table 14.~~

**Table 14 – CDC ASG**

ING class					
Data-object name	Attribute-type	FC	TrgOp	Value/value-range	M/O/C
DataSetName	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
<i>Control and status</i>					
setMag	AnalogueValue	SP			AC_NSQ_M
<i>configuration, description and extension</i>					
minVal	AnalogueValue	CF			O
maxVal	AnalogueValue	CF			O
d	VISIBLE-STRING255	DC	Text		O

**8.3.3.8 — ~~ORG — object reference setting~~**

~~ORG — object reference setting common data class definition (complete details are given in 7.6.5 of IEC 61850-7-3:2010). See Table 15.~~

**Table 15 — ~~CDC ORG~~**

<b>ING class</b>					
<b>Data object name</b>	<b>Attribute type</b>	<b>FC</b>	<b>TrgOp</b>	<b>Value/value range</b>	<b>M/O/C</b>
DataName	Inherited from data class (see IEC 61850-7-2)				
<b>DataAttribute</b>					
<i>Control and status</i>					
setSrcRef	ObjectReference	SP	dchg	Object reference	M
intAddr	VISIBLE-STRING255	SP	dchg	Manufacturer's internal address	Ø
<i>configuration, description and extension</i>					
purpose	VISIBLE-STRING255	DC			Ø
d	VISIBLE-STRING255	DC	Text		Ø

**8.3.3.9 — ~~CSG — curve shape settings CDC~~**

~~CSG — Curve shape settings common data class definition (complete details are given in 7.7.4 of IEC 61850-7-3:2010). The “curve” is created by the linear interpolation of the slope between crvPts(n) and crvPts(n+1) for  $0 < n < \text{numPts}$ . See Table 16.~~

**Table 16 — ~~CDC CSG~~**

<b>CSG class</b>					
<b>Data object name</b>	<b>Attribute type</b>	<b>FC</b>	<b>TrgOp</b>	<b>Value/value range</b>	<b>M/O/C</b>
DataName	Inherited from data class (see IEC 61850-7-2)				
<b>DataAttribute</b>					
<i>Setting</i>					
pointZ	FLOAT32	SP			AC_NSQ_O
numPts	INT16U	SP		$1 < \text{numPts} < \text{maxPts}-1$	AC_NSQ_M
crvPts	ARRAY-0..numPts-1-OF-Point	SP		Point = xVal and yVal, which are FLOAT32 values (only double arrays are used; CSG also allows triple arrays)	AC_NSQ_M
<i>configuration, description and extension</i>					
xUnit	Unit	CF			M
yUnit	Unit	CF			M
maxPts	INTEGER	CF			M
d	VISIBLE-STRING255	DC	Text		Ø

**8.3.3.10 — ~~SCR — schedule specification CDC~~**

~~The SCR CDC provides a means for defining a relative time array of setting values, such as schedules. The time intervals between points may be variable. A modification to this schedule CDC may be needed to handle the scheduling of modes. Future work will address this issue. See Table 17.~~

**Table 17 – Schedule (SCR) common data class specification**

SCR Class (defined in IEC 61850-7-420: 2009)					
Data object name	Attribute type	FC	TrgOp	Value/value range	M/O/C
DataName	Inherited from data class (see IEC 61850-7-2)				
DataAttribute					
setting					
numPts	INT16U	SP		Length of array >= 1	AC_NSG_M
val	ARRAY 1..numPts-OF FLOAT32	SP	dchg	1 to numPts values	AC_NSG_M
rmpTyp	ARRAY 1..numPts-OF ENUMERATED	SP	dchg	1 to numPts values: 1=Fixed, 2=Ramp, 3=Average	AC_NSG_C
tmsOffset	ARRAY 1..numPts-OF UINT32	SP	dchg	1 to numPts of time offsets in seconds	AC_NSG_M
configuration, description and extension					
cur	Currency	CF		Currency as 3-character string as per ISO 4217	Ø
valUnits	Unit	CF		Units of val	Ø
valEq	ENUMERATED	CF		Equation for val: 1 = SI units, 2 = Currency as per ISO 4217 per SI unit, 3 = SI unit per currency	Ø
valD	VISIBLE STRING255	DC		Description of val	Ø
valDU	UNICODE STRING255	DC		Description of val in Unicode	Ø
d	VISIBLE STRING255	DC		Description of instance of data	Ø
dU	UNICODE STRING255	DC			Ø
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M
rmpTyp is conditionally mandatory or optional: if val is a power-related type, then rmpTyp is mandatory; if val is currency, then rmpTyp is not necessary.					

### 8.3.4 Messaging services

As a minimum, the following IEC 61850 messaging services shall be implemented:

- **GetDataValues** to read data (see 10.4.2 of IEC 61850-7-2:2010)
- **SetDataValues** to write data (see 10.4.3 of IEC 61850-7-2:2010)
- **GetDataSetValues** to read Data Sets of values (see 11.3.2 of IEC 61850-7-2:2010)
- **DataSetValues** to write Data Sets of values (see 11.3.3 of IEC 61850-7-2:2010)
- **Logging** for timestamped logs (see 14.3 of IEC 61850-7-2:2010).
- **Reporting** for event-driven information exchanges (e.g. event-driven publish-subscribe notification, report by exception) (see 14.2 of IEC 61850-7-2:2010).

In addition, it is recommended that the following messaging services are implemented:

- **GetDataDirectory** to retrieve the list of all DataAttributeName within Logical Nodes (see 10.4.4 of IEC 61850-7-2:2010)
- **GetDataDefinition** to retrieve the complete list of all DataAttribute definitions (see 10.4.5 of IEC 61850-7-2:2010)

- ~~GetDataSetDirectory~~ to retrieve the list of the data objects within a Data Set (see 11.3.6 of IEC 61850-7-2:2010)

### 8.3.5 Message errors

If messages encounter error conditions, the message error response from Table 18 will be issued (see 61850-7-2).

**Table 18 – Service error type definitions**

ServiceError type definition			
Attribute name /value	Attribute type	Value range/explanation	Used by
ServiceError	Enumerated	instance-not-available   instance-in-use   access-violation   access-not-allowed-in-current-state   parameter-value-inappropriate parameter-value-inconsistent   class-not-supported   instance-locked-by-other-client   control-must-be-selected   type-conflict   failed-due-to-communications-constraint   failed-due-to-server-constraint	IEC 61850-7-2

## 8.4 Basic settings in IEC 61850

### 8.4.1 Logical nodes for basic settings

The following logical nodes are shown with only those objects which are relevant extracted from existing IEC 61850 standards. Additional objects and new logical nodes are shown as ***bold/italic***. For a complete definition of existing logical nodes, refer to the existing standards.

The following logical nodes are used for establishing basic settings:

#### Nameplate values

The ***nameplate values of DER generators*** are defined in LN DRAT (see IEC 61850-7-420:2009). These nameplate values may be pre-installed. If so, LN DRAT is needed only for retrieving these values for informational purposes. No changes have been identified for LN DRAT.

The ***nameplate values of DER storage devices*** are currently defined in LN DRAT for general characteristics, and in LN ZBAT and LN ZBTC for more specific characteristics for batteries (these are planned to be updated in IEC 61850-90-9<sup>6</sup>).

#### ECP basic settings

The ***ECP basic settings*** are set in LN DRCT which defines the control characteristics and capabilities of one DER unit or aggregations of one type of DER system with a single controller.

<sup>6</sup> Under consideration.

After validation by the power converter, these settings may override nameplate values if there is an overlap.

### 8.4.2 IEC 61850 models for basic settings

#### 8.4.2.1 LN DRCT: DER controller characteristics

LN DRCT, which contains the basic settings for DER controllers, is shown in Table 19 with new data objects shown as ***bold-italic***.

**Table 19 – LN DRCT – DER controller characteristics**

DRCT class (existing in IEC 61850-7-420:2009)																				
Data object name	Common data class	Explanation	T	M/O/C																
<i>Settings</i>																				
DERNum	ING	Number of DER units connected to controller or number of units connected to an ECP		M																
DERTyp	ENG	Type of DER unit managed by controller or connected at the ECP (this enumeration will be updated in a future edition):		M																
		<table border="1"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>Not applicable / Unknown</td> </tr> <tr> <td>1</td> <td>Virtual or mixed DER</td> </tr> <tr> <td>2</td> <td>Reciprocating engine</td> </tr> <tr> <td>3</td> <td>Fuel cell</td> </tr> <tr> <td>4</td> <td>Photovoltaic system</td> </tr> <tr> <td>5</td> <td>Combined heat and power</td> </tr> <tr> <td>99</td> <td>Other</td> </tr> </tbody> </table>	Value		Explanation	0	Not applicable / Unknown	1	Virtual or mixed DER	2	Reciprocating engine	3	Fuel cell	4	Photovoltaic system	5	Combined heat and power	99	Other	
		Value	Explanation																	
		0	Not applicable / Unknown																	
		1	Virtual or mixed DER																	
		2	Reciprocating engine																	
		3	Fuel cell																	
4	Photovoltaic system																			
5	Combined heat and power																			
99	Other																			
MaxWLim	ASG	Nominal max output power at controller or ECP		M																
MaxVARLim	ASG	Nominal max output reactive power at controller or ECP		M																
StrDITms	ING	Nominal time delay before starting or restarting <sup>a)</sup>		Q																
StopDITms	ING	Nominal time delay before stopping <sup>b)</sup>		Q																
LodRampRte	ING	Nominal ramp load or unload rate, power versus time <sup>c)</sup>		Q																
<b><i>WMax</i></b>	ASG	Setting for maximum active power and reference value for functions		M																
<b><i>VMax</i></b>	ASG	Setpoint for maximum voltage		Q																
<b><i>VMin</i></b>	ASG	Setpoint for minimum voltage		Q																
<b><i>VAMax</i></b>	ASG	Setpoint for maximum apparent power		Q																
<b><i>VArMax</i></b>	ASG	Setpoint for maximum reactive power		Q																
<b><i>VRef</i></b>	ASG	Reference voltage for functions using grid voltage as input		M																
<b><i>VRefOfs</i></b>	ASG	Reference offset voltage for functions using grid voltage as input		Q																
<b><i>WGra</i></b>	ASG	Default ramp rate for changes in active power: percentage of <b><i>WMax</i></b>		Q																
<b><i>PFSign</i></b>	ENG	Power factor convention: IEC = 1; EEL = 2;		Q																
<b><i>PFExt</i></b>	SPG	Underexcited = True; Overexcited = False		Q																
<b><i>OutPFSet</i></b>	ASG	Setpoint for maintaining fixed power factor;		M																
<b><i>VArAct</i></b>	ENG	VAr action on change between charging and discharging: switch = 1, remain = 2		Q																

DRCT class (existing in IEC 61850-7-420:2009)				
Data object name	Common data class	Explanation	T	M/O/C
<b>OutWRt</b>	ASG	Setpoint for charge or discharge rate		0
<b>WChaMax</b>	ASG	Setpoint for maximum active charging power and reference value for functions		0
<b>VACHaMax</b>	ASG	Setpoint for maximum apparent charging power		0
<b>WChaGra</b>	ASG	Setpoint for maximum charging ramp rate: percentage of WChaMax		0
<b>CICTotVA</b>	ENG	Calculation method used for total apparent power calculation (Vector   Arithmetic)		0
<b>WMaxLimPct</b>	ASG	Percent of reference active power watts as maximum allowed watts output		0
<b>VArRef</b>	ENG	Enumeration for reference of reactive power		
		<b>Value</b>	<b>Explanation</b>	
		0	Not applicable / Unknown	
		1	Reactive power in percent of <b>WMax</b>	
		2	Reactive power in percent of <b>VArMax</b>	
3	Reactive power in percent of <b>VArAval</b>			
<b>VArWMaxPct</b>	ASG	Reactive power in percent of <b>WMax</b>		0
<b>VArMaxPct</b>	ASG	Reactive power in percent of <b>VArMax</b>		0
<b>VArAvalPct</b>	ASG	Reactive power in percent of <b>VArAval</b>		0
<b>RmpRtePct</b>	ING	Setpoint for maximum ramp rate as percentage of nominal maximum ramp rate		0
<b>MinRsvPct</b>	ING	Setpoint for minimum reserve for storage, as a percentage of the nominal maximum storage		0
<p>a) Mostly valid for individual units — may need to have a different understanding of its meaning be useful for aggregated DERs, such as how long to get full response from the aggregated DERs.</p> <p>b) Mostly valid for individual units — may need to have a different understanding of its meaning be useful for aggregated DERs, such as how long to get full stop from the aggregated DERs.</p> <p>c) Mostly valid for individual units — may need to have a different understanding of its meaning be useful for aggregated DERs, such as what an aggregated ramp rate means from the aggregated DERs.</p>				

## 8.5 Mode settings in IEC 61850

### 8.5.1 Logical nodes for establishing and managing modes

#### 8.5.1.1 Establish mode arrays and parameters

Modes are first established and then invoked whenever needed. The logical nodes used for these two processes are described below.

LN **FMAR** is used to establish the curve characteristics for modes. These parameters include:

- Name of mode and this curve. There may be multiple curves associated with a mode.
- Array of independent and dependent variables that defined the graph for the **increasing** and for the **decreasing** direction of the independent variable over time. For example, this array indicates the dependent vars associated with the independent voltage, first as voltage is increasing, and then, if hysteresis is used, as voltage is decreasing.
- Independent variables are those that are either measured locally or provided to the DER. Their values are used to determine what value of the dependent variable is to be used. The

correlation between the independent and the dependent variables may be envisioned as a piecewise linear graph.

- Default parameters for the ramp time for moving from current operational mode settings to another operational mode settings. If combined with the time window, the ramp will start from the time when the command is actually executed.

**8.5.1.2 Invoke mode and one of its curves**

The invoking of a mode and one of its curves is through instantiations of LN **DGSM**, each of which refer to one instance of **FMAR**.

**8.5.2 IEC 61850 models for modes**

**8.5.2.1 LN FMAR: Establish mode curves and parameters**

Mode curves and parameters are set in the new LN **FMAR**, shown in Table 20.

**Table 20 – LN FMAR – set mode array**

<i>FMAR class (new)</i>																												
Data object name	Common data class	Explanation	T	M/O/C																								
<i>Settings</i>																												
<b>PairArray</b>	CSG	Paired array of independent and dependent variables for increasing direction (e.g. increasing voltage, increasing frequency) plus optionally variables for decreasing direction to describe a hysteresis curve:  For crvPts: — xVal = independent values — yVal = dependent values as percent of dependent reference value  Use units field in CSG to define what units		M																								
<b>IndpUnits</b>	ENG	Enumeration of the independent reference parameter units using SI units (see Annex A of IEC 61850-7-3) (enumeration examples) – add 100 to SI unit enumeration for % and add 200 to SI unit enumeration for deviation  <table border="1"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>Not applicable / Unknown</td> </tr> <tr> <td>1</td> <td>None, dimensionless</td> </tr> <tr> <td>4</td> <td>Time</td> </tr> <tr> <td>29</td> <td>Voltage</td> </tr> <tr> <td>33</td> <td>Frequency</td> </tr> <tr> <td>38</td> <td>Watts</td> </tr> <tr> <td>23</td> <td>Celsius temperature</td> </tr> <tr> <td>129</td> <td>Percent voltage</td> </tr> <tr> <td>133</td> <td>Percent frequency</td> </tr> <tr> <td>138</td> <td>Percent watts</td> </tr> <tr> <td>233</td> <td>Frequency deviation</td> </tr> </tbody> </table>	Value	Explanation	0	Not applicable / Unknown	1	None, dimensionless	4	Time	29	Voltage	33	Frequency	38	Watts	23	Celsius temperature	129	Percent voltage	133	Percent frequency	138	Percent watts	233	Frequency deviation		M
Value	Explanation																											
0	Not applicable / Unknown																											
1	None, dimensionless																											
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38	Watts																											
23	Celsius temperature																											
129	Percent voltage																											
133	Percent frequency																											
138	Percent watts																											
233	Frequency deviation																											

<i>FMAR class (new)</i>																								
Data object name	Common data class	Explanation	F	M/O/C																				
<b>DeptRef</b>	ENG	Enumeration of the dependent reference parameter units																						
		<table border="1"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>Not applicable / Unknown</td> </tr> <tr> <td>1</td> <td>None, dimensionless</td> </tr> <tr> <td>2</td> <td>VARs as percent of maximum vars (<b>VArMax</b>)</td> </tr> <tr> <td>3</td> <td>VARs as percent of maximum available vars (<b>VArAval</b>)</td> </tr> <tr> <td>4</td> <td>VARs as percent of maximum watts (<b>WMax</b>)</td> </tr> <tr> <td>5</td> <td>Watts as percent of maximum watts (<b>WMax</b>)</td> </tr> <tr> <td>6</td> <td>Watts as percent of frozen active power WRef (DeptSnptRef)</td> </tr> <tr> <td>7</td> <td>Power factor EEL notation</td> </tr> <tr> <td>99+</td> <td>Other</td> </tr> </tbody> </table>	Value	Explanation	0	Not applicable / Unknown	1	None, dimensionless	2	VARs as percent of maximum vars ( <b>VArMax</b> )	3	VARs as percent of maximum available vars ( <b>VArAval</b> )	4	VARs as percent of maximum watts ( <b>WMax</b> )	5	Watts as percent of maximum watts ( <b>WMax</b> )	6	Watts as percent of frozen active power WRef (DeptSnptRef)	7	Power factor EEL notation	99+	Other		M
		Value	Explanation																					
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		6	Watts as percent of frozen active power WRef (DeptSnptRef)																					
7	Power factor EEL notation																							
99+	Other																							
<b>RmpPT1Tms</b>	ASG	The time of the PT1 in seconds (time to accomplish a change of 95 %)-		Q																				
<b>RmpDecTmm</b>	ASG	The maximum rate at which the dependent value (output) may be reduced in response to changes in the independent value (input). This is represented in terms of % of Reference value (e.g. <b>WMax</b> ) per minute.		Q																				
<b>RmpIncTmm</b>	ASG	The maximum rate at which the dependent value (output) may be increased in response to changes in the independent value (input). This is represented in terms of % of Reference value (e.g. <b>WMax</b> ) per minute.		Q																				
<b>RmpRsUp</b>	ASG	The maximum rate at which the dependent value (output) may be increased after releasing the frozen value of snap-shot function. This is represented in terms of % of Reference value (e.g. <b>WMax</b> ) per minute.		Q																				
<b>DeptRefStr</b>	ASG	Deviation from nominal value of the dependent variable at the time of the snapshot to start constraining power output		Q																				
<b>DeptRefStop</b>	ASG	Deviation from nominal value of the dependent variable at which to release the power output		Q																				
<i>Measurement values</i>																								
<b>DeptSnptRef</b>	MV	Value to use as reference for snapshot function		Q																				

### 8.5.2.2 LN DGSM: Issue “operational mode control” command

Control commands to activate each type of mode are issued through LN **DGSM** (see Table 21). Multiple instances of LN **DGSM** can be used for managing multiple modes. In addition to activation, timing settings can be provided:

- **WinTms – Time Window:** The requirement for a time window within which the requested command will be executed at a randomly selected moment. If the time window is zero, the command will be executed immediately. If the time window is not remotely set, a default time window will be used. The method for determining that randomly selected moment is a local issue.

- ~~**RmpTms — Ramp Time:** The time for moving from current operational mode settings to another operational mode settings. If combined with the time window, the ramp will start from the time when the command is actually executed.~~
- ~~**Reversion Time:** Since communications are not expected to have a high availability, either through design or due to the widespread nature of these DER systems, a reversion timeout period needs to be set for the devices to revert to a default setting or mode, in case communications have been lost. If not established by a remote command, the reversion timeout period will use a locally established timeout period.~~

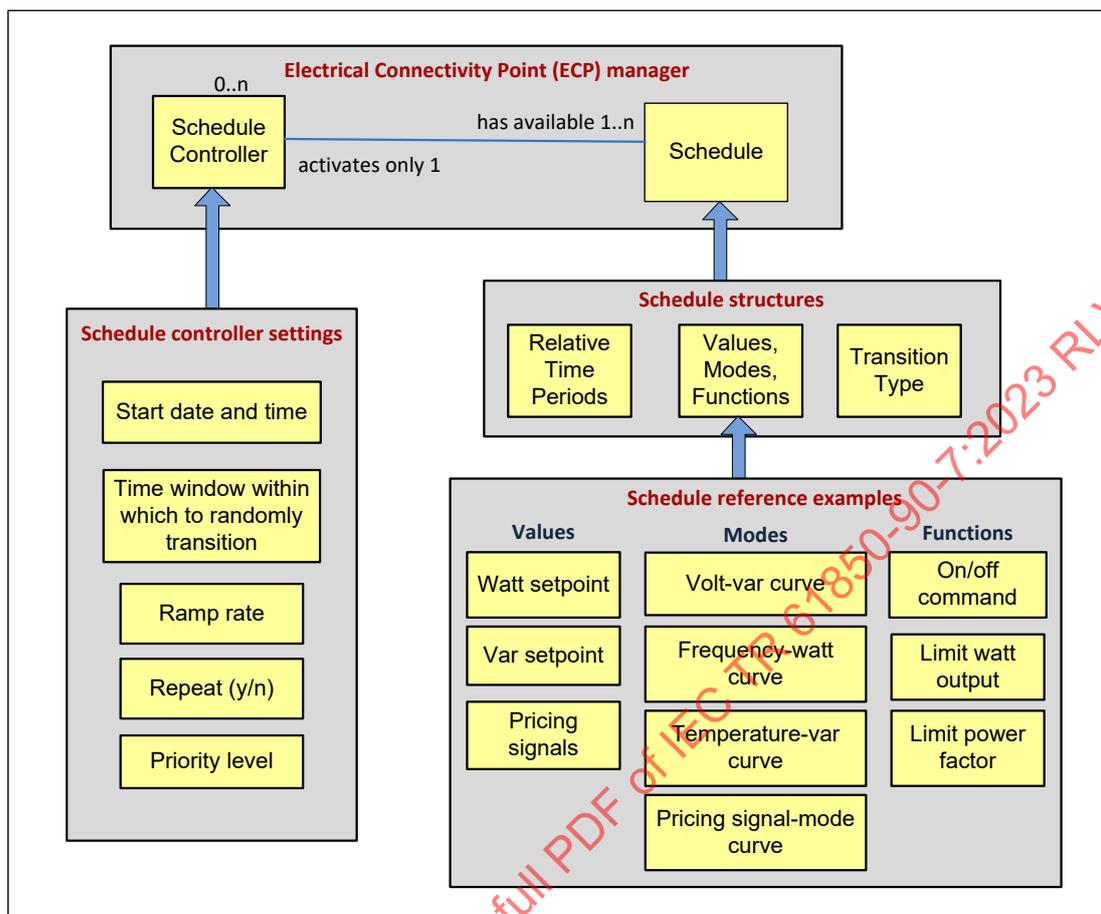
**Table 21 — LN DGSM — issue mode command**

<b>DGSM-class (new)</b>																								
<b>Data object name</b>	<b>Common data-class</b>	<b>Explanation</b>	<b>T</b>	<b>M/O/C</b>																				
<b>InCurve</b>	ORG	Reference to one curve, typically defined by one <b>FMAR</b> logical node		M																				
<b>ModEna</b>	SPC	Activate or deactivate the mode (function) associated with the curve ctlVal = off (FALSE)   on (TRUE) Status of the function stVal = off (FALSE)   on (TRUE)		M																				
<b>ModTyp</b>	ENG	Enumeration of mode types that require curves <table border="1" style="margin-left: 20px;"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>Not applicable / Unknown</td> </tr> <tr> <td>1</td> <td>None</td> </tr> <tr> <td>2</td> <td>Volt-var modes VV11 – VV12</td> </tr> <tr> <td>3</td> <td>Frequency-watt mode FW22</td> </tr> <tr> <td>4</td> <td>Watt-power-factor mode WP42</td> </tr> <tr> <td>5</td> <td>Voltage-watt modes VW51 – VW52</td> </tr> <tr> <td>6</td> <td>Remain connected</td> </tr> <tr> <td>7</td> <td>Temperature mode</td> </tr> <tr> <td>8</td> <td>Pricing signal mode</td> </tr> </tbody> </table>	Value	Explanation	0	Not applicable / Unknown	1	None	2	Volt-var modes VV11 – VV12	3	Frequency-watt mode FW22	4	Watt-power-factor mode WP42	5	Voltage-watt modes VW51 – VW52	6	Remain connected	7	Temperature mode	8	Pricing signal mode		M
Value	Explanation																							
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4	Watt-power-factor mode WP42																							
5	Voltage-watt modes VW51 – VW52																							
6	Remain connected																							
7	Temperature mode																							
8	Pricing signal mode																							
<b>WinTms</b>	ING	Time window (in seconds) within which to randomly execute a command. If the time window is zero, the command will be executed immediately		O																				
<b>RvrtTms</b>	ING	Timeout period (in seconds), after which the device will revert to its default status, such as closing the switch to reconnect to the grid or allowing maximum watts output, in case communications are lost or mitigating messages are not received		O																				
<b>RmpTms</b>	ING	Ramp time, in seconds, for moving from current operational mode settings to new operational mode settings		O																				

**8.6 — Schedules in IEC 61850**

**8.6.1 — Scheduling structures**

A schedule model consists of one logical node for the schedule controller and multiple instances of logical nodes for the schedules and for the curves. An instance of a schedule model exists at an ECP for each schedule established. The interrelationships of schedule controllers, schedules, and schedule references are shown in Figure 35.



IEC 448/13

**Figure 35 – Interrelationships of schedule controllers, schedules, and schedule references**

## 8.6.2 IEC 61850 models for Schedules

### 8.6.2.1 LN FSCH: Define the schedule

The new logical node FSCH that will be developed in IEC 61850-90-10 will replace the existing LN DSCH in IEC 61850-7-420:2009, since it is a more generic scheduling capability that is applicable not only to DER but other devices that use IEC 61850.

### 8.6.2.2 LN FSCC: Control schedules (schedule controller)

The new logical node FSCC that is planned to be developed in IEC 61850-90-10<sup>7</sup> will replace the existing LN DSCC in IEC 61850-7-420:2009 since it is a more generic scheduling control capability that is applicable not only to DER but other devices that use IEC 61850.

## 8.7 Immediate control functions in IEC 61850

### 8.7.1 IEC 61850 models for INV1: connect/disconnect

#### 8.7.1.1 Sequence of interactions

The following sequence of interactions takes place:

- (Optional) Set time window (see DOPM, *WinTms*)

<sup>7</sup> Under consideration.

- ~~(Optional) Set reversion timeout period (see DOPM, *RvrtTms*)~~
- ~~(Optional) Retrieve status of switch (retrieve CSWI, Pos, stVal)~~
- ~~(Mandatory) Issue control command (control CSWI, Pos, CtVal)~~
- ~~(Optional for broadcast control commands) Receive response to control command (receive CSWI, Pos, stVal)~~
- ~~(Optional for broadcast control commands) If message error, receive ServiceError information~~

### 8.7.1.2 IEC 61850 models – LN DOPM

The additions to the IEC 61850 LN-DOPM models are shown in Table 22:

**Table 22 – LN DOPM – operations**

DOPM class (adding objects to the existing logical node)				
Data object name	Common data class	Explanation	T	M/O/C
<i>WinTms</i>	ING	Time window (in seconds) within which to randomly execute a command. If the time window is zero, the command will be executed immediately		○
<i>RvrtTms</i>	ING	Timeout period (in seconds), after which the device will revert to its default status, such as closing the switch to reconnect to the grid or allowing maximum watts output, in case communications are lost or mitigating messages are not received		○
<i>RmpTms</i>	ING	Ramp time, in seconds, for moving from current operational mode settings to new operational mode settings		○
<i>OpModPrc</i>	SPC	Mode of operation – Pricing signal		○

- (1) ~~Issue open/close command to a physical switch via CtVal in LN CSWI that connects the DER to the grid at its ECP~~
- (2) ~~Receive response to the connect/disconnect command via StVal in LN CSWI, shown in Table 23:~~

**Table 23 – INV1 – LN CSWI – issue and respond to control**

CSWI class (existing in IEC 61850-7-4)				
Data object name	Common data class	Explanation	T	M/O/C
<i>Controls</i>				
Pos	DPC	Service parameter for Switch control action – in DPC: — CtVal (binary) = off (FALSE)   on (TRUE)  Switch control results – in DPC: — StVal (2-bit Enum) = intermediate-state   off   on   bad-state — q = quality — t = timestamp		M

### 8.7.2 IEC 61850 models for INV2: adjust maximum generation level up/down

#### 8.7.2.1 Sequence of interactions

This function sets the maximum generation level at the power converter’s electrical coupling point (ECP) as a percentage of set capacity (*WMax*). Setting the percentage to 100 % essentially ends the impact of this function.

The following sequence of interactions takes place:

- (Optional) Set time window (see DOPM, *WinTms*)
- (Optional) Set reversion timeout period (see DOPM, *RvrtTms*)
- (Optional) Set ramp time for moving from current generation level to adjusted maximum generation level, if needed. If combined with the time window, the ramp will start from the time when the command is actually executed. (set DOPM, *RmpTms*)
- (Optional) Retrieve reference active power (retrieve DRCT, *WMax*)
- (Mandatory) Issue control command to set percentage of reference active power to determine maximum output watts at power converter (set DRCT, *WMaxLimPct*)
- (Mandatory) Enable the function (set LN-DOPM-OpModConW)
- (Conditional: Mandatory, except optional for broadcast control commands) Receive response to control command (receive DRCT, *WMaxLimPct*)
- (Conditional: Mandatory, except optional for broadcast control commands) If message error, receive ServiceError information

This function may be deactivated by disabling OpModConW.

#### 8.7.2.2 IEC 61850 models

See Table 19 and Table 22 for the *DRCT* and *DOPM* models.

#### 8.7.3 IEC 61850 models for INV3: adjust power factor

##### 8.7.3.1 Sequence of interactions

Fixed power factor will be managed through issuing a command to set a power factor value. The following sequence of interactions takes place:

- (Optional) Set time window (see DOPM, *WinTms*)
- (Optional) Set reversion timeout period (see DOPM, *RvrtTms*)
- (Optional) Set ramp time for moving from current power factor to adjusted power factor. If combined with the time window, the ramp will start from the time when the command is actually executed. (set DOPM, *RmpTms*)
- (Optional) Set indication of what convention is being used for the power factor setting: overexcited/underexcited (set DRCT, *PFsign* and DRCT, *PFExt*)
- (Mandatory) Issue control command to set power factor (set DRCT, *OutPFSet*)
- (Mandatory) Enable the power factor function (set LN-DOPM-OpModConPF)
- (Optional for broadcast control commands) Receive response to control command (receive DRCT, *OutPFSet*)
- (Optional for broadcast control commands) If message error, receive ServiceError information

This function may be deactivated by disabling OpModConPF.

##### 8.7.3.2 IEC 61850 models

See Table 19 and Table 22 for the *DRCT* and *DOPM* models.

#### 8.7.4 IEC 61850 models for INV4: charge/discharge storage

##### 8.7.4.1 Sequence of interactions

This function requests the storage system to charge or discharge and at a specific rate (% of max charging rate). The following sequence of interactions takes place:

- ~~(Optional) Set time window (see DOPM, *WinTms*)~~
- ~~(Optional) Set reversion timeout period (see DOPM, *RvrtTms*)~~
- ~~(Optional) Set ramp time for moving from setpoint to adjusted setpoint. If combined with the time window, the ramp will start from the time when the command is actually executed. (set DOPM, *RmpTms*)~~
- ~~(Mandatory) Issue control command to set charge/discharge rate (set DRCT, *OutWRte*)~~
- ~~(Mandatory) Enable set charge/discharge rate (set LN-DOPM-OpModExIm)~~
- ~~(Optional for broadcast control commands) Receive response to control command (receive DRCT, *OutWRte*)~~
- ~~(Optional for broadcast control commands) If message error, receive ServiceError information~~

This function may be deactivated by disabling OpModExIm.

#### ~~8.7.4.2 IEC 61850 models~~

See Table 19 and Table 22 for the *DRCT* and *DOPM* models.

### ~~8.7.5 IEC 61850 models for INV5: pricing signal for charge/discharge of storage~~

#### ~~8.7.5.1 Sequence of interactions~~

This function provides a pricing signal (actual price or some relative pricing indication) from which the DER management system may decide whether to charge the storage or discharge the storage, and what charge/discharge rate to allow. The contents and meaning of the pricing signal is a local issue.

The following sequence of interactions takes place:

- ~~(Optional) Set time window (see DOPM, *WinTms*)~~
- ~~(Optional) Set reversion timeout period (see DOPM, *RvrtTms*)~~
- ~~(Optional) Set ramp time for moving from current power factor to adjusted power factor. If combined with the time window, the ramp will start from the time when the command is actually executed. (set DOPM, *RmpTms*)~~
- ~~(Mandatory) Set pricing signal (this information may eventually be a set of data objects defined outside of IEC 61850. For the purposes of IEC 61850, the pricing signal will be treated as a single code that may have implementation-specific or environment-specific meanings.) (see DCCT, *PrcCod*)~~
- ~~(Mandatory) Enable this function (set LN-DOPM-*OpModPrc*) (see Table 22)~~
- ~~(Optional for broadcast control commands) Receive acknowledgment of pricing signal~~
- ~~(Optional for broadcast control commands) If message error, receive ServiceError information~~

This function may be deactivated by disabling *OpModPrc*.

#### ~~8.7.5.2 IEC 61850 models~~

The IEC 61850 models use data objects in LN-DCCT and LN-DOPM (see Table 22).

## ~~8.8 — Volt-var management modes in IEC 61850~~

### ~~8.8.1 — IEC 61850 models for VV11 — VV12: volt-var curve settings~~

#### ~~8.8.1.1 — Sequence of interactions~~

~~Since utilities (and/or other energy service providers) will be requesting var support from many different power converter-based DER systems with different capabilities, different ranges, and different local conditions, it would be very demanding of the communications systems, unnecessary, and ultimately impossible for the utilities to issue explicit settings to each power converter-based DER system every time a change is desired.~~

~~All volt-var modes can be defined by what the different volt-var arrays contain although parameter-based modes may also be used if the var “curve” is flat (constant percentage). The curve-based volt-var modes are determined by setting the volt-var arrays, consisting of voltage values in the first array and corresponding var values in the second array. The first entry in the voltage array is the lowest voltage value, with the following array values having increasing voltage levels. The units for the var array are % of *WMax*, *VArMax*, or *VArAval*.~~

~~The sequence of interactions for all curve-based volt-var modes, using LN *DGSM* for curve-based commands and LN *FMAR* to provide the curves, is as follows:~~

- ~~• (Mandatory) Set one or more volt-var arrays. These volt-var arrays can be set and modified at any time (set *FMAR*, *PairArray*, with *DeptRef* set either to percent available vars (% of LN ZINV *VArAval*) or percent max vars (% of LN DRCT *VArMax*), and (*DGSM*, *WinTms* (Optional), *RmpTms* (Optional), *RvrtTms* (Optional)).~~
- ~~• (Mandatory) Update settings and issue activation command to use a specific volt-var array mode (setting *DGSM*, *ModTyp* = 2, *InCurve* = identity of the *FMAR* curve, *ModEna* = True). This mode can be combined with other (compatible) modes.~~
- ~~• (Optional for broadcasts) Receive response to activation command (receive *DGSM* *ModEna*).~~
- ~~• (Optional for broadcasts) If message error, receive ServiceError information~~

~~These curve-based modes may be deactivated by setting *ModEna* = False.~~

#### ~~8.8.1.2 — IEC 61850 models~~

~~See Table 20 and Table 21 for the *FMAR* and *DGSM* models.~~

## ~~8.8.2 — IEC 61850 models for VV13 — VV14: volt-var parameter settings~~

#### ~~8.8.2.1 — Sequence of interactions~~

~~Some volt-var modes can use the parameter approach since they involve “flat” curves of a constant percent of vars for all voltage levels. For these modes, the sequence of interactions is:~~

- ~~• (Mandatory) Set the appropriate percentage values in LN DRCT, respectively percent vars, percent maximum vars, or percent available vars: *VArWMaxPct*, *VArMaxPct*, or *VArAvalPct*. For VV14, this percentage is zero (0).~~
- ~~• (Optional) Set the time parameters in LN DOPM *WinTms*, *RmpTms*, *RvrtTms*~~
- ~~• (Mandatory) Select which volt-var type in LN DRCT *VArRef*~~
- ~~• (Mandatory) Enable the mode via LN DOPM *OpModConVar*~~
- ~~• (Optional for broadcasts) If message error, receive ServiceError information~~

~~These modes may be deactivated by disabling *OpModConVar*.~~

### ~~8.8.2.2 IEC 61850 models~~

~~See Table 19 and Table 22 for the DRCT and DOPM models.~~

## ~~8.9 Frequency-related modes in IEC 61850~~

### ~~8.9.1 IEC 61850 for FW21: frequency-driven active power modification~~

#### ~~8.9.1.1 Sequence of interactions~~

~~This function permits the utility, energy service provider, customer EMS, and/or other authorized entities to dynamically modify or update various parameters for the mode where frequency drives the active power response.~~

~~Two approaches to modelling this behaviour can be used: the parameter approach used in FW21, and the curve approach used in FW22.~~

#### ~~Parameter approach~~

~~One or more settings can be modified (and optionally read either before or after the setting) at any time. The following new settings are defined (see Table 24):~~

- ~~• (Mandatory) Enable mode of Active Power Reducing by Frequency. This setting will set the mode which is going to be used. (set **FWHZ**, **WCtIHzena**)~~
- ~~• (Mandatory) Set active power gradient. This setting will be applied for calculating new active power set points relating to current frequency. The setting value will be percents of the frozen active power per Hz. (set **FWHZ**, **WGra**)~~
- ~~• (Mandatory) Set delta frequency between stop frequency and nominal grid frequency. This setting will be applied for calculating new active power set points relating to current frequency. The setting value will be Hz. (set **FWHZ**, **HzStop**)~~
- ~~• (Mandatory) Set delta frequency between start frequency and nominal grid frequency. This setting will be applied for calculating new active power set points relating to current frequency. The setting value will be Hz. (set **FWHZ**, **HzStr**)~~
- ~~• (Mandatory) Set hysteresis. This setting will activate or deactivate the hysteresis. (set **FWHZ**, **HysEna**)~~
- ~~• (Optional) Set gradient for release of frozen value of snap shot function. This setting value will be % **WMax** per minute. (set **FWHZ**, **HzStopWGra**)~~

~~This mode may be deactivated by disabling **WCtIHzena**.~~

#### ~~8.9.1.2 IEC 61850 models – LN FWHZ~~

~~Table 24 describes the new **LN FWHZ** that provides the settings for power levels by frequency.~~

**Table 24 — LN-FWHZ — set power levels by frequency for FW21**

<i>FWHZ-class (new)</i>										
Data object name	Common data class	Explanation	T	M/O/C						
<i>Controls</i>										
<b>WCtHzEna</b>	SPC	Activation of the Active Power Reduction by Frequency function ctlVal = off (FALSE)   on (TRUE) Status of the function stVal = off (FALSE)   on (TRUE)		⊖						
<i>Settings</i>										
<b>WGra</b>	ASG	Active power gradient in percent of frozen active power value per Hz		⊖						
<b>HzStop</b>	ASG	Delta frequency between stop frequency and nominal grid frequency		⊖						
<b>HzStr</b>	ASG	Delta frequency between start frequency and nominal grid frequency		⊖						
<b>HysEna</b>	SPG	<table border="1"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>False</td> <td>No use of hysteresis</td> </tr> <tr> <td>True</td> <td>Use of hysteresis</td> </tr> </tbody> </table>	Value	Explanation	False	No use of hysteresis	True	Use of hysteresis		⊖
		Value	Explanation							
		False	No use of hysteresis							
True	Use of hysteresis									
<b>HzStopWGra</b>	ASG	The maximum rate at which the output may be increased after releasing the frozen value of snapshot function. This is represented in terms of % <b>WMax</b> per minute.		⊖						
<b>SnptW</b>	SPG	<table border="1"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>False</td> <td>Off, the snapshot is not active</td> </tr> <tr> <td>True</td> <td>Snapshot is active</td> </tr> </tbody> </table>	Value	Explanation	False	Off, the snapshot is not active	True	Snapshot is active		⊖
		Value	Explanation							
		False	Off, the snapshot is not active							
True	Snapshot is active									

### 8.9.2 — IEC 61850 for FW22: Frequency-watt mode FW22: generating/charging by frequency

#### 8.9.2.1 — Sequence of interactions

This function permits the utility, energy service provider, customer EMS, and/or other authorized entities to dynamically modify or update various parameters for the mode where frequency drives the active power response.

Two approaches to modelling this behaviour can be used: the parameter approach used in FW21, and the curve approach used in FW22.

#### Curve approach

The frequency-watt interactions can also be modelled as pairs of independent dependent variables, including hysteresis, using LN **DGSM** for curve-based commands and LN **FMAR** to provide the curves.

The sequence of interactions for all of the power converter Modes is as follows:

- (Mandatory) Set one or more frequency-watt arrays. These arrays can be set and modified at any time (set **FMAR**, **PairArray** (including hysteresis if required) and (**DGSM**, **WinTms** (Optional), **RmpTms** (Optional), **RvrtTms** (Optional))).

- ~~(Mandatory) Issue settings and activation command to use a specific frequency-watt mode (setting **DGSM**, **ModTyp** = 3, **InCurve** = identity of the **FMAR** curve, **ModEna** = True). This mode can be combined with other (compatible) modes~~
- ~~(Optional for broadcasts) Receive response to activation command (receive **DGSM ModEna**)~~
- ~~(Optional for broadcasts) If message error, receive ServiceError information~~

#### ~~8.9.2.2 IEC 61850 models~~

~~See Table 20 and Table 21 for the **FMAR** and **DGSM** models.~~

### ~~8.10 Voltage management modes in IEC 61850~~

#### ~~8.10.1 IEC 61850 for TV31: dynamic reactive current support~~

##### ~~8.10.1.1 Sequence of interactions~~

~~This function permits the utility, energy service provider, customer EMS, and/or other authorized entities to dynamically modify or update various parameters for the function Dynamic reactive current support.~~

~~One or more settings can be modified (and optionally read either before or after the setting) at any time. The following new settings are defined:~~

- ~~(Mandatory) Set mode of reactive current. This setting will set the mode which is going to be used. Either no reactive current will be feed in or additional reactive current or reactive current through the characteristic will be feed in. (set **RDGS**, **ArGraMod**)~~
- ~~(Optional) Set hysteresis voltage. This setting will be applied to all block zones. The setting value will be percents of the reference voltage (DRCT, **VRef**). (set **RDGS**, **HysBlkZnV**)~~
- ~~(Optional) Set gradient of reactive current for sags and for swells. These settings will be applied to the reactive current characteristic. The setting value will be without unit. (set **RDGS**, **ArGraSag** and **ArGraSwel**)~~
- ~~(Optional) Set block zone voltage. This setting will be applied to set the adjustable block zone. The setting value will be percents of the reference voltage (DRCT, **VRef**). (set **RDGS**, **BlkZnV**)~~
- ~~(Optional) Set block zone time. This setting will be applied to set the adjustable block zone. The setting value will be in milliseconds. (set **RDGS**, **BlkZnTmms**)~~
- ~~(Optional) Set hold time. This setting will be applied to set the hold time. The setting value will be in milliseconds. (set **RDGS**, **HoldTmms**)~~
- ~~(Optional) Set lower limit for voltage deadband. This setting will be applied to the reactive current characteristic. The setting value will be percents of the reference voltage (DRCT, **VRef**). (set **RDGS**, **DbVMin**)~~
- ~~(Optional) Set upper limit for voltage deadband. This setting will be applied to the reactive current characteristic. The setting value will be percents of the reference voltage (DRCT, **VRef**). (set **RDGS**, **DbVMax**)~~

##### ~~8.10.1.2 IEC 61850 models – LN RDGS~~

~~Table 25 describes the new **LN RDGS** that provides the settings for dynamic reactive current support functions.~~

**Table 25 – LN RDGS – dynamic reactive current support for TV31**

<i>RDGS-class (new)</i>										
<b>Data-object name</b>	<b>Common data-class</b>	<b>Explanation</b>	<b>T</b>	<b>M/O/C</b>						
<i>Status information</i>										
<b>LvrtSt</b>	SPS	When equals to TRUE, low-voltage-ride-through incident is occurring		Q						
<i>Settings</i>										
<b>ArGraMod</b>	ENG	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 <table border="1" data-bbox="644 674 1174 853"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Gradients trend toward zero at the deadband</td> </tr> <tr> <td>2</td> <td>Gradient trend toward zero at the centre</td> </tr> </tbody> </table>	Value	Explanation	1	Gradients trend toward zero at the deadband	2	Gradient trend toward zero at the centre		M
Value	Explanation									
1	Gradients trend toward zero at the deadband									
2	Gradient trend toward zero at the centre									
<b>ArGraSag</b>	ASG	Gradient for reactive current during a voltage sag (0 gradient implies no reactive current feed-in)		M						
<b>ArGraSwell</b>	ASG	Gradient for reactive current during a voltage swell (0 gradient implies no reactive current feed-in)		M						
<b>HysBlkZnV</b>	ASG	Hysteresis-voltage		Q						
<b>BlkZnV</b>	ASG	Block-zone voltage		Q						
<b>BlkZnTmms</b>	ING	Block-zone time (in milliseconds)		Q						
<b>FltTms</b>	ING	Filter time window for calculating moving average voltage		Q						
<b>HoldTmms</b>	ING	Hold time (in milliseconds)								
<b>DbVMin</b>	ASG	Lower limit, voltage dead-band		Q						
<b>DbVMax</b>	ASG	Upper limit, voltage dead-band		Q						
<i>Measured values</i>										
<b>DeIV</b>	MV	Delta-voltage		Q						
<b>VAv</b>	MV	Moving average voltage		Q						

**8.10.2 – IEC 61850 for “must disconnect”**

This function can be modelled by using the current PTUV and PTOV protection logical nodes which contain the disconnect curves and associated timing for disconnecting even if protective relays are not used.

**8.10.3 – IEC 61850 for “must remain connected”**

If the “dynamic reactive current support” and “must remain connected” functions are not based on the same settings, then **FMAR** and **DGSM** would be used to establish the limits for the dynamic reactive current support function and other power converter functions. The details of this modelling will be reviewed as this function is moved into the next edition of IEC 61850-7-420:2009.

## ~~8.11 — Watt-triggered behaviour modes in IEC 61850~~

### ~~8.11.1 — IEC 61850 for WP41 and WP42: feed-in watts control of power factor~~

#### ~~8.11.1.1 — Sequence of interactions~~

~~The amount of feed-in watts provided by the DER system at the ECP can be set to gradually modify the power factor.~~

~~Two approaches to modelling this behaviour can be used.~~

#### ~~Parameter approach: WP41~~

~~One or more settings can be modified (and optionally read either before or after the setting) at any time. The following new settings are defined (see Table 26):~~

- ~~• (Mandatory) Set power of start point. The setting value will be percents of the reference active power (DRCT, **WMax**). (set **FPFW**, **WStr**)~~
- ~~• (Mandatory) Set power of stop point. The setting value will be percents of the reference active power (DRCT, **WMax**). (set **FPFW**, **WStop**)~~
- ~~• (Mandatory) Set power factor of start point, (set **FPFW**, **PFStp**)~~
- ~~• (Mandatory) Set power factor of stop point, (set **FPFW**, **PFStop**)~~
- ~~• (Mandatory) Set excitation of start point, (set **FPFW**, **PFExtStr**)~~
- ~~• (Mandatory) Set excitation of stop point, (set **FPFW**, **PFExtStop**)~~
- ~~• (Optional) Set the time parameters in LN-DOPM **WinTms**, **RmpTms**, **RvrtTms**~~
- ~~• (Mandatory) Enable function, (set **FPFW**, **PFctIWEna**)~~

~~This mode may be deactivated by disabling **PFctIWEna**.~~

#### ~~Curve approach: WP42~~

~~The watts-PF interactions can also be modelled as pairs of independent-dependent variables, including hysteresis, using LN-**FMAR**.~~

~~The sequence of interactions for all of the power converter Modes is as follows:~~

- ~~• (Mandatory) Set one or more watts-PF arrays. These arrays can be set and modified at any time (set **FMAR**, **PairArray** (including hysteresis if required) and (**DGSM**, **WinTms** (Optional), **RmpTms** (Optional), **RvrtTms** (Optional))~~
- ~~• (Mandatory) Issue settings and activation command to use a specific watts-PF mode (setting **DGSM**, **ModTyp** = 4, **InCurve** = identity of the **FMAR** curve, **ModEna** = True). This mode can be combined with other (compatible) modes~~
- ~~• (Optional for broadcasts) Receive response to activation command (receive **DGSM** **ModEna**)~~
- ~~• (Optional for broadcasts) If message error, receive ServiceError information~~

~~This mode may be deactivated by disabling **ModEna**.~~

#### ~~8.11.1.2 — IEC 61850 models — LN-**FPFW**~~

~~The Table 26 describes the new LN-**FPFW** that covers setting the power factor based on watts output.~~

**Table 26 — LN FFW — set power factor by feed-in power for WP41**

<i>FFW-class (new)</i>										
Data object name	Common data class	Explanation	T	M/O/C						
<i>Controls</i>										
<b>PFctlWEna</b>	SPC	Activation of function—in SPC (can just be activated if no Power Factor Angle Mode or power converter Mode is active); ctlVal = off (FALSE)   on (TRUE) Status of the function stVal = off (FALSE)   on (TRUE)		M						
<i>Settings</i>										
<b>WStr</b>	ASG	Power of start point		M						
<b>WStop</b>	ASG	Power of stop point		M						
<b>PFStr</b>	ASG	Power factor of start point		M						
<b>PFStop</b>	ASG	Power factor of stop point		M						
<b>PFExtStr</b>	SPG	Excitation of start point		M						
			<table border="1"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>False</td> <td>Overexcited</td> </tr> <tr> <td>True</td> <td>Underexcited</td> </tr> </tbody> </table>		Value	Explanation	False	Overexcited	True	Underexcited
		Value	Explanation							
False	Overexcited									
True	Underexcited									
<b>PFExtStop</b>	SPG	Excitation of stop point		M						
			<table border="1"> <thead> <tr> <th>Value</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td>False</td> <td>Overexcited</td> </tr> <tr> <td>True</td> <td>Underexcited</td> </tr> </tbody> </table>		Value	Explanation	False	Overexcited	True	Underexcited
		Value	Explanation							
False	Overexcited									
True	Underexcited									

Also see Table 20 and Table 24 for the **FMAR** and **DGSM** models.

## 8.12 Voltage-watt management modes in IEC 61850

### 8.12.1 IEC 61850 for VW51: voltage-watt management in generation and charging

#### 8.12.1.1 Sequence of interactions

The voltage-watt interactions can also be modelled as pairs of independent-dependent variables, including hysteresis, using LN **FMAR**.

The sequence of interactions for all of the power converter Modes is as follows:

- (Mandatory) Set one or more voltage-watt arrays. These arrays can be set and modified at any time (set **FMAR**, **PairArray**, and (**DGSM**, **WinTms** (Optional), **RmpTms** (Optional), **RvrtTms** (Optional)).
- (Mandatory) Issue control command to use a specific voltage-watt mode (setting **DGSM**, **ModTyp** = 4, **InCurve** = identity of the **FMAR** curve, **ModEna** = True). This mode can be combined with other (compatible) modes.
- (Optional for broadcasts) Receive response to activation command (receive **DGSM** **ModEna**).
- (Optional for broadcasts) If message error, receive ServiceError information.

This mode may be deactivated by disabling **ModEna**.

### ~~8.12.1.2 IEC 61850 models~~

~~See Table 20 and Table 21 for the **FMAR** and **DGSM** models.~~

### ~~8.13 Non-power mode behaviours in IEC 61850~~

#### ~~8.13.1 IEC 61850 models for temperature mode TMP~~

~~The temperature mode invokes the temperature curve. In the temperature curve, the temperature is the independent variable of the curve, while the dependent value identifies the action to take. Actions can include functions, such as adjust power factor (INV3), or other modes, such as maximum var support mode (VV12).~~

~~The temperature function interactions can be modelled as pairs of independent dependent variables, including hysteresis, using LN **FMAR**.~~

~~The sequence of interactions for all of the power converter Modes is as follows:~~

- ~~• (Mandatory) Set one or more temperature arrays. These arrays can be set and modified at any time (set **FMAR**, **PairArray**, and (**DGSM**, **WinTms** (Optional), **RmpTms** (Optional), **RvrtTms** (Optional)).~~
- ~~• (Mandatory) Issue control command to use a specific temperature mode (setting **DGSM**, **ModTyp** = 6, **InCurve** = identity of the **FMAR** curve, **ModEna** = True). This mode can be combined with other (compatible) modes.~~
- ~~• (Optional for broadcasts) Receive response to activation command (receive **DGSM** **ModEna**).~~
- ~~• (Optional for broadcasts) If message error, receive ServiceError information.~~

~~See Table 20 and Table 21 for the **FMAR** and **DGSM** models.~~

~~This mode may be deactivated by disabling **ModEna**.~~

#### ~~8.13.2 IEC 61850 models for pricing signal mode PS~~

~~The pricing signal mode invokes the pricing signal curve. In the pricing signal curve, the pricing signal is the independent variable of the curve, while the dependent variable identifies the action to take. Actions can include functions, such as adjust maximum generation level (IN2), or other modes, such as frequency watt mode (FW21).~~

~~Multiple pricing signal curves can be established to reflect different energy and ancillary services. For instance, one pricing signal curve could be for watts, another for var support, and a third for frequency support. So long as they are not contradictory (e.g. two curves for watts), these modes can be activated for the same time periods.~~

~~The actual pricing signal would be received from an external source (e.g. broadcast by the utility/ESP) or from a schedule (e.g. pricing signal between 6 am and 2 pm, between 2 pm and 4:30 pm, and between 4:30 pm and 6 am). This pricing signal would be used with the activated curve to determine the DER response.~~

~~The sequence of interactions for all of the pricing modes is as follows:~~

- ~~• (Mandatory) Set one or more pricing arrays. These arrays can be set and modified at any time (set **FMAR**, **PairArray**, and (**DGSM**, **WinTms** (Optional), **RmpTms** (Optional), **RvrtTms** (Optional)).~~
- ~~• (Mandatory) Issue control command to use a specific pricing mode (setting **DGSM**, **ModTyp** = 7, **InCurve** = identity of the **FMAR** curve, **ModEna** = True). This mode can be combined with other (compatible) modes.~~

- ~~(Optional for broadcasts) Receive response to activation command (receive **DGSM ModEna**).~~
- ~~(Optional for broadcasts) If message error, receive ServiceError information~~

See Table 20 and Table 21 for the **FMAR** and **DGSM** models.

This mode may be deactivated by disabling **ModEna**.

## 8.14 IEC 61850 reporting commands

### 8.14.1 IEC 61850 models for DS91: modify DER settings

#### 8.14.1.1 Sequence of interactions

This function permits the utility, energy service provider, customer EMS, and/or other authorized entities to dynamically modify or update various parameters for power converter based DER systems.

One or more settings can be modified (and optionally read either before or after the setting) at any time. The following new settings are defined — many others already exist (see LN DRCT and other LNs in IEC 61850-7-420:2009):

- ~~(Optional) Set maximum intermittent ramp rate for power converter based DER system. This setting will limit the rate that watts delivery to the grid can increase or decrease in response to intermittent PV generation. The setting value will be percent of nominal ramping rate per minute. (set DRCT, **RmpRtePct**)~~
- ~~(Optional) Set storage reserve minimum, the minimum energy charge level allowed, as a percentage of maximum charge level (set DRCT, **MinRsvPct**)~~

#### 8.14.1.2 IEC 61850 models

The IEC 61850 models (see LN DRCT in Table 19) are as follows:

- 1) ~~Set maximum intermittent ramp rate, **RmpRtePct**.~~
- 2) ~~Set the minimum reserve for storage, **MinRsvPct**.~~

### 8.14.2 IEC 61850 models for DS92: event/history logging

#### 8.14.2.1 Log interactions

The specification calls for the ability to select specific types of event codes, based on a scheme being developed for IEC 61968 (CIM). However, at this time it is not fully developed and is not supported by IEC 61850. A simplified approach that is supported in the IEC 61850 standard is to establish multiple event logs for different users, each containing only events of interest to those users. Thus there could be a “utility/ESP” event log, a “customer EMS” event log, and a “maintenance” event log. The types of logs, the data object events captured as entries for each log, and the lengths of each log are implementation issues.

From an implementation view, the IEC 61850 log structure is a circular buffer consisting of 1..n entries, with new entries eventually overwriting older entries. However, this is hidden from the client. The client view of the log is a linear buffer, where the log entries are identified by:

- ~~EntryID: a unique numeric identifier (counter) of a log entry;~~
- ~~TimeOfEntry: the time when the log entry has been added to the log.~~

The log services include:

- ~~QueryLogByTime: Retrieve all log entries between a time range (RangeStartTime and RangeStopTime).~~

- ~~QueryLogAfter: Retrieve all log entries that are after the RangeStartTime.~~
- ~~GetLogStatusValues: Retrieve the log status values, such as the time of the oldest log entry, the time of the most recent log entry, etc.~~

~~Additional event log interactions can include:~~

- ~~Notification if event log is almost full or completely full without having been retrieved~~
- ~~Notification of an event log error~~

#### ~~8.14.2.2 IEC 61850 models~~

~~The basic contents of a log are shown in Table 27 (see 14.3 of IEC 61850-7-2:2010 for details).~~

**Table 27 – DS92 – IEC 61850 log structure**

Log class			
Attribute name	Attribute type	FC	Value/value range/explanation
LogName	ObjectName	-	Instance name of an instance of LOG
LogRef	ObjectReference	-	Path name of an instance of LOG
OldEntrTm	TimeStamp	LG	The attribute OldEntrTm shall indicate the time when the oldest log entry has been stored
NewEntrTm	TimeStamp	LG	The attribute NewEntrTm shall indicate the time when the newest log entry has been stored
OldEntr	INT32U	LG	The attribute OldEntr shall indicate the EntryID (an index into the circular file) for the oldest entry available in the log
NewEntr	INT32U	LG	The attribute NewEntr shall indicate the EntryID for the newest entry available in the log
Entry [1..n]			
TimeOfEntry	EntryTime		The attribute TimeOfEntry shall be the time, when the log entry is added to a LOG
EntryID	EntryID		The attribute EntryID shall be a unique reference to all log entries having the same value of TimeOfEntry
EntryData [1..n]			
DataRef	ObjectReference		
Value	(*)		(*) attribute type(s) depend on the definition of common data classes in IEC 61850-7-3
ReasonCode	TriggerConditions		The value range for reasons for inclusion shall be as listed: — data change (caused by TrgOp = dchg in an instance of DATA) — quality change (caused by TrgOp = qchg in an instance of DATA) — data update (caused by TrgOp = dupd in an instance of DATA) — integrity (caused by the attribute IntgPd in the LCB)

#### ~~8.14.3 IEC 61850 models for DS93: status reporting~~

##### ~~8.14.3.1 Sequence of interactions~~

~~The retrieval of status items may be undertaken using one or all of the following methods:~~

- ~~Single status values:~~
  - ~~On demand, request a single status value. That status value will then be returned to the requester.~~
  - ~~If event triggers have been established, upon a status value change or upon exceeding a deadband or upon exceeding a limit (depending upon the type of status point), that status value will be transmitted~~

● ~~Sets of status values:~~

- ~~— During initialization of the power converter based DER system, sets of status values can be assigned to one or more IEC 61850 “DataSets”. These DataSets can then be used in the following ways:~~
  - ~~On-demand, request one of these DataSets. All of the status values in the requested data set will be returned to the requester~~
  - ~~Periodically, all of the status values in each DataSets will be transmitted~~
  - ~~Upon change or upon exceeding a deadband or upon exceeding a limit of a status point in the DataSets, all of the status values in the affected DataSets will be transmitted~~
- ~~— After initialization, using IEC 61850 services, DataSets can be created, modified, and/or deleted, and the reporting triggers can be established (e.g. upon-demand, periodically, upon-change).~~

~~In the “on-demand” retrieval method, the following command and response actions are used:~~

1) ~~“On-demand” status~~

- a) ~~Status command~~
- b) ~~Identity of which status value or which data set~~

2) ~~Response to on-demand:~~

- a) ~~Requested status value(s)~~
- b) ~~Timestamp~~
- c) ~~Quality of status value(s)~~
- d) ~~Failed (plus reason: equipment not available, message error, security error)~~

~~For the other retrieval methods, the following “unsolicited” information is transmitted:~~

3) ~~Periodic or upon change of a status value:~~

- a) ~~Status value(s)~~
- b) ~~Timestamp~~
- c) ~~Quality of status value(s)~~

**8.14.3.2 IEC 61850 models – additions to LN-DRCS**

~~The data objects which were described in the functional descriptions are mapped to the following IEC 61850 LNs and data objects, found either in IEC 61850-7-4 or IEC 61850-7-420. Although these are specifically identified, there are no restrictions on accessing any data objects (consistent with security access restrictions).~~

~~The most efficient method for retrieving groups of data objects in IEC 61850 is the establishment of one or more data sets. These data sets can be pre-specified and/or can be specified remotely. These data sets can contain any combination of data objects, and therefore can be tailored to specific needs.~~

~~As shown in Table 28, additional status and measurement values are added to the LN-DRCS, which defines the state of one DER unit or aggregations of one type of DER system with a single controller.~~

**Table 28 – LN DRCS – DER state for DS93**

DRCS class (existing in IEC 61850-7-420: 2009)					
Data-object name	Common data-class	Explanation	T	M/O/C	
LNNName		Shall be inherited from logical-node class (see IEC 61850-7-2)			
<b>Data</b>					
<b>Status information</b>					
ModVAr	SPS	Yes/No, var management is available			
ChaSt	ENS	Charge status of a storage device:		O	
		<b>Value</b>			<b>Explanation</b>
		1			Off
		2			Fully discharged
		3			Discharging
		4			Charging
		5			Fully charged
		6			Holding
7	Testing				
<b>Measured and metered values</b>					
VAPct	MV	Actual percentage apparent power output based on VAMax		O	
VAChaPct	MV	Actual percentage charged based on VAChaMax		O	

Examples of existing status, settings, and measurement points that could be retrieved are shown in Table 29.

**Table 29 – DS93 – Status, settings, and measurement points**

Points	Description	LN	Data Object	CDC	
<b>Basic System State</b>					
Connect status	Status of the device's connect/disconnect switch	CSWI	Pos	DPC	
Local/Remote control mode	Power converter is under local control or can be remotely controlled	DRCS	Loc	SPS	
	<b>Value</b>				<b>Explanation</b>
	False				Local
	True	Remote is allowed			
<b>Power converter Information</b>					
PV power converter status	<b>Value</b>	ZINV (for PV)	GridModSt	ENS	
	0				Not applicable / Unknown
	1				Disconnected
	2				Power not delivered
	3				Power delivered
99	Other				

Points	Description		LN	Data Object	CDC
Storage power converter status	<b>Value</b>	<b>Explanation</b>	ZINV (for storage)	GridModSt	ENS
	0	Not applicable / Unknown			
	1	Disconnected			
	2	Power not delivered			
	3	Power delivered			
99	Other				
Type of DER system	Type of DER system		DRCT	DERTyp	ENG
Storage rating	Nominal energy rating of storage device		DRAT	<b>WHRtg</b>	ASG
Active power setpoint	Value of the active power setpoint		DRCT	MaxWLim	ASG
Reactive power setpoint	Value of the output reactive power setpoint		DRCT	MaxVArLim	ASG
Power factor setpoint	Value of the power factor setpoint		DRCT	<b>OutPFSet</b>	ASG
Frequency setpoint	Value of the frequency setpoint		DRCT	<b>HzStr</b>	ASG
Power converter active power output	Present active power output level (Watts)		MMXN	Watt	MV
Power converter reactive output	Present reactive power output level (VArS per convention indicated in PFExt). This is a signed quantity.		MMXN	VolAmpr	MV
DC Current level available for operation	Indicates whether or not there is sufficient DC current to allow operation.		MMDG	Amp	MV
DC power converter input power	Use for determining efficiency of power converter		MMDG	Watts	MV
Available vars	The amount of vars available without impacting watts output		ZINV	<b>VArAval</b>	MV
<b>Grid Information</b>					
Active power	Active power value, plus high and low limits		MMXU	TotW	MV
Reactive power	Reactive power value, plus high and low limits		MMXU	TotVAr	MV
Voltage	Voltage values per phase, plus high and low limits		MMXU	PhV	MV
Power factor	Power factor value, plus high and low limits		MMXU	TotPF	MV
<b>Battery Storage Information<sup>*)</sup></b>					
Capacity rating in amp-hours	The useable capacity of the battery, maximum charge minus minimum charge from a technology capability perspective (Amp-hour capacity rating)		ZBAT	AhrRtg	ASG
Internal battery voltage	Internal battery voltage		ZBAT	InBatV	MV
<b>Nameplate and Rating Information</b>					
Manufacturer name	Text string		LPHD	PhyNam	DPL
Model	Text string		LPHD	PhyNam	DPL
Serial number	Text string		LPHD	PhyNam	DPL
Power converter power rating	The continuous power output capability of the power converter (Watts)		ZINV	WRtg	ASG
Power converter VA rating	The continuous Volt-Amp capability of the power converter (VA)		ZINV	<b>VARtg</b>	ASG

Points	Description	LN	Data Object	CDC
Power converter VAR rating	Maximum continuous var capability of the power converter (VAR)	ZINV	VARrtg	ASG
PV present indicator	Indication of whether or not PV is part of this system.	DRCT	DERtyp	ENG
Storage present indicator	Indication of whether or not storage is part of this system.	DRCT	DERtyp	ENG
Time Synchronization Information				
Time resolution	Time resolution and precision: Number of significant bits in the Fraction-Of-Second in the time accuracy part of the time stamp. See IEC 61850-7-2.	LTMS	TmAcc	INS
Source of time synchronization	Text string	LTMS	TmSrc	VSS
a) The complete model of battery storage will be found in IEC 61850-90-9. If there is a discrepancy, IEC 61850-90-9 will take precedence.				

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~~IEC TR 61850-90-9, *Communication networks and systems for power utility automation - Part 90-9: Use of IEC 61850 for Electrical Energy Storage Systems*~~

~~IEEE 1547-2018, *IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*~~

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~~<sup>8</sup> Under consideration.~~

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# TECHNICAL REPORT



**Communication networks and systems for power utility automation –  
Part 90-7: Object models for power converters in distributed energy resources  
(DER) systems**

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## CONTENTS

FOREWORD.....	5
1 Scope.....	7
2 Normative references .....	7
3 Terms, definitions, acronyms and abbreviated terms .....	7
3.1 Terms and definitions.....	8
3.2 Acronyms.....	10
3.3 Abbreviated terms.....	10
4 Overview of power converter-based DER functions.....	11
4.1 General.....	11
4.2 Power converter configurations and interactions .....	12
4.3 Power converter methods .....	14
4.4 Power converter functions.....	15
4.5 Differing DER architectures.....	16
4.5.1 Conceptual architecture: electrical coupling point (ECP).....	16
4.5.2 Conceptual architecture: point of common coupling (PCC).....	16
4.5.3 Utility interactions directly with power converters or indirectly via a customer EMS .....	17
4.5.4 Communication profiles .....	17
4.6 General sequence of information exchange interactions.....	18
5 Concepts and constructs for managing power converter functions .....	19
5.1 Basic settings of power converters.....	19
5.1.1 Nameplate values versus basic settings .....	19
5.1.2 Power factor and power converter quadrants .....	19
5.1.3 Maximum watts, vars, and volt-amp settings .....	21
5.1.4 Active power ramp rate settings .....	22
5.1.5 Voltage phase and correction settings .....	23
5.1.6 Charging settings.....	23
5.1.7 Example of basic settings .....	23
5.1.8 Basic setting process.....	24
5.2 Modes for managing autonomous behaviour .....	24
5.2.1 Benefits of modes to manage DER at ECPs.....	24
5.2.2 Modes using curves to describe behaviour .....	25
5.2.3 Paired arrays to describe mode curves .....	26
5.2.4 Percentages as size-neutral parameters: voltage and var calculations.....	27
5.2.5 Hysteresis as values cycle within mode curves .....	27
5.2.6 Low pass exponential time rate.....	28
5.2.7 Ramp rates.....	29
5.2.8 Randomized response times.....	29
5.2.9 Timeout period .....	30
5.2.10 Multiple curves for a mode.....	30
5.2.11 Multiple modes .....	30
5.2.12 Use of modes for loosely coupled, autonomous actions .....	30
5.3 Schedules for establishing time-based behaviour.....	30
5.3.1 Purpose of schedules .....	30
5.3.2 Schedule components .....	31
6 DER management functions for power converters.....	32
6.1 Immediate control functions for power converters .....	32

6.1.1	General .....	32
6.1.2	Function INV1: connect / disconnect from grid .....	33
6.1.3	Function INV2: adjust maximum generation level up/down .....	33
6.1.4	Function INV3: adjust power factor .....	34
6.1.5	Function INV4: request active power (charge or discharge storage).....	34
6.1.6	Function INV5: pricing signal for charge/discharge action .....	35
6.2	Modes for volt-var management .....	36
6.2.1	VAr management modes using volt-var arrays .....	36
6.2.2	Example setting volt-var mode VV11: available var support mode with no impact on watts.....	37
6.2.3	Example setting volt-var mode VV12: maximum var support mode based on WMax.....	38
6.2.4	Example setting volt-var mode VV13: static power converter mode based on settings .....	40
6.2.5	Example setting volt-var mode VV14: passive mode with no var support.....	41
6.3	Modes for frequency-related behaviours .....	41
6.3.1	Frequency management modes .....	41
6.3.2	Frequency-watt mode FW21: high frequency reduces active power .....	42
6.3.3	Frequency-watt mode FW22: constraining generating/charging by frequency .....	44
6.4	Dynamic reactive current support during abnormally high or low voltage levels .....	47
6.4.1	Purpose of dynamic reactive current support .....	47
6.4.2	Dynamic reactive current support mode TV31: support during abnormally high or low voltage levels .....	47
6.5	Low/high voltage ride-through curves for “must disconnect” and “must remain connected” zones .....	51
6.5.1	Purpose of L/HVRT .....	51
6.5.2	“Must disconnect” (MD) and “must remain connected” (MRC) curves .....	51
6.6	Modes for watt-triggered behaviours .....	53
6.6.1	Watt-power factor mode WP41: feed-in power controls power factor .....	53
6.6.2	Alternative watt-power factor mode WP42: feed-in power controls power factor .....	53
6.7	Modes for voltage-watt management.....	54
6.7.1	Voltage-watt mode VW51: voltage-watt management: generating by voltage .....	54
6.7.2	Voltage-watt mode VW52: voltage-watt management: charging by voltage .....	54
6.8	Modes for behaviours triggered by non-power parameters .....	55
6.8.1	Temperature mode TMP .....	55
6.8.2	Pricing signal mode PS.....	55
6.9	Setting and reporting functions .....	56
6.9.1	Purpose of setting and reporting functions .....	56
6.9.2	Establishing settings DS91: modify power converter-based DER settings.....	56
6.9.3	Event logging DS92: log alarms and events, retrieve logs.....	56
6.9.4	Reporting status DS93: selecting status points, establishing reporting mechanisms .....	60
	Bibliography.....	62

Figure 1 – DER management hierarchical interactions: autonomous, loosely-coupled, broadcast/multicast.....	14
Figure 2 – Electrical Connection Points (ECP) and Point of Common Coupling (PCC) .....	17
Figure 3 – Producer and Consumer Reference Frame conventions .....	20
Figure 4 – EEI power factor sign convention .....	21
Figure 5 – Working areas for different modes.....	22
Figure 6 – Example of voltage offsets ( $V_{RefOfs}$ ) with respect to the reference voltage ( $V_{Ref}$ ).....	23
Figure 7 – Example of modes associated with different ECPs .....	25
Figure 8 – Example of a volt-var mode curve .....	26
Figure 9 – Example of hysteresis in volt-var curves.....	28
Figure 10 – Example of deadband in volt-var curves .....	28
Figure 11 – Local function block diagram .....	29
Figure 12 – Time domain response of first order low pass filter.....	29
Figure 13 – Interrelationships of schedule controllers, schedules, and schedule references .....	32
Figure 14 – Volt-var mode VV11 – available vars mode .....	37
Figure 15 – Power converter mode VV12 – Maximum var support mode based on $W_{Max}$ .....	39
Figure 16 – Power converter mode VV13 – Example: static var support mode based on $V_{ArMax}$ .....	40
Figure 17 – Frequency-watt mode curves.....	42
Figure 18 – Frequency-based active power reduction .....	43
Figure 19 – Frequency-based active power modification with the use of an array.....	44
Figure 20 – Example of a basic frequency-watt mode configuration .....	45
Figure 21 – Example array settings with hysteresis .....	46
Figure 22 – Example of an asymmetrical hysteresis configuration.....	46
Figure 23 – Example array configuration for absorbed watts vs. frequency .....	47
Figure 24 – Basic concepts of the dynamic reactive current support function .....	48
Figure 25 – Calculation of delta voltage over the filter time window.....	48
Figure 26 – Activation zones for dynamic reactive current support .....	49
Figure 27 – Alternative gradient behaviour, selected by ArGraMod .....	50
Figure 28 – Settings to define a blocking zone .....	50
Figure 29 – Must disconnect and must remain connected zones .....	52
Figure 30 – Examples of “must remain connected” requirements for different regions .....	52
Figure 31 – Power factor controlled by feed-in power.....	53
Figure 32 – Example configuration curve for maximum watts vs. voltage .....	54
Figure 33 – Example configuration curve for maximum watts absorbed vs. voltage .....	55
Table 1 – Producer Reference Frame (PRF) conventions.....	19
Table 2 – Example basic settings for a storage DER unit .....	24
Table 3 – Events.....	58
Table 4 – Examples of status points.....	60

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**COMMUNICATION NETWORKS AND SYSTEMS  
FOR POWER UTILITY AUTOMATION –****Part 90-7: Object models for power converters  
in distributed energy resources (DER) systems**

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IEC TR 61850-90-7 has been prepared by IEC technical committee 57: Power systems management and associated information exchange. It is a Technical Report.

This second edition cancels and replaces the first edition published in 2013. This edition is primarily an editorial revision in order to be consistent with the publication of Edition 2 of IEC 61850-7-420:2021.

This edition includes the following significant changes with respect to the previous edition:

- a) Clause 3 has been updated.
- b) Clause 8 (IEC 61850 information models for power converter-based functions) has been deleted. This clause defined data models with the transitional namespace “(Tr) IEC 61850-90-7:2012”. The data models are now defined in IEC 61850-7-420.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
57/2558/DTR	57/2610/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at [www.iec.ch/members\\_experts/refdocs](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/publications](http://www.iec.ch/publications).

A list of all parts of the IEC 61850 series, under the general title *Communication networks and systems for power utility automation*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under [webstore.iec.ch](http://webstore.iec.ch) in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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# COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

## Part 90-7: Object models for power converters in distributed energy resources (DER) systems

### 1 Scope

This part of IEC 61850, which is a Technical Report, describes functions for power converter-based distributed energy resources (DER) systems, focused on DC-to-AC and AC-to-AC conversions and including photovoltaic systems (PV), battery storage systems, electric vehicle (EV) charging systems, and any other DER systems with a controllable power converter.

The functions defined in this document were used to help define the information models described in IEC 61850-7-420 and which can be used in the exchange of information between these power converter-based DER systems and the utilities, energy service providers (ESPs), or other entities which are tasked with managing the volt, var, and watt capabilities of these power converter-based systems.

These power converter-based DER systems can range from very small grid-connected systems at residential customer sites, to medium-sized systems configured as microgrids on campuses or communities, to very large systems in utility-operated power plants, and to many other configurations and ownership models. They may or may not combine different types of DER systems behind the power converter, such as a power converter-based DER system and a battery that are connected at the DC level.

NOTE The term power converter is being used in place of “inverter” since it covers more types of conversion from input to output power:

- AC to DC (rectifier)
- DC to AC (inverter)
- DC to DC (DC-to-DC converter)
- AC to AC (AC-to-AC converter)

### 2 Normative references

There are no normative references in this document.

### 3 Terms, definitions, acronyms and abbreviated terms

For the purposes of the present document, the following terms, definitions, acronyms and abbreviated terms apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

### 3.1 Terms and definitions

#### 3.1.1

##### **autonomous automatic operation**

operating mode in which all functions of the control equipment are performed without action of a human operator

[SOURCE: IEC 60050-351:2013, 351-55-03]

#### 3.1.2

##### **distributed energy resource DER**

energy resource comprised of generation and/or storage and/or controllable load connected at the low or medium voltage distribution level

Note 1 to entry: DER may include associated protection, control, and monitoring capabilities, and may consist of aggregated DER units.

Note 2 to entry: DER may interact with the area and/or local electric power systems (EPS) by providing energy through the EPSs, by adapting their behaviour based on EPS conditions, and/or by providing other EPS-related services for regulatory, contractual, or market reasons.

[SOURCE: IEC 61850-7-420:2021, 3.1.13]

#### 3.1.3

##### **electrical connection point ECP**

point of electrical connection between the DER and any electric power system (EPS)

Note 1 to entry: Each DER (generation or storage) unit has an ECP connecting it to its local power system; groups of DER units have an ECP where they interconnect to the power system at a specific site or plant; a group of DER units plus local loads have an ECP where they are interconnected to the utility power system.

Note 2 to entry: For those ECPs between a utility EPS and a plant or site EPS, this point is identical to the point of common coupling (PCC) in the IEEE 1547 *Standard for Interconnecting Distributed Resources with Electric Power Systems*.

[SOURCE: IEC 61850-7-420:2021, 3.1.17]

#### 3.1.4

##### **electric power system EPS**

composite, comprised of one or more generating sources, and connecting transmission and distribution facilities, operated to supply electric energy

Note 1 to entry: A specific electric power system includes all installations and plant, within defined bounds, provided for the purpose of generating, transmitting and distributing electric energy.

[SOURCE IEC 60050-692:2017, 692-01-02]

#### 3.1.5

##### **electric power system, area area EPS**

electric power system that serves multiple local electric power systems

Note 1 to entry: A typical area EPS is a MV/LV distribution network.

[SOURCE: IEEE 1547:2018, modified - addition of Note 1 to entry]

**3.1.6**  
**event**  
**event information**

monitored information on the change of state of operational equipment

Note 1 to entry: In power system operations, an event is typically state information and/or state transition (status, alarm, or command) reflecting power system conditions.

[SOURCE: IEC 60050-371:1984, 371-02-04, modified – addition of term "event" and Note 1 to entry]

**3.1.7**  
**process control function**

function to work on process variable quantities, which is composed of basic functions of process control, specific to particular functional units of the plant

[SOURCE: IEC 60050-351:2013, 351-55-16, modified - deletion of Note 1 to entry]

**3.1.8**  
**generator**

energy transducer that transforms non-electric energy into electric energy

Note 1 to entry: The reverse conversion of electrical energy into mechanical energy is done by an electric motor, and motors and generators have many similarities. The source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a hydropower turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, or any other source of mechanical energy.

[SOURCE: IEC 60050-151:2001, 151-13-35, modified - addition of Note 1 to entry]

**3.1.9**  
**inverter**

electric energy converter that changes direct electric current to single-phase or polyphase alternating currents

[SOURCE: IEC 60050-151:2001, 151-13-46]

**3.1.10**  
**monitor**

acquire a quantity value continuously or sequentially in order to check whether it is within normal operating limits and, where appropriate, to signal if it passes its tolerance boundaries

[SOURCE: IEC 60050-351:2013, 351-43-03]

**3.1.11**  
**point of common coupling**  
**PCC**

electrical connection point (ECP) in an electric power system, electrically nearest to a particular load or generator, at which other loads or generators are, or may be, connected

Note 1 to entry: These loads can be either devices, equipment or systems, or distinct network users' installations.

Note 2 to entry: The point where a local EPS is connected to an area EPS [IEEE 1547]. The local EPS may include distributed energy resources.

[SOURCE: IEC 61850-7-420:2021, modified – addition of "connection"]

**3.1.12****power converter**

electronic equipment that converts:

- AC to DC (rectifier)
- DC to AC (inverter)
- DC to DC (DC-to-DC converter)
- AC to AC (AC-to-AC converter)

**3.2 Acronyms**

DER:	Distributed Energy Resource
ECP:	Electrical Connection Point
EEL:	Edison Electric Institute
EMS:	Energy Management System
EPS:	Electric Power System
ESP:	Energy Service Provider
ISO:	Independent System Operator
L/HRVT:	Low/High Voltage Ride-Through
MMS:	Manufacturing Message Specification
PCC:	Point of Common Coupling
PF:	Power Factor
PV:	Photovoltaic
RTO:	Regional Transmission Operator
TSO:	Transmission System Operator

**3.3 Abbreviated terms**

Clause 4 of IEC 61850-7-4 defines abbreviated terms for building concatenated data names. Additional abbreviated terms used in this document are:

Ar	Amperes reactive
Array	Array of ...
Aval	Available
Db	Deadband
Dec	Decrease
Del	Delta
Dept	Dependent
Dsct	Disconnect
Gra	Gradient
Hold	Hold
Hys	Hysteresis
Inc	Increase
Rcnt	Reconnect
Sag	Sag
Snpt	Snapshot
Swell	Swell

## 4 Overview of power converter-based DER functions

### 4.1 General

The advent of decentralized electric power production is a reality in the majority of the power systems of the world, driven by the need for new types of energy converters to mitigate the heavy reliance on non-renewable fossil fuels, by the increased demand for electrical energy, by the development of new technologies of small power production, by the deregulation of energy markets, and by increasing environmental constraints.

The numbers of interconnected DER systems are increasing rapidly. The advent of decentralized electric power production is a reality in the majority of power systems all over the world, driven by many factors:

- The need for new sources of energy to mitigate the heavy reliance on externally-produced fossil fuels.
- The requirements in many countries for renewable portfolios that have spurred the movement toward renewable energy sources such as solar and wind, including tax breaks and other incentives for utilities and their customers.
- The development of new technologies of small power production that have made, and are continuing to improve, the cost-effectiveness of small energy devices.
- The trend in deregulation down to the retail level, thus incentivizing energy service providers to combine load management with generation and energy storage management.
- The increased demand for electrical energy, particularly in developing countries, but also in developed countries for new requirements such as Electric Vehicles (EVs).
- The constraints on building new transmission facilities and increasing environmental concerns that make urban-based generation more attractive.

These pressures have greatly increased the demand for Distributed Energy Resource (DER) systems that consist of both generation and energy storage systems which are interconnected with the distribution power systems.

DER systems challenge traditional power system management. These increasing numbers of DER systems are also leading to pockets of high penetrations of these variable and often unmanaged sources of power which impact the stability, reliability, and efficiency of the power grid. DER systems can be no longer viewed only as “negative load” and therefore insignificant in power system planning and operations. Their unplanned locations, their variable sizes and capabilities, and their fluctuating responses to both environmental and power situations make them difficult to manage, particularly as greater efficiency and reliability of the power system is being demanded.

At the same time, DER systems could become very powerful tools in managing the power system for reliability and efficiency. The majority of DER systems use power converters to convert their primary electrical form (often direct current (DC) or non-standard frequency) to the utility power grid standard electrical interconnection requirements of 60 Hz or 50 Hz and alternating current (AC). In addition to these basic conversions, power converters can readily modify many of their electrical characteristics through software settings and commands, so long as they remain within the capabilities of the DER system that they are managing and within the standard requirements for interconnecting the DER to the power system.

DER systems are becoming quite “smart” and can perform “autonomously”<sup>1</sup> most of the time according to pre-established settings or “operating modes”, while still responding to occasional commands to override or modify their autonomous actions by utilities and/or energy service providers (ESPs). DER systems can “sense” local conditions of voltage levels, frequency

---

<sup>1</sup> Not controlled by others or by outside forces; independent. This word is used in the definition of “distributed process computer system” as a “set of spatial distributed process computer systems for the monitoring and control of basically autonomous sub-processes” (IEC 60050-351:2006, 351-30-05).

deviations, and temperature, and can receive emergency commands and pricing signals, which allow them to modify their power and reactive power output. These autonomous settings can be updated as needed. To better coordinate these DER autonomous capabilities while minimizing the need for constant communications, utilities and ESPs can also send schedules of modes and commands for the DER systems to follow on daily, weekly, and/or seasonal timeframes.

Given these sophisticated capabilities, utilities and energy service providers (ESPs) are increasingly desirous (and even mandated by some regulations) to make use of these capabilities to improve power system reliability and efficiency. Several countries are using the concept of "operating envelopes" that define upper and lower limits on the import or export power in a given time interval for specific connection points. The DER systems are then responsible for applying appropriate limits to individual energy resources.

None of the functions described in this document are necessarily "mandatory" from an implementation perspective – actually requiring certain functions to be implemented is the purview of regulators and of the purchasers of systems.

#### 4.2 Power converter configurations and interactions

Bulk power generation is generally managed directly, one-on-one, by utilities. This approach is not feasible for managing thousands if not millions of DER systems.

DER systems cannot and should not be managed in the same way as bulk power generation. New methods for handling these dispersed sources of generation and storage must be developed, including both new power system functions and new communication capabilities. In particular, the "smart" capabilities of power converter-based DER systems must be utilized to allow this power system management to take place at the lowest levels possible, while still being coordinated from region-wide and system-wide utility perspectives.

This "dispersed, but coordinated intelligence" approach permits far greater efficiencies, reliability, and safety through rapid, autonomous DER responses to local conditions, while still allowing the necessary coordination as broader requirements can be addressed through communications on an as-needed basis.

Communications, therefore, play an integral role in managing the power system, but are not expected or capable of continuous monitoring and control. Therefore the role of communications must be modified to reflect this reality.

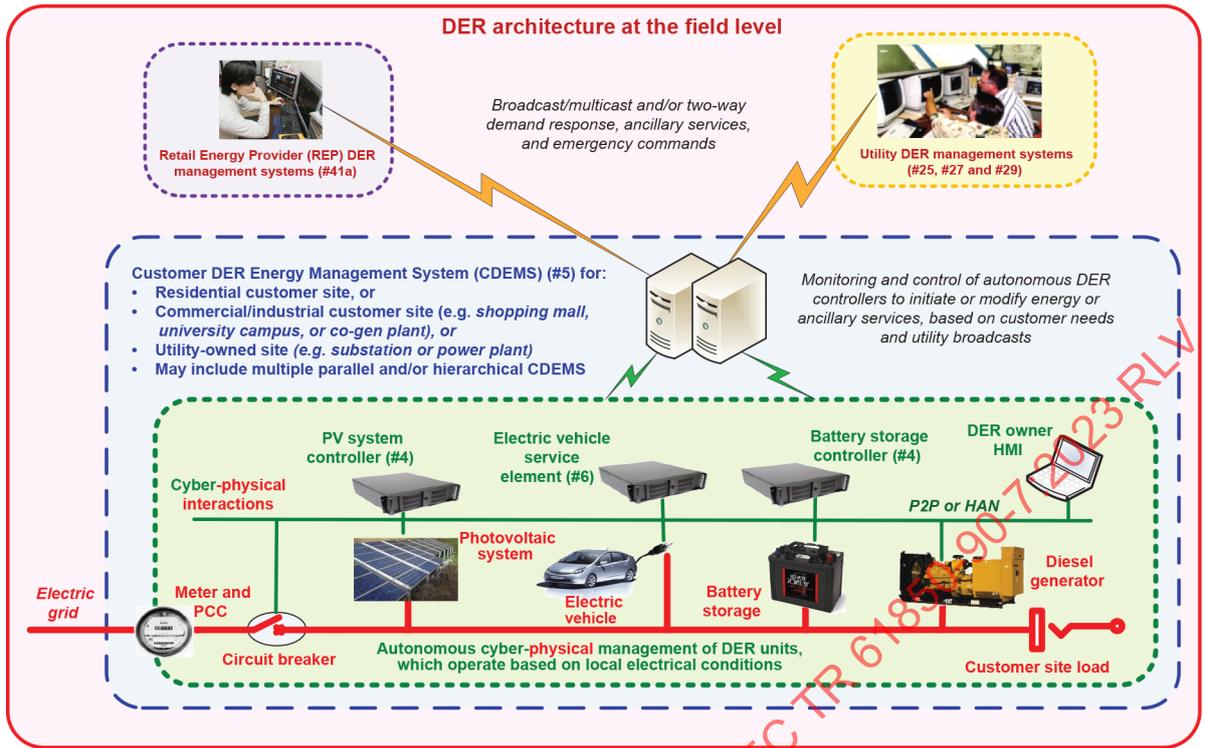
Power converter-based DER functions range from the simple (turn on/off, limit maximum output) to the quite sophisticated (volt-var control, frequency/watt control, and low-voltage ride-through). They also can utilize varying degrees of autonomous capabilities to help cope with the sophistication.

At least three levels of information exchanges are envisioned:

- a) Autonomous DER behaviour responding to local conditions with controllers focused on direct and rapid monitoring and control of the DER systems: This autonomous behaviour would use one or more of the pre-set modes and/or schedules to direct their actions, thus not needing remote communications except occasionally to modify which modes or schedules to use.
  - Autonomous behaviour is defined as DER systems utilizing pre-set modes and schedules that respond to locally sensed conditions, such as voltage, frequency, and/or temperature, or to broadcast information, such as pricing signals or requests for using specific modes. These pre-settings are updated as needed (not in real-time), possibly through the Internet or through other communication methods.
  - The DER systems would utilize its detailed knowledge of the status and capabilities of the DER equipment as well as the status of the local electric power grid, such as voltage and frequency, to determine the output from the DER system.

- Common types of autonomous DER systems consist of the controllers that directly manage one or more power converters, such as a small PV system, a battery storage system, an electric vehicle service element (EVSE), and each of the individual DER systems within an office building, a wind farm, or a microgrid.
  - Interaction times are millisecond to seconds.
- b) DER management system interactions with multiple DER systems in which the DER management system has a more global vision of all the DER systems under its control. It understands the overall capabilities of the DER systems under its management but may not have (or need) detailed data.
- DER management systems can issue direct commands but they primarily establish the autonomous settings for each DER system.
  - On start-up, the DER management system may provide various possible autonomous mode settings to each of the DER systems, and then over time modify which of these autonomous mode settings are active, possibly in response to utility requests or pricing signals.
  - Common scenarios include a campus DER management system coordinating many DER systems on different buildings or an energy service provider managing disparate DER systems within a community.
  - Additional scenarios include an ISO/RTO/TSO managing a large storage device through Automatic Generation Control (AGC) or requesting a specific power factor at the PCC of a wind farm.
  - A microgrid scenario would include a microgrid management system managing the intentional islanding of the microgrid and then coordinating the generation, storage, and load elements to maintain microgrid stability through the combination of setting autonomous modes for some DER systems and issuing direct commands to other DER systems.
  - Interaction frequency may be seconds to minutes, hours, or even weeks.
- c) Broadcast/multicast consist essentially of one-way notifications without one-to-one communications with large numbers of DER systems. These notifications could be emergency signals, pricing signals, or requests for specific DER modes. Typically these would come from utilities and/or Energy Service Provider (ESP).
- No direct responses from the DER systems would be expected. If there were power system changes expected, these would be monitored elsewhere, such as on the feeder or in a substation. If there were financial implications to the broadcast/multicast request, the DER system responses would be determined during the billing and settlements process.
  - These broadcast or multicast requests may be to DER management systems or to individual DER systems.
  - These broadcast/multicast requests would be interpreted by the DER systems as possible modifications of their current autonomous behaviour or could be direct commands for response to emergency situations.
  - Since broadcast/multicast can be used to request actions without necessarily knowing which DER systems can or will respond, the expectation could be that only a certain percentage will respond.
  - Common scenarios include an energy service provider broadcasting a pricing signal, which is then reacted to by the individual DER systems, or a utility multicasting a reduction in generation to all DER systems on a constrained feeder that cannot handle reverse power flows.
  - Broadcast/multicast frequency may be hours, weeks, or seasons.

These hierarchical DER management interactions are shown in Figure 1.



**Figure 1 – DER management hierarchical interactions: autonomous, loosely-coupled, broadcast/multicast**

### 4.3 Power converter methods

DER power converters and their controllers can perform many autonomous functions, based on their intrinsic capabilities, various parameter settings, and locally measured conditions, such as voltage levels, frequency, rates of changes in voltage and frequency, temperature, and other information.

The methods for power converters to manage their autonomous behaviour include the following:

- “Modes” consist of pre-established groups of settings that can enable autonomous DER behaviour, where the DER senses local conditions, and, using those mode settings, responds appropriately. This approach minimizes the communications requirements and permits more rapid responses. “Modes” can be established for volt-var control, frequency-watt control, charging/discharging storage, and some other complex actions, where the arrays and parameters for each mode are sent ahead of time – maybe once a year or season, and then “go to mode” commands/requests can be broadcast/multicast.
- Schedules can also be established, which can operate for a specific time period or indefinitely (once initiated) completely autonomously. For instance, a schedule can establish what modes to use during weekday mornings, versus mid-afternoon, versus weekends.
- Temperature-based curves and pricing-signal curves provides settings for what actions to take based on the current temperature or pricing signal. A pricing signal curve can indicate which mode(s) to go to, based on the pricing signal level (can be \$\$, but can also be tiers, or H-M-L, or other signal). When a new pricing signal is broadcast, the DERs can ramp to the specified modes. There can even be a schedule of pricing signals so that they do not need to be broadcast, unless an emergency calls for a different level.
- Ramp rates and parameters based on “% of capability” (rather than absolute amounts) are also included. In addition there is a time-window randomization that requires DERs to respond to commands using a random number within the time window to actually initiate the command. This prevents sharp jumps whenever a new command/request/pricing signal is broadcast. (Obviously the time window can be set to zero if immediate emergency action is required.)

Although the DER generator and storage power converter functions do not directly cover loads, the same mechanisms of modes, schedules, graphic curves, arrays, timing constraints, etc. could be very readily applied to loads. The actual modes would be different (lighting cannot create vars, but could dim slightly), but the mechanisms would be the same.

#### 4.4 Power converter functions

Power converter functions range from the simple to the complex. Most power converter functions are based on settings or curves that allow them to respond autonomously to local conditions, while some require direct control commands.

This document covers many of these key power converter functions, including:

- a) Immediate control functions for power converters
  - Function INV1: connect / disconnect from grid
  - Function INV2: adjust maximum generation level up/down
  - Function INV3: adjust power factor
  - Function INV4: request active power (charge or discharge storage)
  - Function INV5: pricing signal for charge/discharge action
- b) Volt-var management modes
  - Volt-var mode VV11: available vars support mode with no impact on watts
  - Volt-var mode VV12: maximum var support mode based on WMax
  - Volt-var mode VV13: static power converter mode based on settings
  - Volt-var mode VV14: passive mode with no var support
- c) Frequency-watt management modes
  - Frequency-watt mode FW21: high frequency reduces active power
  - Frequency-watt mode FW22: constraining generating/charging by frequency
- d) Dynamic reactive current support during abnormally high or low voltage levels
  - Dynamic reactive current support TV31: support during abnormally high or low voltage levels
- e) Functions for “must disconnect” and “must remain connected”
  - “Must disconnect” MD curve
  - “Must remain connected” MRC curve
- f) Watt-triggered behaviour modes
  - Watt-power factor WP41: feed-in power controls power factor
  - Alternative Watt-power factor WP42: feed-in power controls power factor
- g) Voltage-watt management modes
  - Voltage-watt mode VW51: volt-watt management: generating by voltage
  - Voltage-watt mode VW52: volt-watt management: charging by voltage
- h) Non-power-related modes
  - Temperature-function mode TMP: ambient temperature indicates function
  - Pricing signal-function mode PS: pricing signal indicates function to execute
- i) Parameter setting and reporting
  - Function DS91: modify power converter-based DER settings
  - Function DS92: event/history logging
  - Function DS93: status reporting

- j) Scheduled commands, in which a schedule is sent to the power converter with commands scheduled for particular times. These commands can also invoke pre-established parameters. Examples include:
- Week-day schedule for volt-var actions
  - Weekly schedule for frequency-watt actions

It is expected that functions will be added in the future, for instance for handling intentional and unintentional islanding.

These different mechanisms can be intermingled, or only a specific type used, depending upon the requirements of implementations and configurations.

## 4.5 Differing DER architectures

### 4.5.1 Conceptual architecture: electrical coupling point (ECP)

Some power converter-based DER systems may be directly connected to the utility grid, while others may be part of a site microgrid. In either case, the power converter-based DER systems will have a point of electrical connection, which is defined as:

“The electrical coupling point (ECP) is the point of electrical connection between the DER source of energy (generation or storage) and any electric power system (EPS). Each DER (generation or storage) unit has an ECP connecting it to its local power system; groups of DER units have an ECP where they interconnect to the power system at a specific site or plant; a group of DER units plus local loads have an ECP where they are interconnected to the utility power system.”

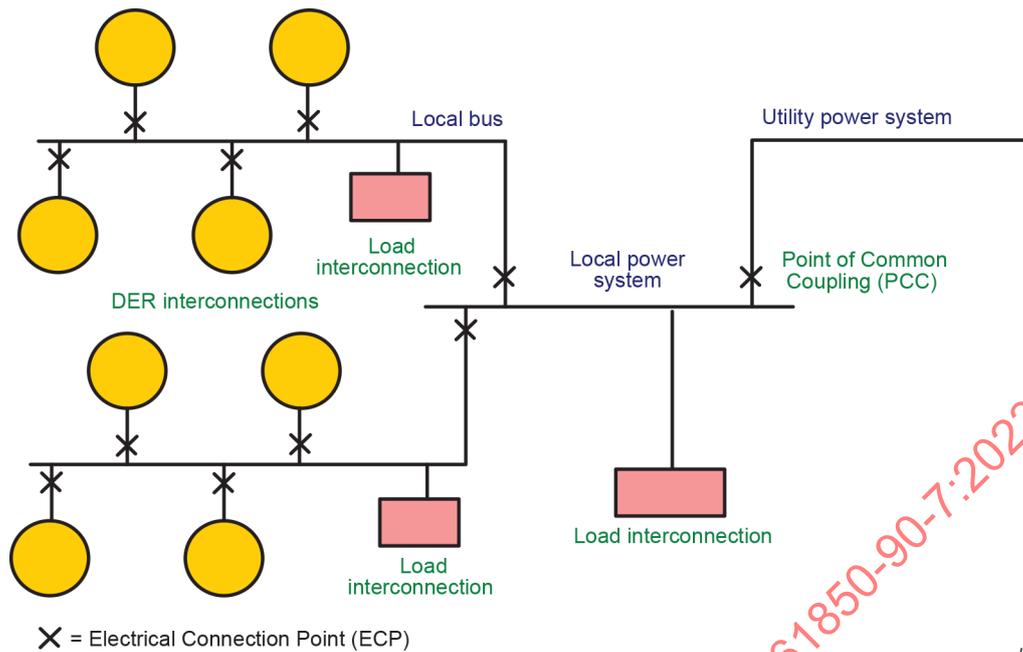
### 4.5.2 Conceptual architecture: point of common coupling (PCC)

For those ECPs that demarcate the point between a utility EPS and a plant or site EPS, this point is identical to the point of common coupling (PCC) defined as “the point where a Local EPS is connected to an Area EPS” in IEEE 1547, *Standard for Interconnecting Distributed Resources with Electric Power Systems* (see 3.1 for additional definitions).

Many functions reflect conditions at the DER’s ECP. For instance, the measured voltage levels used for volt-var management are those at the DER’s ECP.

ECPs are also hierarchical, such as in a university campus environment where the PCC is between the campus and the utility, but where multiple ECPs exist for the different DER systems located in different university buildings. Requests for DER actions can be made at the highest level, say for volt-var settings at the PCC. The university DER energy management system would then allocate different volt-var settings for each of the DER ECPs to reflect their DER capabilities, the needs/desires of the university buildings (people), and the overall campus reliability and efficiency requirements.

This hierarchical concept is illustrated in Figure 2.



**Figure 2 – Electrical Connection Points (ECP) and Point of Common Coupling (PCC)**

#### 4.5.3 Utility interactions directly with power converters or indirectly via a customer EMS

Utilities/ESPs can interact with power converter-based DER systems using different architectures. They may issue requests or commands directly to the DER systems either one-on-one or via broadcast/multicast communications.

Alternatively, a customer energy management system (EMS) can help manage power converter-based DER system responses to the broadcast utility request. This customer EMS may be managing multiple power converter-based DER systems, customer appliances, other types of distributed generators and storage devices, and plug-in electric vehicles.

For instance, if the utility broadcasts a specific mode request for power converter-based DER system actions, then these can be passed directly or indirectly (through explicit commands) to the power converter-based DER systems. If the utility broadcasts Demand Response (DR) signals or more generic volt-var requests, then the customer EMS could use other devices in addition to power converter-based DER systems to meet these requests. With this approach, the customer EMS could manage responses locally to meet the requests with the most effective mix of devices.

#### 4.5.4 Communication profiles

The communication profiles between the utility and the customer EMS, will consist of different technologies at different layers, for example:

- Data object models: IEC 61850-7-420
- Application protocols: Mapping of IEC 61850 data objects to web services, IEC 61850-8-1 Mapping to MMS (ISO 9506), IEC 60870-5, ModBus, IEEE 1815 (DNP3), IEEE 2030.5
- Transport protocols: TCP/IP, UDP/IP, ModBus, IEC 60870-5-101, IEEE 1815 (DNP3) serial
- Media layers: Public Internet, cellular (mobile) network, AMI network, utility private network, leased services from telecommunication providers

#### 4.6 General sequence of information exchange interactions

The (generic) sequence for interactions between a utility/ESP and power converter-based DER systems is:

- a) The DER systems operate autonomously by default, based on pre-established settings and curves. Multiple groups of these settings/curves may be available to be triggered by a remote command, and may be updated as needed through local or remote communications.
- b) The utility determines what types of services are desired from power converter-based DER systems within a region, on a feeder, or in some other area. This determination will be based on assessments of the power system status, abilities of other equipment to perform the required actions (e.g. capacitor banks for var control), market considerations, etc.
- c) The utility broadcasts a general request that power converter-based DER systems (within a region or feeder or other area) go into a specific mode or that certain parameters are set. This request may be sent either to individual power converter-based DER system controllers, or to more general “customer EMSs” that know how to interpret such requests for the power converter-based DER system controllers that they are managing. In either case, the utility does not necessarily need to know anything about the power converter-based DER system capabilities, current PV status, market or tariff agreements on using the power converter-based DER system, or desires of the PV owner.
- d) At each customer site or other facility, the power converter-based DER system controller OR a customer EMS receives and interprets this broadcast utility request.

If a customer EMS is used:

- a) The customer EMS interprets the utility request. It determines whether it will take any action, and what the command(s) will be to the power converter-based DER system controller(s) under its control, including responding to any customer overrides or changes. These actions could be explicit commands to each power converter-based DER system it is managing, or could be a schedule of commands if the power converter-based DER system has the ability to handle schedules.
- b) The customer EMS then issues specific commands to the power converter-based DER system(s): First it requests (or already has) the current status of the power converter-based DER system(s), modifies the command if necessary to reflect the status, and then issues the appropriate command.
- c) The power converter-based DER system(s) respond to the customer EMS command, indicating success or rejection, as well as any error codes. In addition, the current status of the power converter-based DER system could be sent if either explicitly requested by the customer EMS or if it is “automatically” sent as part of the sequence.
- d) The customer EMS may or may not be required to respond to the utility request.
  - If the utility does not expect a direct response, it may both monitor conditions to determine if enough power system changes have occurred and/or read the meter (or meter event log) to determine if the power converter-based DER system responded appropriately.
  - If it does respond, it will acknowledge receipt of the command and returning the appropriate information.

If a power converter-based DER system controller directly receives the broadcast request from the utility:

- a) The power converter-based DER system controller determines internally how best to respond, and performs those actions.
- b) The power converter-based DER system controller may or may not respond to the command from the utility with an acknowledgement and any appropriate information.
- c) If the utility does not expect a direct response, it may both monitor conditions to determine if enough power system changes have occurred and/or read the meter (or meter event log) to determine if the power converter-based DER system responded appropriately.

- d) If it does respond, it will acknowledge receipt of the command and returning the appropriate information.
- e) The power converter-based DER system(s) are metered either individually or via net metering, with their output (in response to the command) captured as part of the metering data. If electric storage is part of the power converter-based DER system, then it could be metered separately or the power converter-based DER system as a whole could just be metered. (Metering is out of scope for this document).
- f) If communications are lost, the power converter-based DER system goes to a default mode, possibly after a timeout period. The default mode, the timeout period, and other parameters for this situation would be established ahead of time.
- g) Customers can override or modify commands at any time if they desire.

## 5 Concepts and constructs for managing power converter functions

### 5.1 Basic settings of power converters

#### 5.1.1 Nameplate values versus basic settings

Nameplate values are expected to be fixed, based on the type, model, and capabilities of the power converter. However, installation-specific requirements may require modifications to the nameplate values, so long as these basic settings remain within the constraints of the nameplate values. These basic settings are usually established upon installation and start-up, and are usually due to varying power converter configurations, power grid environments, desired power converter capabilities, and DER owner preferences.

Basic power converter settings are needed for several functions and include power and voltage settings. These basic settings will be applied to power adjusting functions. At the beginning of this clause the power settings will be described and afterwards voltage settings. The basic setting functions assume a tightly coupled interaction between the power converter-based DER systems and a controlling entity (utility, energy service provider, or customer EMS).

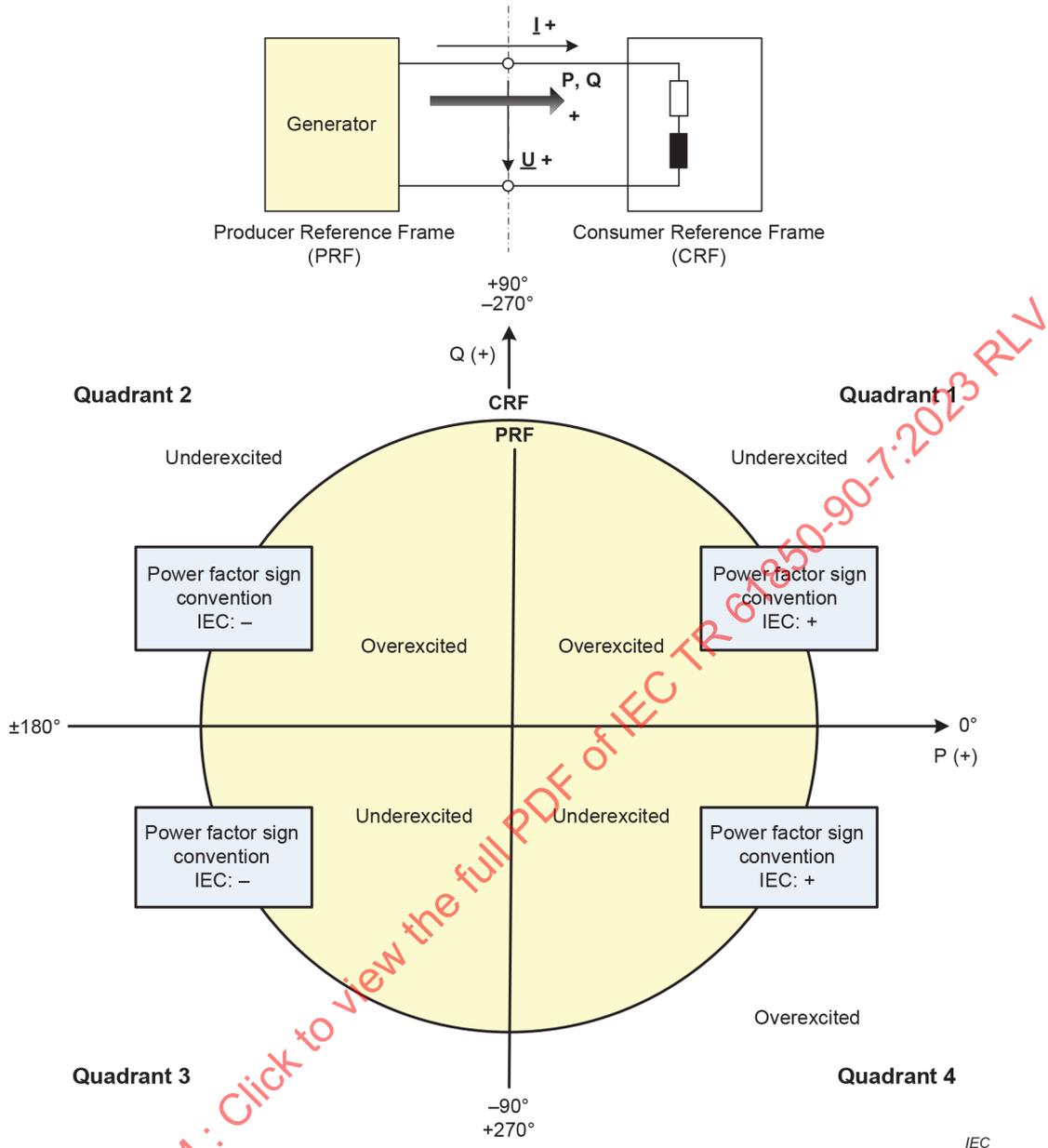
#### 5.1.2 Power factor and power converter quadrants

Figure 3 shows the possible working areas of a DER power converter from both a Producer Reference Frame (PRF) and from a Consumer Reference Frame (CRF). In general for DER systems, the PRF is used, in which the 1<sup>st</sup> and 4<sup>th</sup> quadrants are for delivering power to the grid (vars either overexcited or underexcited, respectively), while the 2<sup>nd</sup> and 3<sup>rd</sup> quadrants are for receiving power from the grid (vars either overexcited or underexcited, respectively).

DER power converters can work in any of these four quadrants, depending upon their capabilities and the desired functions. Historically, there are two conventions, IEC and EEI (Edison Electric Institute), which are reflected in the two PFSign conventions. These conventions are illustrated in Figure 3 and Figure 4, and are shown in Table 1 from the point of view of the Producer Reference Frame:

**Table 1 – Producer Reference Frame (PRF) conventions**

Quadrant	Excitation	PFSign Active Power (usually IEC)	PFSign (usually EEI)
I	Overexcited	+	–
II	Overexcited	–	+
III	Underexcited	–	–
IV	Underexcited	+	+



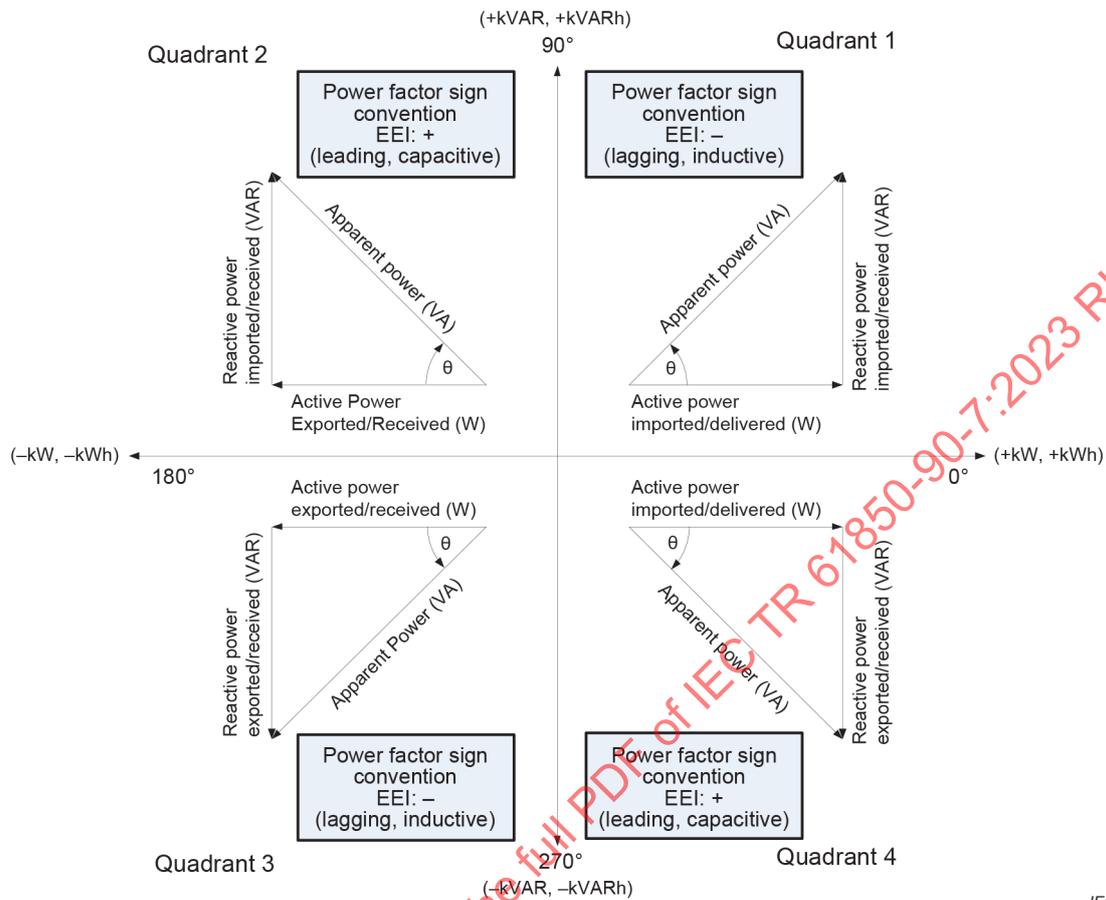
**Figure 3 – Producer and Consumer Reference Frame conventions**

Therefore, all commands that affect the power factor (PF) must include three elements in order to specify which quadrant is being referenced:

- a) The signed power factor value
- b) PFExt identification of “overexcited” or “underexcited”
- c) PFsign convention indicator (which may be set as either nameplate or basic setting for an implementation)

If the power converter does spontaneously change between charging and discharging without an explicit command, it can continue to maintain the vars according to what it was previously doing, either providing vars or absorbing vars, or the reverse. The spontaneous change action (reversing or maintaining var direction) is set either as nameplate or basic setting (VArAct).

The EEI power factor sign convention is based on the power triangle acc. handbook for electricity metering (EEI) and IEC 61557-12 (2007).



IEC

**Figure 4 – EEI power factor sign convention**

### 5.1.3 Maximum watts, vars, and volt-amp settings

Each power converter's power connection to its local grid is called its electrical connection point (ECP). If there are multiple power converters within a site, they may all contribute to the interconnection of the site to the main grid at the point of common coupling (PCC).

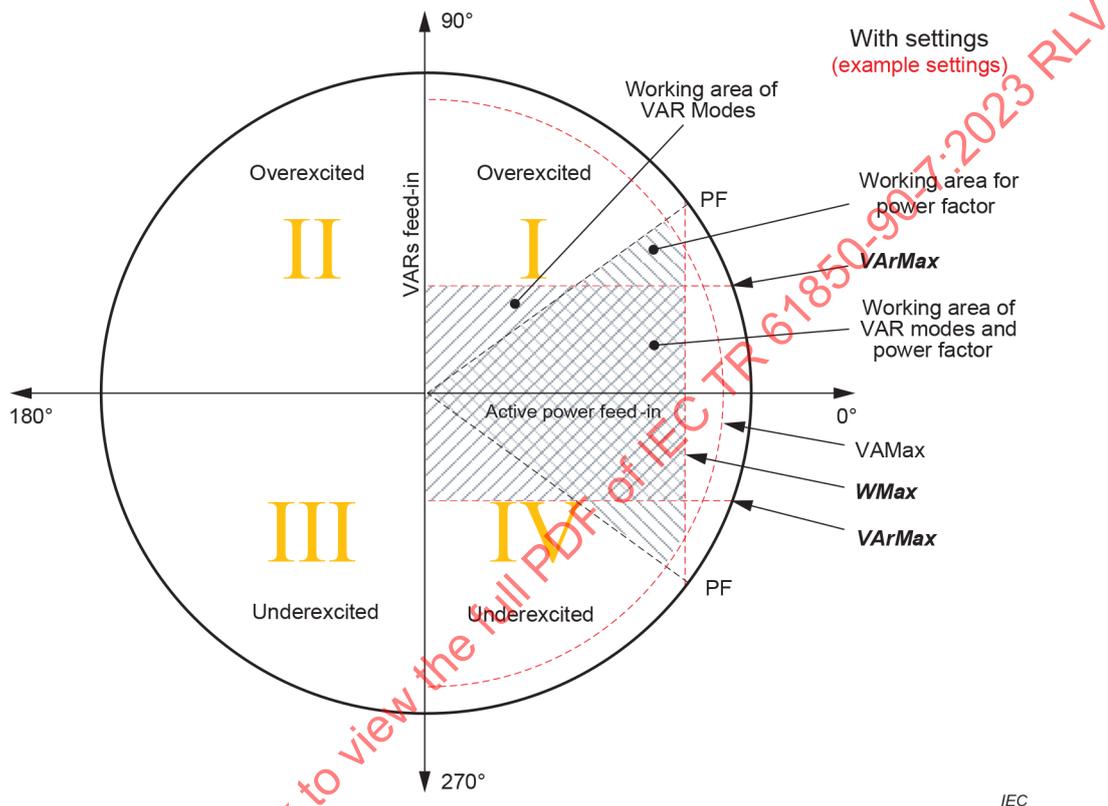
The power converter quadrant areas can be constrained in order to meet specified limits at its ECP or at the PCC. In order to determine the limits at the PCC, all power converters must have three parameters, called WMax (for active power), VAMax (for apparent power), and VARMax (for reactive power) that establish their limits at the ECP of each power converter. Collectively, these ECP limits provide the limits at the PCC.

WMax, VAMax, and VARMax are these settable limits that may be the same as the nameplate values, or may be (typically) lower values reflecting actual implementation limits. They would normally be set at the initial deployment time, although they could be modified occasionally to reflect changes to the implementation.

The parameter WMax is the most critical value: it is used as the reference value for power requests. VARMax may be the same as WMax, such that a single process can set the limits for both real and reactive power functions, but these settings may also be set separately. Active power control commands can then be issued as a percentage of WMax: each power converter can then calculate its own actual values from its own WMax value. This approach allows the reduction of a DER's power level by relative values in an unlimited range.

For a facility with multiple power converters, the maximum continuous active power output capability of the facility is given by the sum of parameter WMax of all power converters. Likewise, the maximum continuous reactive power output capability is given by summing the VArMax parameters of all power converters. Furthermore, in some cases it can be an advantage to set the maximum continuous reactive power output capability in same manner as WMax. However, the basic settings for power do not intend to limit the energy flow to be one directional.

An example is shown in Figure 5 for the 1<sup>st</sup> and 4<sup>th</sup> quadrant (assuming the arrows indicate a producer reference frame).



**Figure 5 – Working areas for different modes**

The different hatched areas show the different working areas and working area limits. The red hatched lines show the maximum values for active power WMax, reactive power VArMax and apparent power VAMax.

Possible power factor settings may range from a minimum PF (OutPFSet) (underexcited) in quadrant 4, going through the maximum value of 1 to a minimum power factor (overexcited) in quadrant 1. Possible var settings (see function INV2 below) are limited by VArMax.

Since some possible settings are limited by regulations or device capabilities, more than one boundary may apply to a selected DER management function for power converters, resulting in zones limited by more than one hatching type.

**5.1.4 Active power ramp rate settings**

The default ramp rate of change of active power is provided by the parameter WGra. This parameter sets the change of active power due to either a change by a command or by an internal action such as the release of power reduction by use of the hysteresis in the function Active Power Reduction by Frequency. This ramp rate (gradient) is not intended to replace the specific ramp rates that are set by the commands or schedules, but acts as the default if no specific ramp rate is specified. WGra is defined as a percentage of WMax per second.

### 5.1.5 Voltage phase and correction settings

In the case of single phase power converters, the voltage value used in the power converter functions is based on whichever phase circuit (A, B, or C) the power converter is connected to. The identity of the phase can be set in the power converter as a basic setting. In the case of three-phase power converters that do not act independently, the mean value of A, B, and C is to be used, unless abnormally high or low voltage levels of individual phases are measured in unbalanced systems, in which case the voltage levels of those individual phases may be used.

For functions using voltage parameters (like the volt-var modes, volt-watt modes, and dynamic reactive current support), a reference voltage ( $V_{Ref}$ ) and a correction voltage ( $V_{RefOfs}$ ) are additionally introduced to the previously mentioned parameters,  $W_{Max}$ ,  $V_{AMax}$  and  $W_{Gra}$ . All power converters behind one PCC have a common reference voltage, but differ in the voltage between their own ECP and the PCC due to configuration differences within a plant. These differences can be corrected by the parameter  $V_{RefOfs}$  that will be applied to each power converter, as can be seen in Figure 6, where a positive value means that voltage at the ECP is higher than the voltage at the PCC. This correction voltage will be applied to the voltage-based modes and will allow a homogenous setting and broadcasts for the plant.

The equation for the effective percent voltage is:

$$\text{Effective Percent Voltage} = 100 \times (\text{local voltage} - V_{RefOfs}) / (V_{Ref})$$

#### Example settings

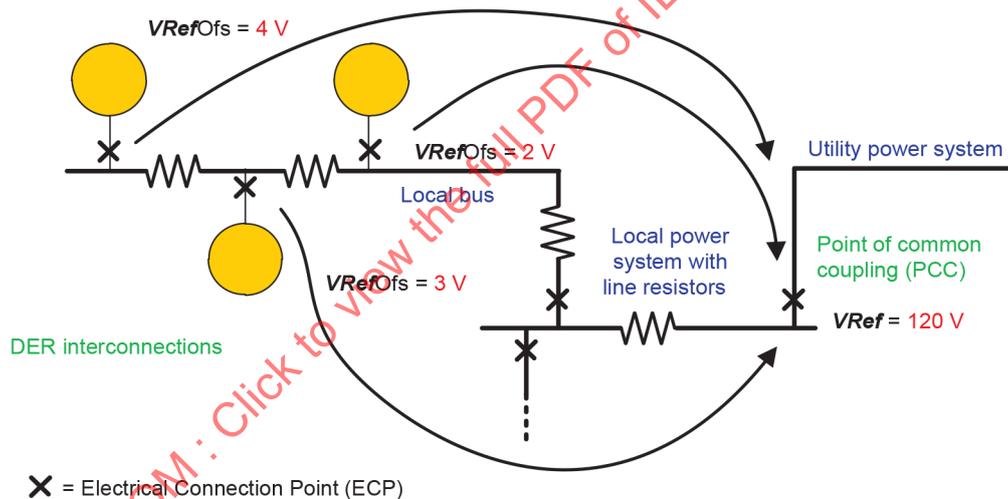


Figure 6 – Example of voltage offsets ( $V_{RefOfs}$ ) with respect to the reference voltage ( $V_{Ref}$ )

### 5.1.6 Charging settings

For those power converters that manage storage DER units that can both deliver power (discharging in quadrants 1 and 4) and absorb power (charging in quadrants 2 and 3), additional parameters<sup>2</sup> are needed if the maximum discharge limits are different from the maximum charge limits:  $W_{ChaMax}$ ,  $V_{AChaMax}$ , and  $W_{ChaGra}$ .

### 5.1.7 Example of basic settings

An example of settings for a power converter is shown in Table 2.

<sup>2</sup> Additional details on storage parameters are described in IEC TR 61850-90-9.

**Table 2 – Example basic settings for a storage DER unit**

Parameter	Example Values
PFsign	1 = IEC; 2 = EEI;
PFExt	Underexcited = True; Overexcited = False
VArAct	1 = reverse var underexcited/overexcited characterization when changing between charging and discharging) 2 = maintain var characterization
WMax, delivered	14 500 W
WChaMax, received	–14 500 W
VAMax	16 000 VA
VACHaMax	16 000 VA
VArMax	12 000 VAR
VRef	120 V
VRefOfs	2 V
WGra	20 % WMax/second
WChaGra	15 % WChaMax/second

### 5.1.8 Basic setting process

The settings described above are expected to only be set once or infrequently over the life time of the system. The utility/ESP or the customer EMS would take the following actions:

- a) (Optional) Request status of power converter-based DER system: Request a pre-defined set of the status information, including the status values, the quality flag, and the timestamp of the status (see Function DS93 for details of status points).
- b) Issue command or mode to modify power converter-based DER settings:
  - Data element to be modified (e.g. WMax, VAMax, VArMax, VRef, VRefOfs, WGra, mode)
  - New value for that data element
- c) Receive response to the command:
  - Successful (plus new value of data element)
  - Rejected (plus reason: equipment not available, message error, overridden, security error)

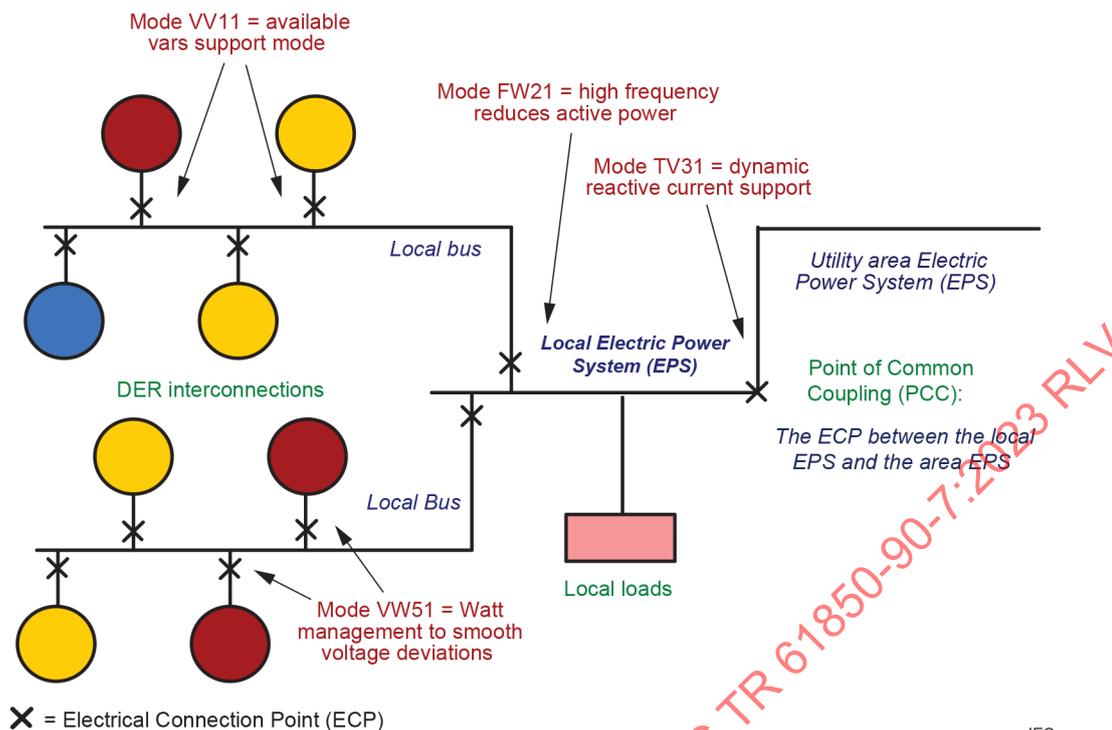
## 5.2 Modes for managing autonomous behaviour

### 5.2.1 Benefits of modes to manage DER at ECPs

Modes are methods for managing DER systems by pre-setting desired parameters and curves that describe desired behaviour in response to local conditions (e.g. voltage, frequency, power factor, temperature, and pricing signal). Many different mode settings can be defined once and updated only infrequently. Utilities and/or ESPs can then invoke a specific mode by a single command whenever they wish the DER to follow the behaviour defined by that mode.

The use of modes allows the DER to act autonomously without moment-by-moment commands, thus both simplifying the tasks of the utilities/ESPs, as well as minimizing the necessary communications burden. Utilities and ESPs can either monitor the behaviour of the DERs or can simply monitor the power system to determine how well their mode requests are affecting the power system.

Generally, modes will be applied to one power converter or groups of power converters that are connected at different levels of ECPs (see Figure 7 for examples).



**Figure 7 – Example of modes associated with different ECPs**

### 5.2.2 Modes using curves to describe behaviour

Modes are defined as using curves to describe autonomous behaviour. These curves correlate a measured or triggering value (the independent variable) with a requested response by the DER (dependent variable).

In order to generate a curve, two-column arrays are used, with the first column containing monotonically increasing triggering values (x-axis) and the second column containing the response values (y-axis). These arrays are combined into a piecewise linear curve by interpolating each response values to correspond with each triggering value.

When an operational mode is invoked, the real-time measured value or stipulated external value of the triggering parameter is used to derive the interpolated response value.

Examples include the following modes, although others could be added. The first four modes are power-related modes, while the last two modes utilize non-power-related triggering values:

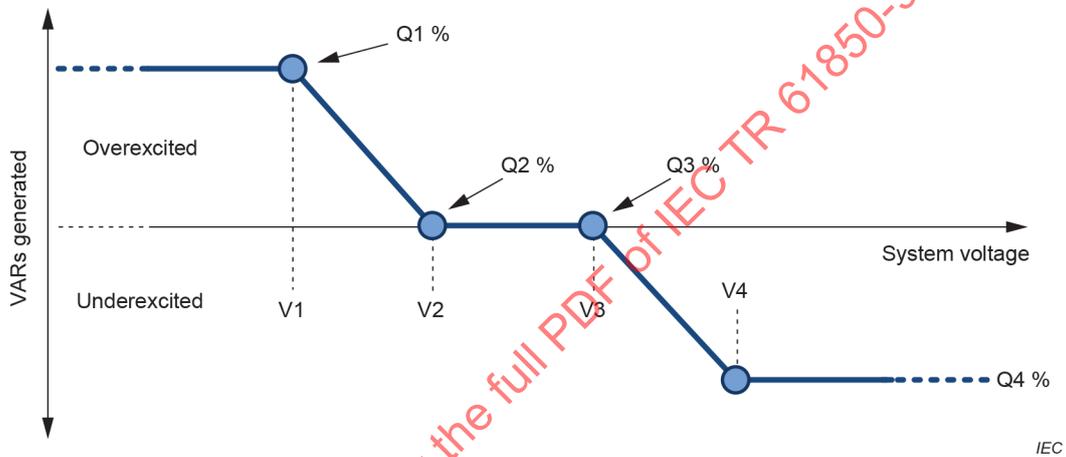
- Volt-Var Mode:** Voltage values to determine what vars the power converter should produce at each voltage level.
- Frequency-Watt Mode:** Frequency values to determine what watts the power converter should produce for each frequency value.
- Dynamic reactive current support Mode:** Apply volt-var management during short times of abnormally low or high voltage values to support the grid until either the voltage returns within its normal range or the power converter must disconnect.
- Volt-Watt Mode:** Voltage values to determine what watts the power converter should produce as a function of the voltage level.
- Temperature-var Mode:** Temperature values to determine what vars or what volt-var mode the power converter should produce within each temperature range.
- Pricing Signal Mode:** Pricing signal values to determine what watts, vars, power-related mode, or other ancillary service the power converter should produce for each range of pricing signals.

In most of these modes, the real-time triggering values (voltage, frequency, etc.) are measured locally. In some modes, the triggering value might be received from external sources, such as regional average temperature or energy pricing signal.

Unlike direct control commands, modes indicate behaviour that the power converter should follow autonomously without further intervention. This approach alleviates the need for continuous control commands being sent out to large numbers of power converters.

Because autonomous behaviour must take into account the current capabilities of the DER system, these power converter modes are designed to request DER systems to provide the needed mode support as best as their capabilities allow them. For this reason, the curve settings are generally in percentages of nominal or nameplate values, rather than absolute values. That approach permits both small and large power converter-based DER systems to respond within their limits.

An example of a curve used in a volt-var mode is shown in Figure 8.



**Figure 8 – Example of a volt-var mode curve**

### 5.2.3 Paired arrays to describe mode curves

Each mode curve is described by a two-column array of pairs of values: the first column in the array contains the breakpoints of the independent variable values, while the second column contains the dependent variable values at those breakpoints. These two columns of values can be used to derive a piece-wise linear curve.

The independent variables are typically values which may be measured locally or calculated from locally available measurements or values. For instance, when a DER controller receives a mode curve which uses voltage as the independent variable, the DER may determine its current location along the curve by averaging the three voltage phase values at the ECP and applying the appropriate voltage offset. The independent variable may be an absolute value (e.g. frequency value) or may be a percentage of nominal (e.g. percentage of nominal voltage).

The dependent variables are typically (but not exclusively) percentages of a nominal value. These dependent variables are used to calculate what behaviour the DER is being requested to follow. For instance, if the dependent variable is the percentage of the maximum watts (WMax) and the independent variable is percentage of nominal voltage, the DER controller can determine its desired watts based on its measured voltage.

The paired arrays therefore consist of the breakpoints of the independent variables, the breakpoints of the dependent variables, and the units (either SI units or percentage of SI units).

#### 5.2.4 Percentages as size-neutral parameters: voltage and var calculations

As noted previously, because broadcast/multicast commands cannot necessarily know the size or capabilities of a power converter, the curve settings are generally in percentages of nominal or nameplate values, rather than absolute values. That approach permits both small and large power converter-based DER systems to respond within their limits.

In particular, given this size-neutral and connection-point-neutral approach, power converters will need to calculate an effective percent value for the locally measured voltage as follows:

$$EffectiveLocalVoltage = \left( \frac{LocallyMeasuredVoltage - VRefOffset}{VRef} \right) \times 100$$

A power converter would then compare this *EffectiveLocalVoltage* to the voltage percentages (X-Values) in the configuration curve, so the X-Values of the curve points would be calculated as follows:

$$PercentVoltage = \left( \frac{DesiredVoltageValue}{VRef} \right) \times 100$$

These definitions allow the same *PercentVoltage* values to be used in the configuration curves of many different power converters without adjusting for local conditions at each power converter. Such adjustments can be made by setting the global Reference Voltage (VRef) or Reference Voltage Offset (VRefOfs) when the device is first commissioned or occasionally thereafter, without affecting the curve settings.

In similar fashion, the requested var (y-values) to be written for each curve point would be a percentage calculated in one of three ways, as indicated by the y-value type specified in the curve:

- a) VARs based on %WMax

$$PercentVARs = \left( \frac{DesiredVARValue}{WMax} \right) \times 100$$

- b) VARs based on %VArMax

$$PercentVARs = \left( \frac{DesiredVARValue}{VArMax} \right) \times 100$$

- c) VARs based on available vars as measured and calculated by the DER system

$$PercentVARs = \left( \frac{DesiredVARValue}{AvailableVARs} \right) \times 100$$

The percentage of VARs is a signed value, so that it can represent VARs generated (positive) or absorbed (negative).

#### 5.2.5 Hysteresis as values cycle within mode curves

Although the simplest curve is a piece-wise linear curve, hysteresis can be added to provide different return routes. This hysteresis adds stability to the power converter responses to possibly fluctuating primary curve values by not following the minor fluctuations, but by maintaining a constant level until the trend of the primary curve value stabilizes.

There are two modes available (parameter names are shown in the example in Figure 9):

- by specifying a hysteresis path, or
- via a deadband path to simulate hysteresis.

A ramp rate can be configured by RmpTmsPT1 for getting of system voltage to this function. This parameter is configured in seconds. This is the time this function requires reaching 95 % of the grid voltage change (3 times the RC time constant).

Examples of volt-var curves with hysteresis are shown in Figure 9 and Figure 10.

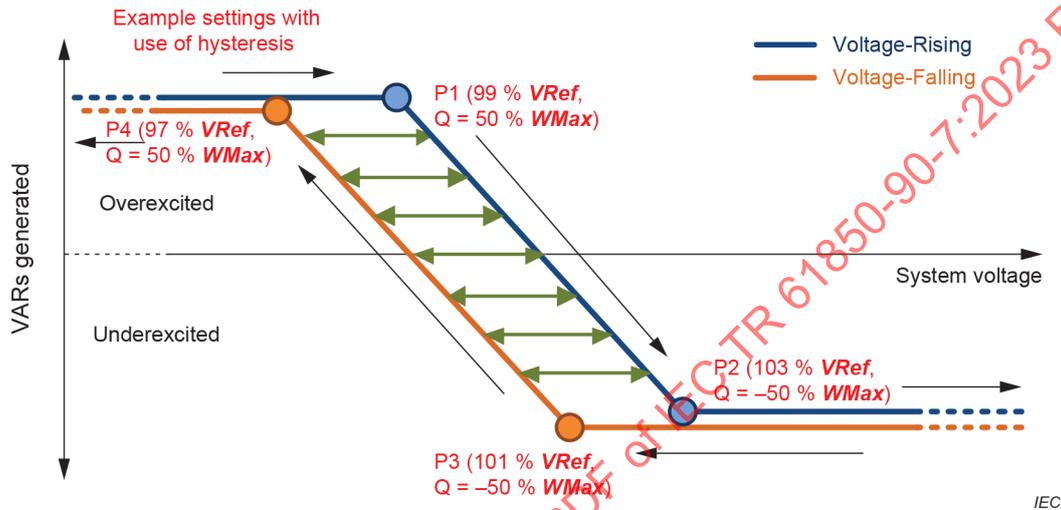


Figure 9 – Example of hysteresis in volt-var curves

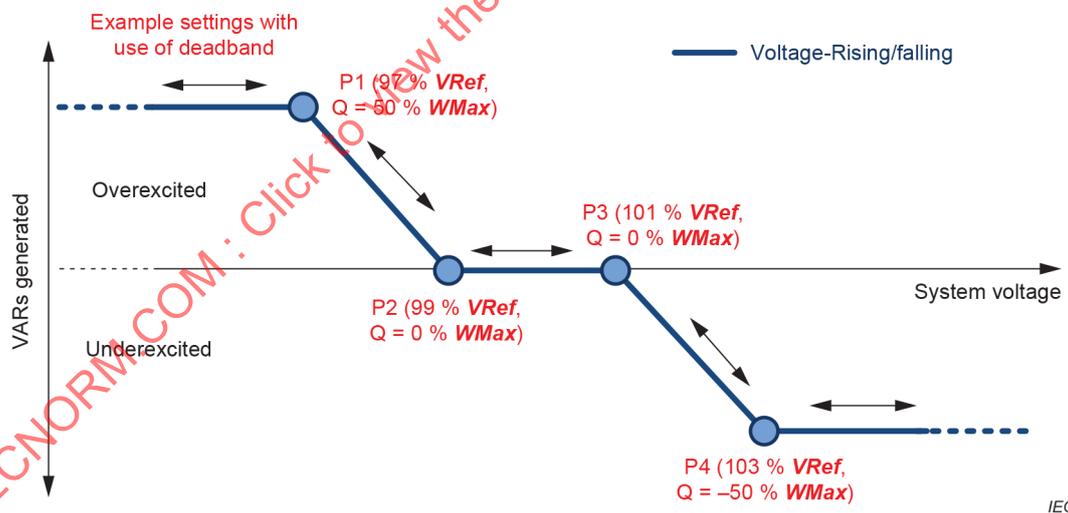
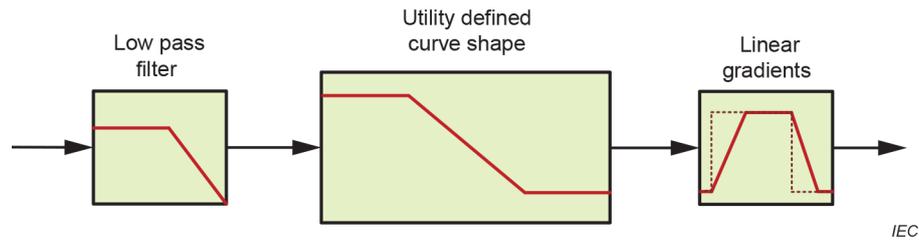


Figure 10 – Example of deadband in volt-var curves

### 5.2.6 Low pass exponential time rate

The local function block diagram in Figure 11 shows the topology for low pass, utility defined curve shapes and linear gradient (ramp rates). The utility defined curve shape can be assumed to be the any function defined by paired arrays.



**Figure 11 – Local function block diagram**

The Low-Pass filter is a simple first-order filter with a frequency response magnitude given by:

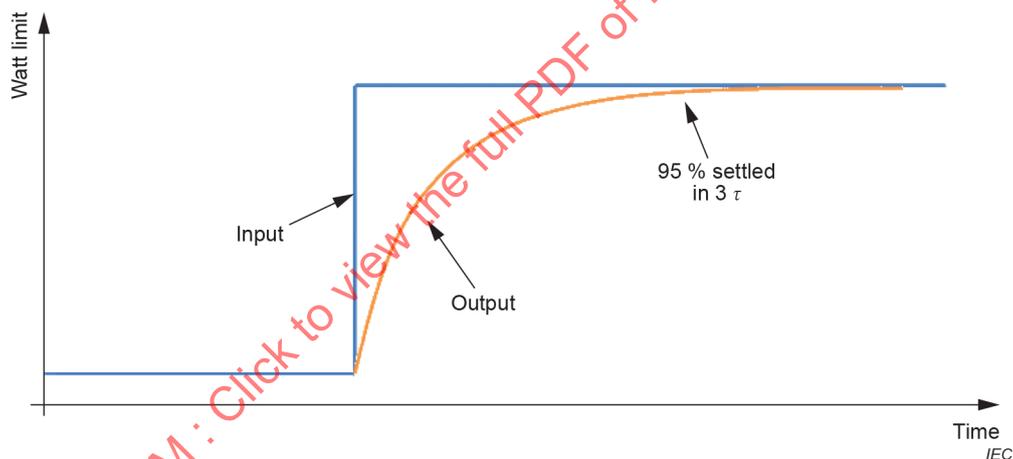
$$\left| \frac{\text{Output}}{\text{Input}} \right| = \frac{1}{\sqrt{1 + (\omega\tau)^2}}$$

where

$\omega$  =  $2\pi \times$  frequency;

$\tau$  is the time constant of the filter

The time-response of such a filter to a step change in the input is as illustrated in Figure 4.



**Figure 12 – Time domain response of first order low pass filter**

The configuration parameter for this filter is a time, in seconds, in which the filter will settle to 95 % of a step change in the input value. This is equivalent to  $3\tau$ .

### 5.2.7 Ramp rates

To avoid sharp shifts at the breakpoints of the piecewise linear curve, a ramp rate is included for each transition in order to smooth and stabilize the responses of large numbers of power converter-based DER systems. In order to distinguish the decrease and increase of the independent output value two ramp rates are in use, called RmpTmmDec and RmpTmmInc.

### 5.2.8 Randomized response times

Since mode requests will (most likely) be broadcast or multicast to large numbers of DER systems at the same time, it may be beneficial to stagger the responses. This is achieved by providing a time window within which a random “start” time actually triggers the execution of the mode.

### 5.2.9 Timeout period

A timeout period is available for reverting to a default state of the DER system, to ensure that a missed or lost command does not impact normal operations beyond that timeout period. If the mode is the default state, then the timeout period would be set to infinite.

### 5.2.10 Multiple curves for a mode

Each type of operational mode could have multiple curves with different settings. For instance, a volt-var mode could have different curves that could be invoked during colder days or hotter days. The pricing signal mode could have different curves for weekdays and for weekends. The low-voltage-ride-through mode could have different curves for different situations.

### 5.2.11 Multiple modes

Multiple modes may be in effect at any one time, so long as they are not mutually exclusive. Modes may also be overridden by immediate control commands, such as for emergency situations. For instance, DER systems that are executing a volt-var mode under normal circumstances could be triggered by a high temperature to execute a temperature-var mode to provide or absorb more vars.

Multiple pricing signal modes could be effect. For instance there could be different pricing signal modes for energy, for vars, for frequency response, or for other ancillary services. When actual pricing signals are received for each type, then an assessment would be performed to determine which may be mutually exclusive, which of those may be the preferred mode, and which modes might co-exist at the same time. For instance, a high pricing signal for vars might out-weigh a lower pricing signal for watts, while frequency-watt mode might co-exist with either.

### 5.2.12 Use of modes for loosely coupled, autonomous actions

Power converter mode requests to power converter-based DER systems are examples of decentralized coordination of generation or loosely-coupled generation control. Loosely-coupled interactions also cannot expect complete compliance from all DER systems. For instance, power converter-based DER systems may not be able to respond completely for any number of reasons: the sun is behind a cloud, the customer has overridden the mode setting, local situations are impacting what response the power converter-based DER system can provide, etc.

Therefore the expectation for issuing mode requests is that an aggregated response will be gotten from many or most power converter-based DER systems, but not necessarily all. Any financial ramifications will be determined by the metering results.

Since these mode requests maybe broadcast (multicast) to specific groups of power converter-based DER systems and since the responses from the power converter-based DER systems will generally not be explicit, the utility may not know what the actual responses will end up being, and could require subsequent interactions not only with these power converter-based DER systems but possibly with distribution grid capacitor controllers, load tap changers, voltage regulators, storage devices, and other types of DER.

## 5.3 Schedules for establishing time-based behaviour

### 5.3.1 Purpose of schedules

Larger power converter-based DER systems and large aggregations of small power converter-based DER systems have significant influence on the distribution system and have local volt-var characteristics that may vary throughout the day. As a result, a single function or operational mode such as a specific volt-var curve may not be suitable at all times. Yet sending many control commands every few hours to many different DER systems may impact bandwidth-limited communications systems or may not be received in a timely manner, leading to