NIST Technical Note 2217

IEC 61850 Profile for Distributed Energy Resources Supporting IEEE 1547

Hasan Giray Oral
Dhananjay Anand
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Hasan Giray Oral, Dhananjay Anand, Cuong Nguyen, Avi Gopstein
Smart Grid Group
Communications Technology Laboratory

Christoph Brunner, Alexander Apostolov
ESTA International, LLC

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Abstract

This document provides an IEC 61850 profile for a Distributed Energy Resource supporting IEEE 1547 and the grid support functions therein. The profile utilizes the IEC 61850 data object model and maps the requirements of IEEE 1547 to the data object model for the integration of DERs in the electric power system. By establishing a required subset of data objects and data attributes from the IEC 61850 model, the profile reduces model complexity and aims to improve the interoperability, and the engineering, testing and maintenance of IEC 61850 based protection, automation and control systems. A description of how the profile maps the IEEE 1547 requirements to the required IEC 61850 data objects is provided and use case examples are given.

Key words

Data Modeling, DER, Functional Decomposition, Grid Automation, IEC 61850, IEEE 1547, Interoperability, Profile, Renewable Integration, Smart Grid, Standards, Substation Automation

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Glossary

Client: Requestor of data from a server.

DA: Data attribute.

Data Attribute: Single value descriptor for a data object.

Data Object: Domain specific information that is contained in logical nodes and is available in the devices integrated in a networked automation system.

Distributed Energy Resource (DER): A source of electric power that is not directly connected to a bulk power system, including both generators and energy storage devices that can provide active power to an EPS [1].

DO: Data object.

ECP: Electrical connection point.

EPS: Electric power system.

Function: A specific process, action or task that a system (such as a substation IED) is able to perform.

Function Element: An atomic sub-function that can exchange standardized information so that it may be composed into a function.

ICD File: Intelligent electronic device (IED) capability description file.

IEC 61850: A standard for communication networks and systems for power utility automation.

IEC 61850-6: Part 6 of the IEC 61850 standard: Configuration description language for communication in power utility automation systems related to IEDs.

IEC 61850-7-2: Part 7-2 of the IEC 61850 standard: Basic information and communication structure - Abstract communication service interface (ACSI).

IEC 61850-7-3: Part 7-3 of the IEC 61850 standard: Basic communication structure - Common data classes.

IEC 61850-7-4: Part 7-4 of the IEC 61850 standard: Basic communication structure - Compatible logical node classes and data object classes.

IEC 61850-7-420: Part 7-420 of the IEC 61850 standard: Basic communication structure - Distributed energy resources and distribution automation logical nodes.

IED: Intelligent electronic device.

IEEE 1547: 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

LD: Logical device.

LN: Logical node.

Logical Device: Represents the information produced and consumed by a group of function elements (or logical nodes).

Logical Node: The smallest part of a logical device that exchanges data.

PCC: Point of common coupling.

ROCOF: Rate of change of frequency.

Server: Represents the information produced and consumed by a physical device in the network. In EPSs a single instance of an IED is typically considered a server.

Substation: A facility comprised of switchgear, transformers, relays, generators and other equipment required to manage power flows in an EPS. In the context of IEC 61850, a substation represents the boundary of a digital network between IEDs.

Trip: Inhibition of immediate return to service, which may involve disconnection [1].

1. Introduction

Distributed generators are increasingly important in the drive towards a cleaner energy system. They are of different sizes and types and are being connected to all levels of the electric power system (EPS) – transmission, distribution and low voltage.

In many cases distributed energy resources (DERs) are used to provide power to the EPS, and so DERs providing this function integrate into the various protection, automation and control systems of the grid. Considering the large number of already deployed DERs, accelerating installation rates, and the growing impact DERs have on the operation and stability of the electric power grid, many countries around the world have developed standards defining requirements for the behavior of these technologies during varying electric power system conditions. IEEE Standard 1547, which is the Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, defines many DER functional requirements [1].

The expanding capabilities and increasingly distributed control strategies of modernized power systems depend on effective communication between devices and across systems. Developed by the International Electrotechnical Commission, the IEC 61850 standard was developed for communication networks and systems in substations and it has since been updated to an edition that more broadly addresses communication networks and systems for power utility automation [2]. In addition, IEC 61850-7-420 (Basic Communication Structure – Distributed Energy Resources Logical Nodes [3]) has been introduced to better integrate DER functions into substation automation systems.

This document provides a specific IEC 61850 profile that meets the requirements of IEEE 1547 for DER integration with the electric power system. This profile uses the modeling principles of the IEC 61850 core standard as well as DER integration specific models defined in IEC 61850-7-420. This profile facilitates integration of inverter-based DERs with IEC 61850-based grid systems, and use of this profile for those systems can:

- Reduce the complexity of IEC 61850-7-420 to a well-defined subset which facilitates the implementation of inverter controllers for vendors without the need of detailed knowledge of IEC 61850-7-420;
- Improve interoperability between different components of DER protection, automation, and control systems;
- Simplify and improve the quality of the certification testing process;
- Enable the development of vendor-independent engineering, testing and maintenance tools for microgrids and other systems with high penetration of inverter based DERs; and
- Provide a template for the development of IEC 61850 profiles to meet the requirements of other users or application domains.

Development of this profile requires a good understanding of:

- Normal and abnormal behavior of the electric power system;

- Operation and control principles for DERs with inverter-based interface to the grid;
- Interfaces between the inverter controller, the inverter, and the different electrical points of coupling;
- Definitions, functional, and communication requirements of IEEE 1547;
- Modeling principles of IEC 61850;
- Detailed data models of IEC 61850-7-2, IEC 61850-7-3, and IEC 61850-7-4;
- System Configuration Language defined in IEC 61850-6;
- Detailed DER integration models of IEC 61850-7-420;
- Requirements for certification testing; and
- Requirements for functional testing.

The main focus of this document is on the considerations for including operational functions from IEEE 1547 in the IEC 61850 profile. Supporting material is provided in the appendices.

2. Overview of the Profile

2.1. DER Modeling in IEC 61850 and the Decomposition of the Profile

IEC 61850 is based on the following principles:

- It utilizes a detailed object model with well defined data objects (DOs) and data attributes (DAs) and standard names.
- Functional decomposition is used to model protection, automation, and control devices. The building blocks of the model are function elements defined in the standard as logical nodes (LNs). LNs are grouped in hierarchical logical devices (LDs) which may have multi-level hierarchy depending on the complexity of the functionality of the intelligent electronic device (IED).
- The communication services support both client-server and peer-to-peer communications, which meets both the requirements of traditional energy management functions, as well as the high-speed performance for protection applications.

IEC 61850 includes a combination of mandatory and optional DOs and DAs to support interoperability and flexibility. However, increased model complexity leads to differences in IEC 61850 implementations, which results in significant challenges for interoperability, and the engineering, testing, and maintenance of IEC 61850 based protection, automation, and control systems. A solution to address these challenges is to limit the flexibility of the standard that results in often incompatible implementations. This means developing a profile of the standard which is focused on meeting specific requirements that are useful across a range of electric power systems. A profile can address interoperability challenges because:

- All DOs and DAs included in the profile are mandatory, even if they are optional in the core standard; and
- Certification testing is based on profile definitions instead of a manufacturer defined implementation.

The generic model of a DER according to IEC 61850-7-420 is built using LNs that can be categorized as shown in Table 1 below [3]. Each category may contain multiple LNs and LNs can be grouped in hierarchical LDs. Decomposition of the profile presented in this document follows this generic DER model.

Table 1 Logical nodes of the DER Generic Model Skeleton for IEC 61850-7-420 [3]

Model Component	LN Name
A model of the DER	DEResourceLN
A model of the electrical reference point	ElectricalReferencePointLN
A model of the power management function	PowerManagementLN
Models of the operational functions	OperationalFunctionLN

The profile includes the models of the following operational functions:

- Voltage disturbance
- Frequency disturbance
- Return to service after trip
- Voltage and reactive power control
- Voltage and active power control
- Control capability requirements

In addition to this generic model, there may be technology specific information available, for example the details of a specific photovoltaic array.

The profile is based on the hierarchical modeling principles of IEC 61850, which are introduced in Section 2.2.

2.2. IEC 61850 Modeling Principles Applied to a DER Controller

The IEC 61850 model is based on a functional hierarchy that is shown in a simplified form in Table 2 below.

Table 2 IEC 61850 abstract model and the functional hierarchy contained in the model (terms are given in decreasing hierarchical order)

IEC 61850 Abstract Model [3]	Functional Hierarchy
Server	DER controller
Logical device	Function
Logical node	Function element
Data object	Domain specific information available in a device
Data attribute	Single value descriptor for domain specific information (data object)

The DER controller is modeled as a server containing different functions that are represented by LDs. These functions include:

- Process interface (LDs containing ElectricalReferencePointLNs that model circuit breakers and switches);
- Measurements (LDs containing ElectricalReferencePointLNs for measurements at the electrical connection point (ECP) of the inverter and the point of common coupling (PCC));
- DER capabilities and power management (LDs containing DEResourceLNs and PowerManagementLNs); and
- Control and electric power system (EPS) disturbance operation (LDs containing OperationalFunctionLNs).

A function contains function elements – the building blocks of the IEC 61850 model. A LN is defined as "the smallest part of a function that exchanges data". It is an object that is defined by its data and methods.

Multiple instances of different LNs become components of different functions[1] in automated electric power systems. LNs are used to represent individual steps in a function – for example, different under-voltage levels for the trip operation during a voltage disturbance.

LNs contain DOs and DOs contain DAs. A DO represents domain specific information that is available in the devices integrated in a networked automation system. DOs can be simple or complex and can be grouped in data sets as required by the application.

[1] For example, protection, control, and monitoring functions.

One of the main interoperability challenges with IEC 61850 based systems is that a large number of DOs and DAs defined in the IEC 61850 standard are optional. That is why it is neededto define profiles, such as the one described in this document. The profile identifies:

- A subset of LNs that are required to model the functionality of a DER Controller IED,
- A set of optional DOs in specific LNs as mandatory in order to implement the functionality; and
- The grouping of LNs in LDs.

Specific LNs are generally named using four upper case letters with the first letter reserved for the group indicator and the remaining three letters providing a descriptive abbreviation. A prefix can be used to differentiate between LNs that would otherwise have the same four letter name. Examples of group indicators are provided in Table 3 below. Note that a group indicator is not unique to the categories of LNs in the generic DER model, which are given in Table 1 above. For example, LN DXXX can be contained in each of these categories.

Table 3 The naming convention used for specific groups of logical nodes

LN Name	LN Group
DXXX	DERs
MXXX	Measurement
PXXX, RXXX	Protection
TXXX	Instrument transformers and sensors
XXXX	Switchgear

3. Model for DER

The DER for the case of a photovoltaic (PV) based generator is modeled with the following LNs:

- DGEN representing a generic DER generator
- DPVC representing the PV array controller

The DOs for LN DGEN and LN DPVC are given in Table 19 and Table 20, respectively, in Appendix D.

4. Model for Electrical Reference Point

The following LNs are used for modeling an electrical reference point:

- DPCC representing the PCC;

- PoCMMXU1 with the instantaneous measurements at the output of the PV system inverter;
- PCCMMXU2 with the instantaneous measurements at the PCC;
- rmsMMXU3 with the calculated rms values;
- MSQI to monitor and detect short circuit faults or open phase conditions
- XCBR and XSWI representing breakers and switches, respectively; and
- TCTR and TVTR representing current and voltage transformers.

If the DER is single phase connected, LN MMXN replaces LN MMXU. The DOs for these LNs are given in Appendix E.

5. Model for Power Management Function

LN DPMC represents the power management function. This LN

- Receives active and reactive power, and power factor setpoints from operational functions in accordance with the DER strategy; and
- Distributes setpoints and control actions to DER components if DER modeled is a hierarchical system or to the DER itself if it is a single unit.

The DOs for LN DPMC are given in Table 26 in Appendix F.

Power management function LN DPMC also requires setpoint values for operational functions that it references through the DO FctRef. These setpoint values are given in Table 27 in Appendix F.

6. Considerations for the Modeling of Operational Functions from IEEE 1547

Sections 6.1 and 6.2 describe models for managing when a DER should trip during voltage or frequency disturbances, while Section 6.3 describes a model for returning the DER to service after a trip. Sections 6.4 through 6.6 describe models for managing DER active and reactive power control.

6.1. Voltage Disturbance

This section summarizes the modeling of the requirements described in Chapter 6.4 in IEEE 1547 [1]. The requirements considered here are:

- Mandatory voltage tripping requirements
- Voltage disturbance ride-through requirements

Dynamic voltage support as per Chapter 6.4.2.6 in IEEE 1547 is not considered in this document.

A use case for the voltage disturbance requirements is described in Fig. 1 below. Shall trip and ride-through requirements are examined based on the system parameters received from the EPS operator and voltage measurements received from the ECP. Voltage disturbance events are monitored using a ride-through status, which informs the power management function. Due to shall trip and ride-through conditions, a trip signal is fed to the breaker and an operate signal is fed to the power management function, respectively.

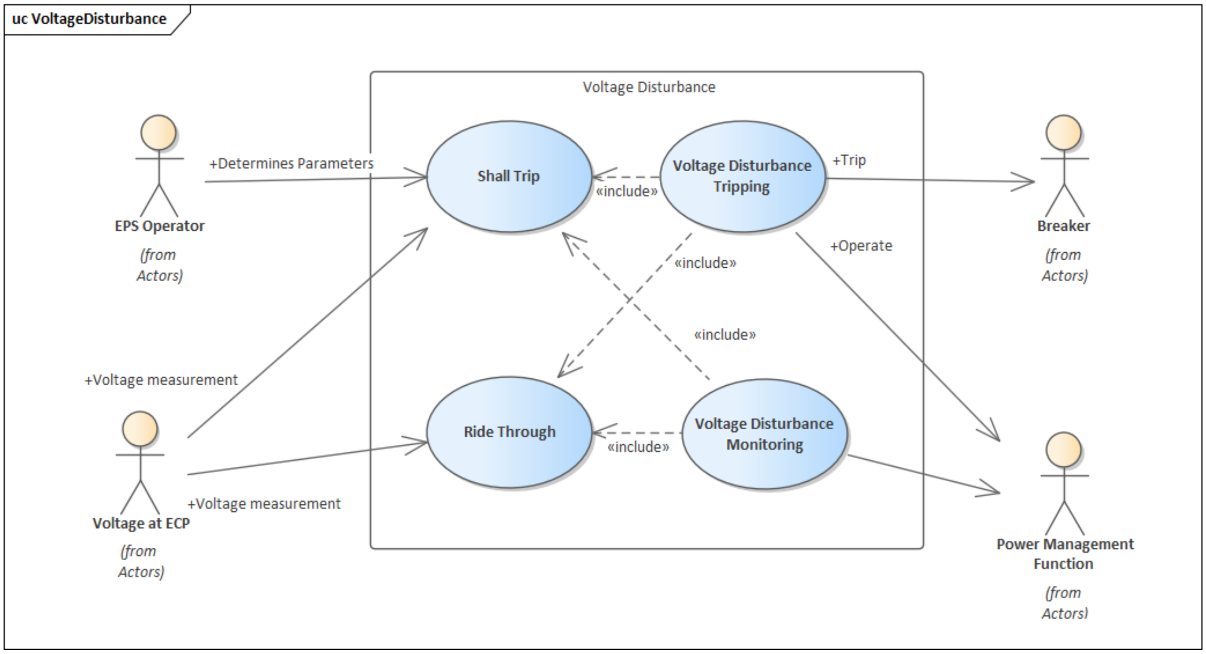

Fig. 1 Use case diagram for voltage disturbance

6.1.1. IEEE 1547 Requirements

Shall trip and *ride-through* requirements are described in Chapter 6.4.1 and Chapter 6.4.2 in IEEE 1547, respectively, and are defined in terms of voltage threshold and clearing time values. Tripping is allowed after the ride-through time is over and before the trip clearing time expires. While the ride-through requirements are fixed, the trip requirements can be set within certain boundaries by the area EPS operator. In some cases, it is possible that the trip is earlier than the duration of the ride through. In that case, tripping has priority. The shall trip and ride-through requirements for a Category III DER are given in Table 13 and Table 16 in IEEE 1547, respectively.

Chapter 6.4.2.5 in IEEE 1547 also specifies the ride-through requirements in the case of consecutive voltage disturbances. The ride-through voltage range and minimum duration requirements for a single disturbance are described in Table 16 in IEEE 1547. The maximum number of ride-through disturbance sets, the minimum time between consecutive disturbance sets, and the time window after which a new count of consecutive disturbance sets would start are provided in Table 17 in IEEE 1547. The ride-through voltage range and cumulative duration for consecutive disturbances can therefore be determined through these requirements.

6.1.2. IEC 61850 Model

The IEC 61850 model for IEEE 1547 voltage disturbance requirements contain LNs that perform the following tasks:

- Identify shall trip and ride-through conditions;
- Monitor voltage disturbances, i.e., identifying high-voltage (HV) and low-voltage (LV) events; and
- Control voltage disturbance tripping, i.e., generating "trip" and "operate" signals.

6.1.2.1. Identifying Shall Trip and Ride-through Conditions

Shall trip and ride-through requirements are modeled using LNs that represent over or under voltage elements:

- LN PTOV (over-voltage)
- LN PTUV (under-voltage)

These over-voltage and under-voltage elements are differentiated based on the specific operation requirement:

- Shall trip requirement: A prefix "Tr" is used for LNs PTOV and PTUV
- Ride-through requirements:
    - Mandatory operation (must ride-through): A prefix "Rt" is used for LNs PTOV and PTUV
    - Momentary cessation: A prefix "Cea" is used for LNs PTOV and PTUV

Shall trip LNs (prefix "Tr") use the requirements from Table 13 in IEEE 1547, whereas ride-through LNs (prefixes "Rt" or "Cea") use the requirements from tables 16 and 17 in IEEE 1547. Each of these LNs also use a numbering convention based on the "distance" to the continuous operation zone. The LN assumes a larger number as the shall trip or ride-through condition is further from the continuous operation zone. Since mandatory operation (prefix "Rt") and momentary cessation (prefix "Cea") are both ride-through requirements, their over-voltage and under-voltage LNs use unique numbers.

This results in the instances of LNs and their DOs as given in Table 4 below for DER of Category III. DOs StrVal, OpDlTmms, and RsDlTmms define a start value for the voltage threshold, an operate delay timer value, and a reset timer value, respectively.

Table 4 Logical nodes modeling 'shall trip' and 'ride-through' requirements for voltage disturbances with the setting values

LN	StrVal (p.u.)	min / max	OpDlTmms (ms)	min / max	RsDlTmms	Remarks
Tr2PTOV	Voltage threshold from Table 13 in IEEE 1547		0			Shall Trip OV2
Tr1PTOV	Voltage threshold from Table 13 in IEEE 1547	Range of values from Table 13 in IEEE 1547	Clearing time from Table 13 in IEEE 1547	Range of values from Table 13 in IEEE 1547		Shall Trip OV1
Cea1PTOV	Voltage threshold from Table 16 in IEEE 1547		Minimum duration from Table 16 in IEEE 1547		Minimum time between disturbance sets from Table 17 in IEEE 1547	Momentary cessation
Rt1PTUV	Voltage threshold from Table 16 in IEEE 1547		Minimum duration from Table 16 in IEEE 1547		Minimum time between disturbance sets from Table 17 in IEEE 1547	Mandatory operation
Tr1PTUV	Voltage threshold from Table 13 in IEEE 1547	Range of values from Table 13 in IEEE 1547	Clearing time from Table 13 in IEEE 1547	Range of values from Table 13 in IEEE 1547		Shall Trip UV1
Rt2PTUV	Voltage threshold from Table 16 in IEEE 1547		Minimum duration from Table 16 in IEEE 1547		Minimum time between disturbance sets from Table 17 in IEEE 1547	Mandatory operation
Cea3PTUV	Voltage threshold from Table 16 in IEEE 1547		Minimum duration from Table 16 in IEEE 1547		Minimum time between disturbance sets from Table 17 in IEEE 1547	Momentary cessation
Tr2PTUV	Voltage threshold from Table 13 in IEEE 1547	Range of values from Table 13 in IEEE 1547	Clearing time from Table 13 in IEEE 1547	Range of values from Table 13 in IEEE 1547		Shall Trip UV2

6.1.2.2. Voltage Disturbance Monitoring

Voltage disturbance events are monitored through the following LNs:

- LN DHVT for the summary of HV events,
- LN DLVT for the summary of LV events,
- LN DVRT (new LN) for handling consecutive disturbances.

6.1.2.3. Voltage Disturbance Tripping

Trip and operate signals are generated using the following LNs:

- LN PTRC for the shall trip,
- LN mayPTRC for the trip in the “may ride-through or may trip zone”.

6.1.2.4. Model Description

The model for IEEE 1547 voltage disturbances is given in Fig. 2. The abbreviations used in Fig. 2 are explained in Sections 6.1.2 and 6.1.3, and in Table 28 and Table 29 in Appendix G.1. The LNs for shall trip and ride-through requirements PTOV and PTUV inform the voltage disturbance tripping LNs PTRC and mayPTRC. Voltage disturbance monitoring LNs DHVT and DLVT also receive information from LNs PTOV and PTUV, respectively, to determine HV and LV events. Using this information, LNs DHVT and DLVT trigger the voltage disturbance monitoring LN DVRT, which leads LN mayPTRC to generate tripping or ride-through signals for consecutive voltage disturbances.

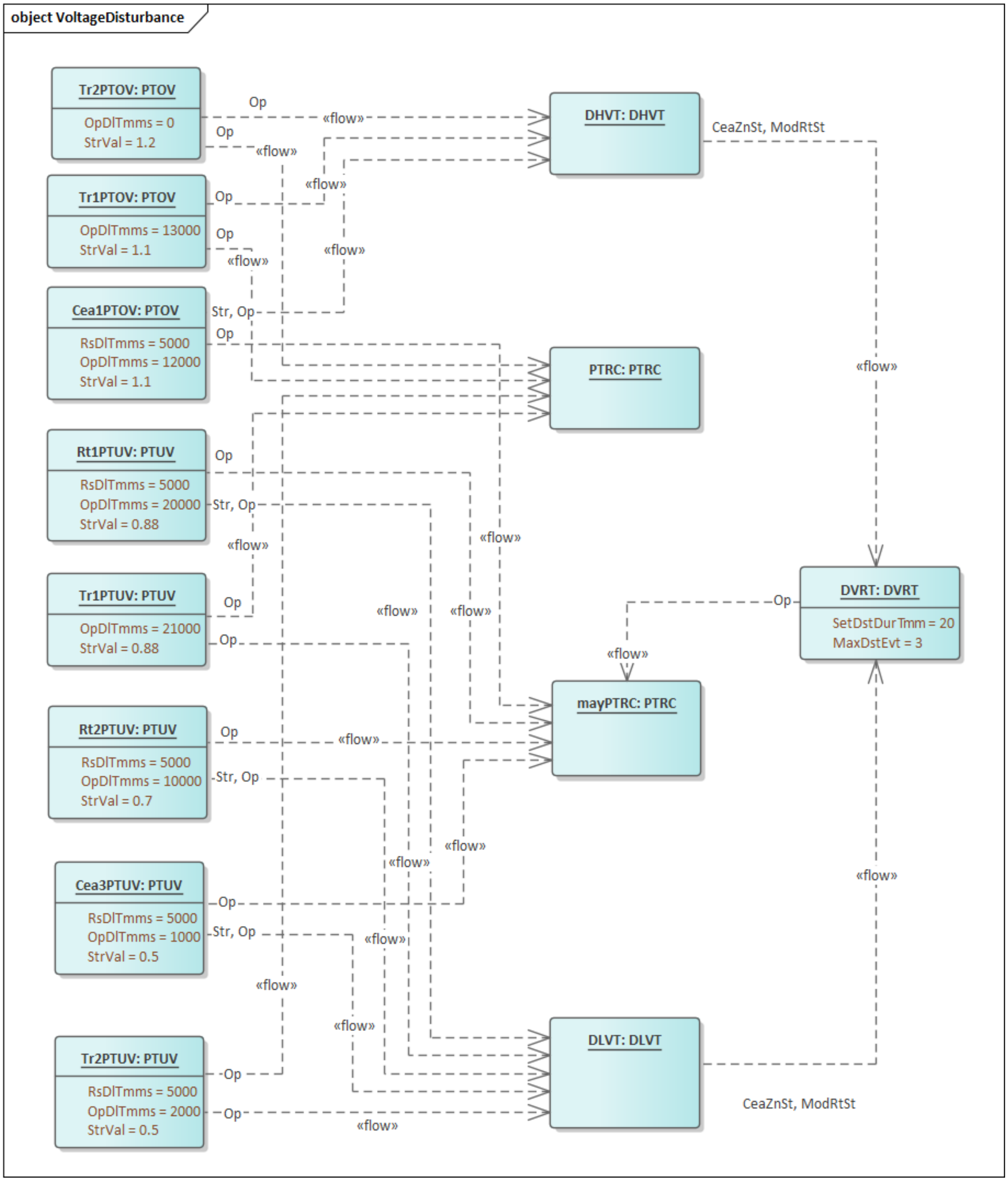

Fig. 2 IEC 61850 model for IEEE 1547 voltage disturbances

6.1.3. Implementation Details

6.1.3.1. Identifying Shall Trip and Ride-through Conditions

Both tripping and ride-through requirements are modeled with multiple over or under voltage elements, as discussed in Section 6.1.2.1. Each of these elements has a start and an operate signal, a start value, an operate delay timer and a reset timer.

For the tripping requirements, start means that the voltage threshold has been crossed; operate results in a trip. For the ride-through, start means a ride-through event has started, operate means, the ride-through time is over and the DER can cease to operate or trip. Depending on the zone, the ride-through event may either be "mandatory operation" or "momentary cessation". As multiple start and operate signals may be active, the ones related to the start value further away from the continuous operation zone are the ones to be considered.

For the trip LNs, the allowed range for the settings shall be configured with the min / max configuration attributes in the IEC 61850 data model. The value to be configured is then determined by the area EPS operator.

For the ride-through LNs, the reset timer is configured according to Table 17 (column 3) in IEEE 1547. For the trip LNs, the reset timer is set to 0 ms.

6.1.3.2. Voltage Disturbance Monitoring

The details for the DOs presented here are given in Table 28 in Appendix G.1. Definitions of DAs for these DOs are also given in Appendix G.1.

The ride-through status is summarized in the DOs for LNs DHVT (Voltage high ride-through) and DLVT (Voltage low ride-through) as follows:

- The signals that operate from the shall trip LN determine the DO TrZnSt (status indicating that the voltage is in the trip zone)
- The signals that start and operate from the mandatory operation LN determine the DO ModRtSt (ride-through event is occurring)
- The signals that start and operate from the momentary cessation LN determine the DO CeaZnSt (momentary cessation is occurring).

To model the requirements for consecutive voltage disturbances, a new LN DVRT (Voltage ride-through) that applies to the voltage ride-through shall be defined with the data in Table 29, which is given in Appendix G.1.

6.1.3.3. Voltage Disturbance Tripping

A LN PTRC is used to create an "operate and a trip" signal from the operate signals of the LNs implementing the "shall trip" requirement. IEEE 1547 specifies that "trip" is "inhibition of immediate return to service, which may involve disconnection [1]." Accordingly, the model shall send PTRC.Tr to a breaker (LN XCBR) if a physical disconnection happens; otherwise, it shall send PTRC.Op to the power management function (LN DPMC).

IEEE 1547 does allow for a range of voltages where the DER may ride-through or may trip.

- This is modeled with mayPTRC (note the prefix "may") to differentiate the required tripping from the trip in the "may ride-through" or "may trip" zone. The operate output of mayPTRC goes to the power management function that can then decide what to do. Alternately, the trip output may be configured to directly trip the breaker.

- The voltage disturbance monitoring LNs DHVT and DLVT shall be extended with a DO indicating that the DER is in the “may ride-through or may trip” zone.

Details for the DOs corresponding to LN PTRC and LN mayPTRC are given in Appendix G.1.

6.2. Frequency Disturbance

This section summarizes the modeling of the requirements described in Chapter 6.5 in IEEE 1547 [1]. The requirements considered here are:

- Mandatory frequency tripping requirements;
- High and low frequency disturbance ride-through requirements;
- Rate of change of frequency (ROCOF) ride-through;
- Voltage phase angle change ride-through requirements; and
- Frequency droop (frequency-power) during low and high frequency ride-through.

A use case for the frequency disturbance requirements is described in Fig. 3 below. Shall trip and ride-through requirements are examined based on the system parameters received from the EPS operator and frequency measurements received from the ECP. Frequency disturbance events are monitored using a ride-through status, which informs the power management function. Due to shall trip and ride-through conditions, a trip signal is fed to the breaker and an operate signal is fed to the power management function, respectively. ROCOF ride-through and voltage phase angle ride-through functions inform; and the frequency droop (during ride-through) function provides an active power setpoint value to the power management function.

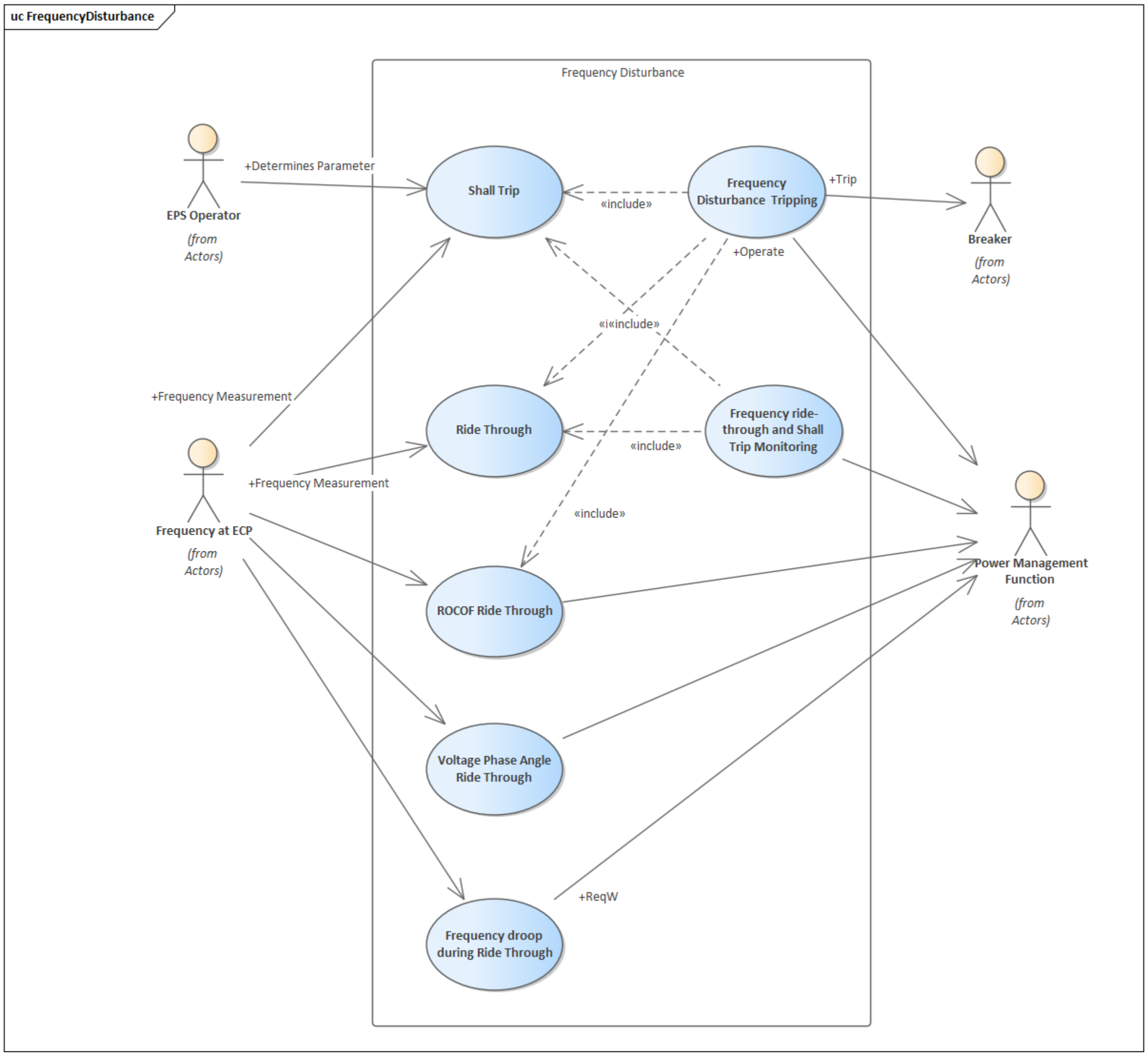

Fig. 3 Use case diagram for frequency disturbance

6.2.1. IEEE 1547 Requirements

Shall trip and *ride-through* requirements are given in Chapters 6.5.1 and 6.5.2 in IEEE 1547, respectively. Shall trip requirements are defined in terms of frequency threshold and clearing time values. Ride-through requirements are defined in terms of frequency ranges for each operation mode and minimum ride-through time. The DER must trip if the fundamental-frequency component of voltage of any phase is greater than a certain percentage of nominal. Tripping is allowed in the period between the ride-through time and the expiration of the trip clearing time. While the ride-through requirements are fixed, the trip requirements can be set within certain boundaries by the area EPS operator. In some cases, it is possible, that the trip is earlier than the duration of the ride-through. In that case, tripping has priority.

The shall trip and ride-through requirements for a Category III DER are given in Table 18 (note that the shall trip requirements are the same for category I, II and III) and Table 19 in IEEE 1547, respectively.

Of note is that Table 19 in IEEE 1547 does not specify an operating mode between 61.8 and 62.0 Hz. Considering Figure 10 in IEEE 1547, we assume that $f > 61.8$ Hz should be "No ride through requirement."

ROCOF ride-through requirements are given in Chapter 6.5.2.5 in IEEE 1547. The maximum ROCOF that a Category III DER is required to ride-through is given in Table 21 in IEEE 1547.

Voltage phase angle changes ride-through requirements are given in Chapter 6.5.2.6 in IEEE 1547. These requirements are considered since unbalanced short circuit faults in the electric power systems can cause sudden shift in the phase angle of the three-phase voltages at the PCC. These requirements specify the values for the following parameters:

- The maximum positive-sequence phase angle change of the applicable voltage that a multi-phase DER shall ride through within a sub-cycle-to-cycle timeframe,
- The maximum change in the phase angles of individual phases that a multi-phase DER shall ride through (the maximum allowable positive-sequence phase angle change for ride-through is defined separately),
- The maximum phase angle change of the applicable voltage that a single-phase DER shall ride through within a sub-cycle-to-cycle timeframe,
- The maximum duration for the momentary cessation of a DER in response to phase angle changes.

Frequency droop (frequency-power) requirements are given in Chapter 6.5.2.7 in IEEE 1547. A DER must operate with a frequency droop when the frequency is outside an adjustable setting. For these operation requirements, nominal values and ranges of allowable values for parameters such as single-sided deadband values, per unit frequency droop gains for high-frequency and low-frequency and open-loop response time are specified in Table 24 in IEEE 1547 for a DER of Category III.

6.2.2. IEC 61850 Model

The IEC 61850 model for IEEE 1547 frequency disturbance requirements contain LNs that perform the following tasks:

- Identifying shall trip and ride-through conditions;
- Frequency shall trip and ride-through monitoring, i.e., identifying high frequency and low frequency events;
- Frequency disturbance tripping, i.e., generating "trip" and "operate" signals;
- Identifying ROCOF ride-through conditions;
- Identifying voltage phase angle changes ride-through conditions; and
- Frequency droop (frequency-power) operation.

6.2.2.1. Identifying Shall Trip and Ride-through Conditions

In order to model the LNs that are used to identify the shall trip and ride-through conditions associated with frequency disturbances, the same approach is taken as described for voltage disturbances in Section 6.1.2.1. LNs for under and over frequency elements are used to model the "shall trip" and "ride-through" requirements as shown in Table 5 below. These LNs contain DOs StrVal and OpDlTmms which define a start value for the frequency threshold and an operate delay timer value, respectively.

Table 5 Logical nodes modeling shall trip and ride-through requirements for frequency disturbances with the setting values

LN	StrVal (Hz)	min / max	OpDlTmms (ms)	min / max	Remarks
Tr2PTOF	Frequency threshold from Table 18 in IEEE 1547	Range of values from Table 18 in IEEE 1547	0	min: 0 max: value from Table 18 in IEEE 1547	Shall Trip OF2
Rt2PTOF	Frequency threshold from Table 19 in IEEE 1547		0		May trip or may ride-through
Tr1PTOF	Frequency threshold from Table 18 in IEEE 1547	Range of values from Table 18 in IEEE 1547	Clearing time from Table 18 in IEEE 1547	Range of values from Table 18 in IEEE 1547	Shall Trip OF1
Rt1PTOF	Frequency threshold from Table 19 in IEEE 1547		Minimum ride-through time from Table 19 in IEEE 1547		Mandatory operation
Rt1PTUF	Frequency threshold from Table 19 in IEEE 1547		Minimum ride-through time from Table 19 in IEEE 1547		Mandatory operation
Tr1PTUF	Frequency threshold from Table 18 in IEEE 1547	Range of values from Table 18 in IEEE 1547	Clearing time from Table 18 in IEEE 1547	Range of values from Table 18 in IEEE 1547	Shall Trip UF1
Rt2PTUF	Frequency threshold from Table 19 in IEEE 1547		0		May trip or may ride-through
Tr2PTUF	Frequency threshold from Table 18 in IEEE 1547	Range of values from Table 18 in IEEE 1547	0	min: 0 max: value from Table 18 in IEEE 1547	Shall Trip UF2

6.2.2.2. Frequency Shall Trip and Ride-through Monitoring

Following a similar approach to the one for voltage disturbance monitoring described in Sections 6.1.2.2 and 6.1.3.2, LNs for frequency high ride-through and frequency low ride-through events are used:

- LN DHFT for the summary of high frequency events,
- LN DLFT for the summary of low frequency events.

6.2.2.3. Frequency Disturbance Tripping

The approach taken for voltage disturbance tripping described in Sections 6.1.2.3 and 6.1.3.3 is followed. The following LNs determine the trip:

- LN PTRC for the shall trip,
- LN mayPTRC for the trip in the “may ride through or may trip zone” (The LNs used for identifying ROCOF ride-through conditions as defined in Section 6.2.2.4 and identifying voltage phase angle changes ride-through conditions as defined in Section 6.2.2.5 inform LN mayPTRC for generating may ride through or may trip signals).

6.2.2.4. ROCOF Ride-through

The ROCOF ride-through shall be modeled with LN PFRC.

6.2.2.5. Voltage Phase Angle Changes Ride-through

For voltage phase angle changes ride-through, two instances of a new LN RPAC are required:

- PhVRPAC for the phase voltage angle change,
- SeqVRPAC for the sequence voltage angle change.

6.2.2.6. Frequency Droop (Frequency-power)

Frequency droop is modeled with two different LNs:

- LN DHFW for the droop operation during high-frequency events,
- LN DLFW for the droop operation during low-frequency events.

6.2.2.7. Model Description

The model for IEEE 1547 frequency disturbances is given in Fig. 4 below. The abbreviations used in Fig. 4 are explained in Sections 6.2.2 and 6.2.3, and in Table 30, Table 31, Table 32, and Table 33 in Appendix G.2. The LNs for identifying shall trip and ride-through conditions PTOF and PTUF inform the frequency tripping LNs PTRC and mayPTRC. Frequency disturbance monitoring LNs DHFT and DLFT also receive information from LNs PTOF and PTUF, respectively, to identify HV and LV events. Phase angle change LNs PhVRPAC and SeqVRPAC, and ROCOF LN PFRC lead LN mayPTRC to generate tripping or ride-through signals based on “may trip or may ride through” conditions. Frequency droop LNs DHFW and DLFW are also included in the model.

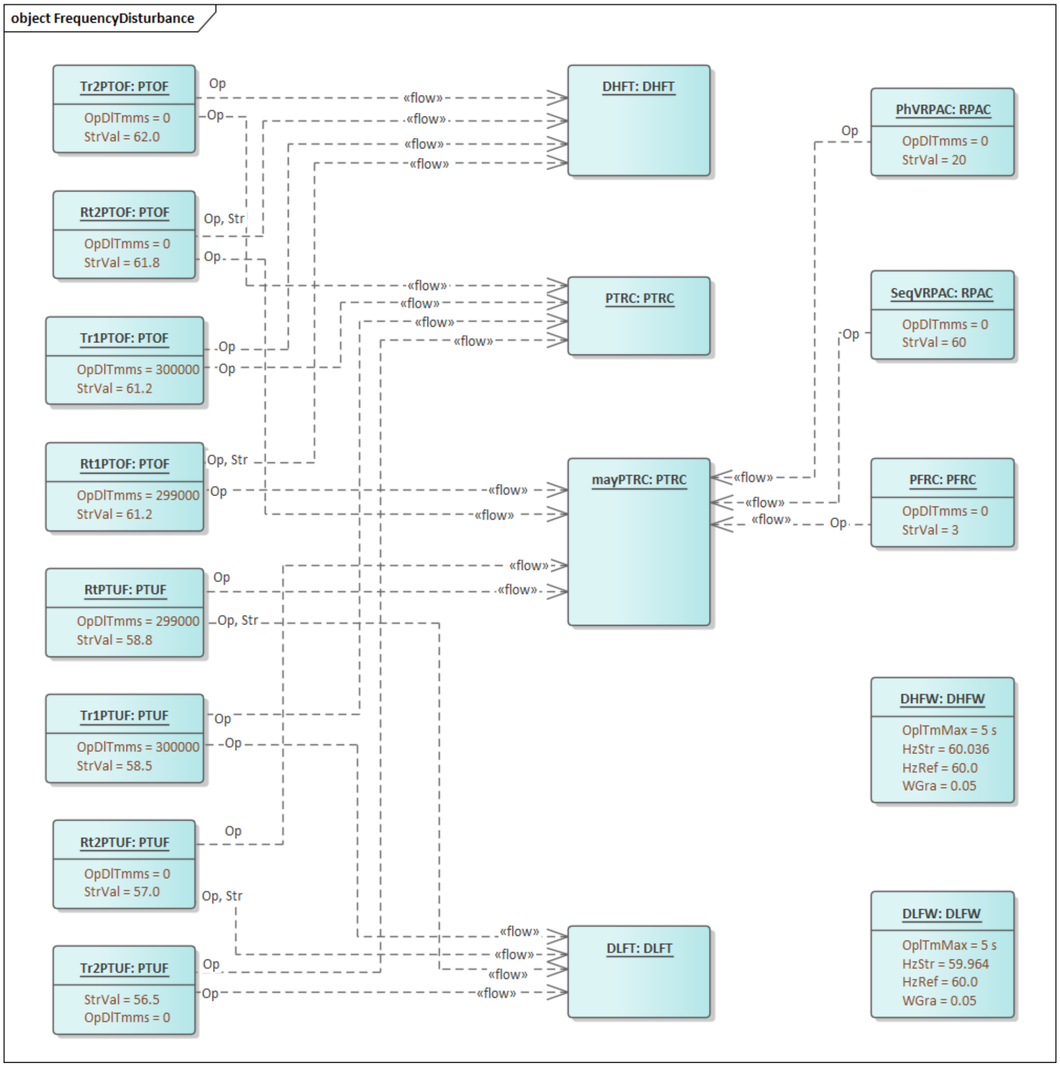

Fig. 4 IEC 61850 model for IEEE 1547 frequency disturbances

6.2.3. Implementation Details

6.2.3.1. Identifying Shall Trip and Ride-through Conditions

The frequency ride-through requirements do not apply, when voltage is outside the ride-through range. This does not raiseany particular concern in the model, assuming that the elements from the frequency ride-through are not blocking any decision the power management function may have based on an indication of a “may ride-through or may trip” zone from the voltage disturbance.

Both tripping as well as ride-through requirements are modeled with multiple over or under voltage elements as discussed in Section 6.2.2.1. Each of these elements has a start and operate signal, a start value, an operate delay timer and a reset timer.

6.2.3.2. Frequency Ride-through and Shall Trip Monitoring

The DO CeaZnSt (momentary cessation is occurring) is not used for the LNs that are defined in Section 6.2.2.2 as the frequency ride-through requirements do not have any momentary cessation requirements. But these LNs shall as well be extended with a DO indicating that the

DER is in the "may ride-through or may trip" zone. The details for the DOs are given in Table 30 in Appendix G.2. Definitions of DAs for these DOs are also given in Appendix G.2.

6.2.3.3. Frequency Disturbance Tripping

Definitions of DOs and DAs for the LNs that are defined in Section 6.2.2.3 are given in Appendix G.2.

6.2.3.4. ROCOF Ride-through

The DOs for the LN PFRC that is defined in Section 6.2.2.4 are given in Table 31 in Appendix G.2.

6.2.3.5. Voltage Phase Angle Changes Ride-through

There is currently no LN in IEC 61850-7-4 or IEC 61850-7-420 that can be used for modeling of voltage phase angle change ride-through. A new protection related LN RPAC for monitoring phase angle change is proposed to be added to IEC 61850-7-4. LN RPAC has two instances PhVRPAC and SeqVRPAC as defined in Section 6.2.2.5.

The modeling for the voltage phase angle change is shown in Fig. 5. LNs TCTR1 and TVTR1, which are contained in LD PCMU (PCC merging unit), provide sampled values of PCC current (I) and voltage (V) to measurement LNs MMXU1 and MSQI1 contained in LD MEAS. These LNs calculate instantaneous measurement values of the electrical parameters at the PCC and transmit them to the LD HzDST for voltage phase angle disturbance operation. The voltage phase angles from LN MMXU1 can be used in the new LN PhVRPAC to determine the changes in the phase angles of each phase voltage and determine if these phase angles exceed the specified threshold. The calculated sequence component values from LN MSQI1 can be used in the new LN SeqVRPAC to determine the changes in the phase angles of each phase voltage or the change in the positive sequence voltage phase angle and determine if these phase angles exceed the specified threshold.

If RPAC operates instantaneously or after a settable time delay, it will send a signal to the power management function.

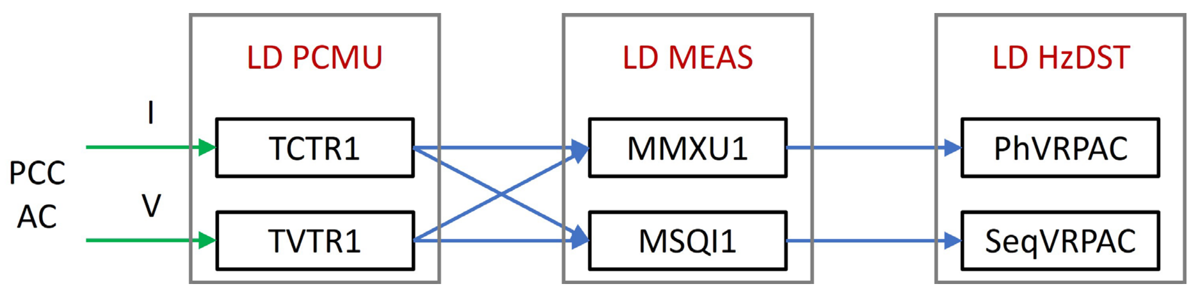

Fig. 5 Modeling of voltage phase angle change

The DOs of the LN RPAC are given in Table 32 in Appendix G.2. Furthermore, it is proposed to add the DO PhVAngChg (CDC WYE) to the LN MMXU and SeqVAngChg (CDC SEQ) to the LN MSQI.

6.2.3.6. Frequency Droop (Frequency-power)

The DOs for LNs DHFW and DLFW, which are defined in Section 6.2.2.6, are given in Table 33 in Appendix G.2.

6.3. Return to Service After Trip

6.3.1. IEEE 1547 Requirements

Chapters 4.10 and 6.6 in IEEE 1547 define the conditions for *entering service* or *returning to service after trip* [1]. These conditions determine

- The minimum delay time;
- The enter service period;
- The requirements for increasing active power during the enter service period; and
- The upper and lower limits on voltage and frequency.

The return to service values for voltage and frequency limits for a Category I, II or III DER are specified in Table 4 in IEEE 1547. In addition to voltage and frequency conforming to the limits, the "Permit Service Setting" (which determines whether a DER is allowed to enter or remain in service) needs to be enabled to return to service. For the minimum delay time, the enter service period, and the requirements for increasing active power during the enter service period, the following criteria apply (as specified in Chapter 4.10.3 in IEEE 1547):

- DER shall have a setting for a minimum delay to enter service, once the voltage and frequency are within the specified range. The delay shall have a default value and be configurable between lower and upper bounds.
- The enter service period shall have a default value and be configurable between lower and upper bounds.
- DER shall increase active power with a linear or stepwise ramp with a rate of change not exceeding rated active power divided by the enter service period.
- If stepwise ramping is used, a step shall not be more than a certain fraction of the active power rating.

6.3.2. IEC 61850 Model and Implementation Details

The parameters defining the conditions for return to service after trip is modeled with a LN DCTE. Note that LN DCTE also models the cease to energize request, which is out of the scope of this profile.

This LN manages return to service based on the information for upper and lower limits on voltage and frequency, and the minimum delay time and the enter service period. These parameters are represented by the DOs for LN DCTE, which are given in Table 34 in Appendix G.3.

Note that DO RtnSrvAuth (automatic return to service authorized) is used to support the capability to disable permit service. Also, see Appendix G.3, for further details on the use of DO RtnSrvAuth for the permit service requirement.

6.4. Voltage and Reactive Power Control

This section summarizes the modeling of the control functions described in Chapter 5.3 in IEEE 1547 [1]. The control functions considered here are:

- Constant power factor mode
- Voltage-reactive power mode
- Active power-reactive power mode
- Constant reactive power mode

The DER shall be capable of activating each of these modes one at a time.

The above voltage and reactive power control functions do not create a requirement for the DER to operate at points outside of the minimum reactive power capabilities specified in Chapter 5.2 in IEEE 1547.

A use case for voltage and reactive power control is described in Fig. 6 below. Each of the modes are enabled by information received from the EPS operator. The EPS operator also determines the system parameters used by these modes. Except for the constant power factor mode, all modes require voltage measurements from the ECP. Constant power factor mode provides a power factor setpoint value and other modes provide reactive power setpoint values to the power management function.

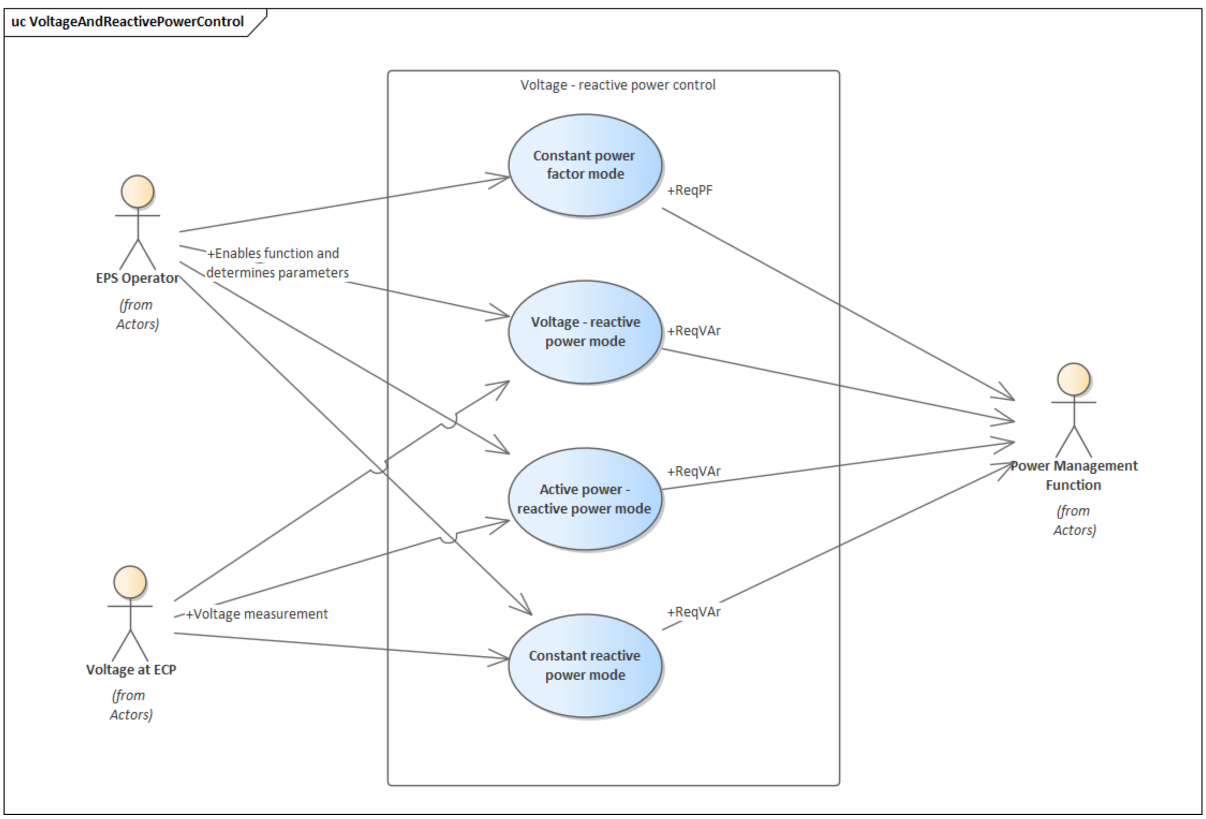

Fig. 6 Use case diagram for voltage and reactive power control

6.4.1. IEEE 1547 Requirements

In the *constant power factor mode*, the DER receives the setpoint for the power factor from the EPS operator. The maximum response time to achieve the desired power factor is specified in Chapter 5.3.2 in IEEE 1547.

In the *voltage-reactive power mode*, reactive power is controlled as a piecewise linear function of voltage (an example voltage-reactive power curve is given in Figure H.4 in IEEE 1547). The voltage-reactive power curve under normal operating conditions is specified for a Category B DER by the values given in Table 8 in IEEE 1547. The EPS operator may specify the values in the range of allowable settings.

In the *active power-reactive power mode*, reactive power is controlled as a piecewise linear function of active power (an example active power-reactive power curve is given in Figure H.5 in IEEE 1547). The active power-reactive power curve under normal operating conditions is specified for a Category B DER by the values given in Table 9 in IEEE 1547. The EPS operator may specify the values in the range of allowable settings.

In the *constant reactive power mode*, the DER receives the setpoint for the reactive power from the EPS operator. The maximum response time to achieve the desired reactive power is specified in Chapter 5.3.5 in IEEE 1547.

6.4.2. IEC 61850 Model

The voltage and reactive power control modes are represented by LNs in the IEC 61850 model. These LNs are:

- LN DFPF (constant power factor mode)
- LN DVVR (voltage-reactive power mode)
- LN DWVR (active power-reactive power mode)
- LN DVAR (constant reactive power mode)

An overview of the model for voltage and reactive power control is shown in Fig. 7 below. It shows the LNs for the four functions that issue setpoints towards the LN for the power management function.

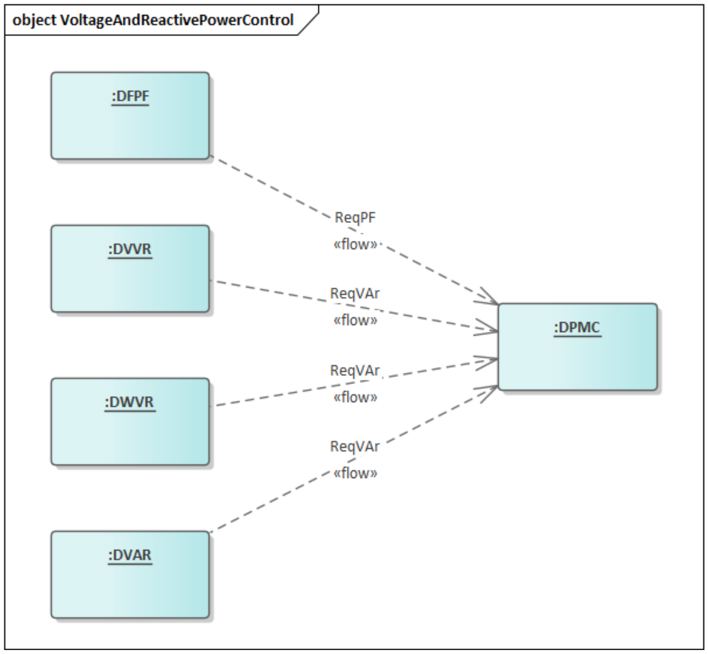

Fig. 7 IEC 61850 model for voltage and reactive power control

6.4.3. Implementation Details

The settings for each voltage and reactive power control mode are defined through the DOs for the LNs for each mode. These DOs are given in Appendix G.4 with the following organization:

- LN DFPF (constant power factor mode): Table 35 in Appendix G.4
- LN DVVR (voltage-reactive power mode):
    - DOs are given in Table 36 in Appendix G.4
    - DAs for the DO VVArCrv (defines the voltage-reactive power curve) are given in Table 37 in Appendix G.4
- LN DWVR (active power-reactive power mode):
    - DOs are given in Table 38 in Appendix G.4
    - DAs for the DO WVArCrv (defines the active power-reactive power curve) are given in Table 39 in Appendix G.4
- LN DVAR (constant reactive power mode): Table 40 in Appendix G.4

The following implementation details should be noted for these LNs.

IEC 61850 defines the LN DFPF to set the power factor and the quadrant with the possibility of different settings for generating and consuming.

LNs DVVR and DWVR define the reactive power values of the respective voltage-reactive power and active power-reactive power curves as one of the following:

- Percentage of maximum active power
- Percentage of maximum reactive power
- Percentage of available reactive power

However, the default settings of IEEE 1547 require a percentage of nameplate apparent power. According to Figure H.3 in IEEE 1547, the rated active power (P_{rated}) is less than the rated apparent power (S_{rated}). So, an option is needed to be added in IEC 61850 to use the rated apparent power as a reference. Also, for these references, IEC 61850 assumes the operational setting values instead of the nameplate values.

For LN DWVR, the DO WBarEna, which is defined in Table 38 in Appendix G.4, shall be true since the active power-reactive power curve defines exact values to be followed, not bounds.

In IEC 61850, a reactive power can be set through the LN DVAR. The setpoint for reactive power can either be an absolute value or a percentage. A percentage valued setpoint will be used in the model.

6.5. Voltage and Active Power Control

This section summarizes the modeling of the requirements for the voltage-active power control mode described in Chapter 5.4 in IEEE 1547. The area EPS operator may deactivate or activate this function [1].

A use case for voltage and active power control is described in Fig. 8 below. The EPS operator enables the voltage-active power mode and determines the system parameters used by this mode. This mode of operation requires a voltage measurement from the ECP and provides an active power setpoint value to the power management function.

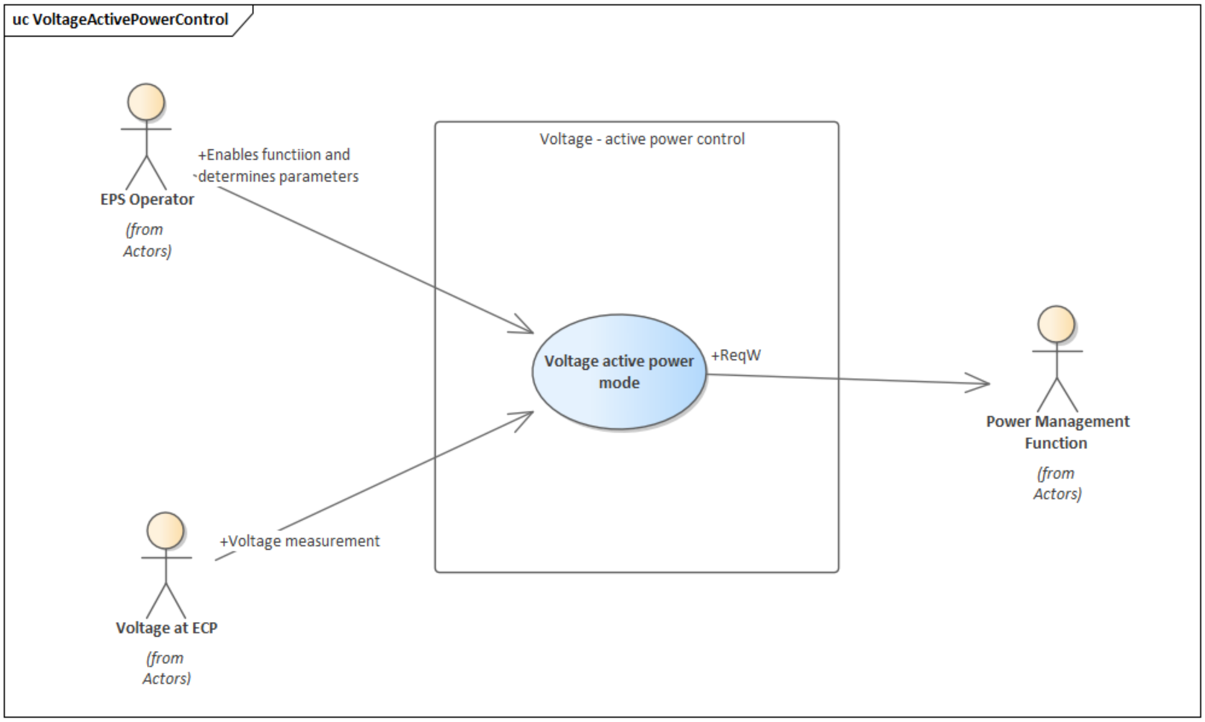

Fig. 8 Use case diagram for voltage and active power control

6.5.1. IEEE 1547 Requirements

In the *voltage-active power mode*, the DER maximum active power is limited using a piecewise linear function of voltage as upper bound (examples of such voltage-active power curves are given in Figure H.6 in IEEE 1547). The voltage-active power curve under normal operating conditions is specified by the values given in Table 10 in IEEE 1547. The EPS operator may specify the values in the range of allowable settings.

6.5.2. IEC 61850 Model and Implementation Details

In IEC 61850, the voltage-active power mode is modeled with LN DVWC. The settings for this mode of operation are defined through the DOs for LN DVWC, which are given in Table 41 in Appendix G.5. The DAs for DO VWCrv (defines the voltage-active power curve) are given in Table 42 in Appendix G.5.

LN DVWC defines the active power values of the voltage-active power curve as one of the following:

- Absolute value
- Percent of maximum active power
- Percent of snapshot active power
- Percent of available range of active power
- Percent of full range of active power

IEEE 1547 refers to the rated active power, which corresponds to the maximum active power in IEC 61850.

6.6. Control Capability Requirements

This section summarizes the modeling of the control capability requirements described in Chapter 4.6 in IEEE 1547 [1]. The requirements considered here are:

- Capability to disable permit service
- Capability to limit active power

6.6.1. IEEE 1547 Requirements

Chapter 4.6.1 in IEEE 1547 specifies the maximum time for the DER to *disable* the *permit service setting*, to cease to energize the area EPS and to trip. Chapter 4.6.2 in IEEE 1547 also provides a requirement for the DER to *limit active power* as a percentage of the nameplate active power rating.

6.6.2. IEC 61850 Model and Implementation Details

The control capability requirements are represented by LNs in the IEC 61850 model. These LNs are described below.

- LN DCTE defines the capability to disable permit service. This LN also defines the conditions for returning to service after trip, as given in Section 6.3.2. The DOs for this LN are given in Table 34 in Appendix G.3. In order to disable permit service, the value of the DA DCTE.RtnSrvAuth is set to false.
- LN DWMX defines the capability to limit active power. The settings for this capability are specified through the DOs given in Table 43 in Appendix G.6.

References

[1] IEEE (2018) *IEEE Std 1547-2018 (Revision of IEEE Std 1547-2003) – IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces* (IEEE), p 138. https://doi.org/10.1109/IEEESTD.2018.8332112

[2] IEC (2022) *IEC 61850:2022 SER Series – Communication Networks and Systems for Power Utility Automation - ALL PARTS* (IEC), p 8043.

[3] IEC (2021) *IEC 61850-7-420:2021 – Communication Networks and Systems for Power Utility Automation - Part 7-420: Basic Communication Structure - Distributed Energy Resources and Distribution Automation Logical Nodes* (IEC), p 1126.

[4] IEC (2020) *IEC 61850-7-4:2010+AMD1:2020 CSV Consolidated version – Communication Networks and Systems for Power Utility Automation - Part 7-4: Basic Communication Structure - Compatible Logical Node Classes and Data Object Classes* (IEC), p 490.

Appendix A Supplemental Materials

An IED capability description (ICD) file containing the model for the IEC 61850 profile supporting IEEE 1547 presented in this document can be accessed at https://doi.org/10.18434/mds2-2615.

Appendix B IEEE 1547 Information Exchange Requirements

A set of mandatory information elements that shall be supported by the DER is defined in Chapters 10.3-10.6 in IEEE 1547. These information elements can be categorized as given in Chapter 10.2 in IEEE 1547 [1]:

- Nameplate information: This information provides the as-built characteristics of the DER and may be read.
- Configuration information: This information provides the present capacity and ability of the DER to perform functions and may be read or written.
- Monitoring information: This information provides the present operating conditions of the DER and may be read.
- Management information: This information is utilized for modifying functional and mode settings for the DER and may be read or written.

This appendix describes how this information is mapped to the IEC 61850 data model presented in this profile.

B.1. Nameplate and Configuration Information

Nameplate information describes the rated values based on the declaration by the manufacturer. As specified in Chapter 10.4 in IEEE 1547, each rating may have an associated configuration setting that represents the as-configured value. If a configuration setting value is different from the corresponding nameplate value, the configuration setting value shall be used as the rating within the DER. In Table 6 below, for the IEC 61850 objects, the nameplate value is shown first and the configuration setting is shown second if available.

Table 6 Nameplate and configuration information

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Active power rating at unity power factor (nameplate active power rating)	Active power rating in watts at unity power factor	DGEN.WMaxRtg DGEN.WMax
Active power rating at specified over-excited power factor	Active power rating in watts at specified over-excited power Factor	DGEN.WOvPFRtg
Specified over-excited power factor	Over-excited power factor as described in Chapter 5.2 in IEEE 1547	DGEN.OvPFRtg

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Active power rating at specified under-excited power factor	Active power rating in watts at specified under-excited power Factor	DGEN.WUnPFRtg
Specified under-excited power factor	Under-excited power factor as described in Chapter 5.2 in IEEE 1547	DGEN.UnPFRtg
Apparent power maximum rating	Maximum apparent power rating in voltamperes	DGEN.VAMaxRtg DGEN.VAMax
Normal operating performance category	Indication of reactive power and voltage/power control capability. (Category A/B as described in Chapter 1.4 in IEEE 1547)	DGEN.RegClas
Abnormal operating performance category	Indication of voltage and frequency ride-through capability Category I, II, or III, as described in Chapter 1.4 in IEEE 1547	DGEN.RegClas
Reactive power injected maximum rating	Maximum injected reactive power rating in vars	DGEN.IvarMaxRtg DGEN.IvarMax
Reactive power absorbed maximum rating	Maximum absorbed reactive power rating in vars	DGEN.AvarMaxRtg DGEN.AvarMax
Active power charge maximum rating	Maximum active power charge rating in watts	DLOD.WMaxRtg DLOD.WMax
Apparent power charge maximum rating	Maximum apparent power charge rating in voltamperes. May differ from the apparent power maximum rating	DLOD.VAMaxRtg DLOD.VAMax
AC voltage nominal rating	Nominal AC voltage rating in RMS volts	DECP.EcpVRtg
AC voltage maximum rating	Maximum AC voltage rating in RMS volts	DGEN.VMaxRtg DGEN.VMax
AC voltage minimum rating	Minimum AC voltage rating in RMS volts	DGEN.VMinRtg DGEN.VMin
Supported control mode functions	Indication of support for each control mode function	Presence of any of the LNs representing the model of the function
Reactive susceptance that remains connected to the Area EPS in the cease to energize and trip state	Reactive susceptance that remains connected to the Area EPS in the cease to energize and trip state	DGEN.SuscRtg
Manufacturer	Manufacturer	LPHD.PhyNam.vendor
Model	Model	LPHD.PhyNam.model
Serial number	Serial number	LPHD.PhyNam.serNum
Version	Version	LPHD.PhyNam.hwRev LPHD.PhyNam.swRev

The data related to charging, which is mapped to LN DLOD (represents a load), is only relevant if the DER supports charging.

The data mapped to the LN DECP could as well be used from a LN DPCC, depending on if the electrical connectivity point is a PCC or not.

To identify the performance category, IEC 61850 introduces a DO RegClas – regulatory classification. IEC 61850-7-420 provides the following information for this DO:

- "Regulatory classification, using text strings which may have pre-specified values. For example, for IEEE 1547:2018, the specified text is "IEEE 1547:2018 Normal Category A (B) & Abnormal Category I (II,III)", where either "A" or "B" is stated for the Normal Category and either "I", "II", or "III" is stated for the Abnormal Category [3]."

Concerning the manufacturer, mode, serial number and version information, the following are differentiated:

- The DER controller – this is modeled with the LPHD as shown in Table 6 above,
- The DER Inverter – this is modeled with DINV.EEName,
- The DER itself (e.g. Photo voltaic installation) – this is modeled with DPVC.EEName.

B.2. Monitoring Information

The monitoring information required as defined in Chapter 10.5 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 7 below.

Table 7 Monitoring information

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Active power	Active power in watts	MMXU.TotW
Reactive power	Reactive power in vars	MMXU.TotVAr
Voltage	Voltage(s) in volts. (One parameter for single-phase systems and three parameters for three-phase systems)	MMXU.PhV MMXU.PNV
Frequency	Frequency in Hertz	MMXU.Hz
Operational State	Operational state of the DER. The operational state should represent the current state of the DER. The minimum supported states are on and off but additional states may also be supported	DGEN.DEROpSt
Connection Status	Power-connected status of the DER	DGEN.DEROpSt XCBR.Pos XSWI.Pos
Alarm Status	Active alarm status	LPHD.PhyHealth

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Operational State of Charge	0% to 100% of operational energy storage capacity	DSTO.SocUsePct

Concerning the alarm status:

- LPHD.PhyHealth would indicate an alarm of the inverter controller,
- DPVC.EEHealth would indicate an alarm of the DER in case it is a photo voltaic installation.

B.3. Management Information

The following sections present the management information required for various IEEE 1547 operational functions and the mapping of this information to the IEC 61850 data model.

B.3.1. Constant Power Factor Mode

The management information required for constant power factor mode as defined in Chapter 10.6.2 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 8 below.

Table 8 Management information for constant power factor mode

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Constant Power Factor Mode Enable	Enable constant power factor mode	DEPF.FctEna
Constant Power Factor	Constant power factor setting	DEPF.PFGnTgtSet
Constant Power Factor Excitation	Constant power factor excitation setting	DEPF.PFGnExtSet

B.3.2. Voltage-Reactive Power Mode

The management information required for voltage-reactive power mode as defined in Chapter 10.6.3 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 9 below.

Table 9 Management information for voltage-reactive power mode

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Voltage-Reactive Power Mode Enable	Enable voltage-reactive power mode	DVVR.FctEna
*V*Ref	Reference voltage	DVVR.VRefEsp
Autonomous *V*Ref adjustment Enable	Enable/disable autonomous *V*Ref adjustment	DVVR.VRefAdjEna
*V*Ref adjustment time constant	Adjustment range for *V*Ref time constant	DVVR.VRefTmms
V/Q Curve Points	Voltage-reactive power curve points	DVVR.VVArCrv
Open Loop Response Time	Time to ramp up to 90% of the new reactive power target in response to the change in voltage	DVVR.OpnLoopMax

B.3.3. Active Power-Reactive Power Mode

The management information required for active power-reactive power mode as defined in Chapter 10.6.4 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 10 below.

Table 10 Management information for active power-reactive power mode

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Active Power-Reactive Power Mode Enable	Enable active power-reactive power mode	DWVR.FctEna
P/Q Curve Points	Active power-reactive power curve points	DWVR.WVArCrv

B.3.4. Constant Reactive Power Mode

The management information required for constant reactive power mode as defined in Chapter 10.6.5 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 11 below.

Table 11 Management information for constant reactive power mode

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Constant Reactive Power Mode Enable	Enable constant reactive power mode	DVAR.FctEna
Constant Reactive Power	Constant reactive power setting	DVAR.VArTgtPctSpt

B.3.5. Voltage-Active Power Mode

The management information required for voltage-active power mode as defined in Chapter 10.6.6 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 12 below.

Table 12 Management information for voltage-active power mode

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Voltage-Active Power Mode Enable	Enable voltage-active power mode	DVWC.FctEna
V/P Curve Points	Voltage-active power curve points	DVWC.VWCrv
Open Loop Response Time	Time to ramp up to 90% of the new active power target in response to the change in voltage	DVWC.OpnLoopMax

B.3.6. Voltage Trip

The management information required for voltage trip as defined in Chapter 10.6.7 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 13 below. Note that instead of a curve, individual start values and operate delays are used.

Table 13 Management information for voltage trip

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
HV Trip Curve Points	High-voltage shall trip curve points	Tr1PTOV.StrVal Tr1PTOV.OpDlTmms Tr2PTOV.StrVal Tr2PTOV.OpDlTmms
LV Trip Curve Points	Low-voltage shall trip curve points	Tr1PTUV.StrVal Tr1PTUV.OpDlTmms Tr2PTUV.StrVal Tr2PTUV.OpDlTmms

B.3.7. Momentary Cessation

The management information required for momentary cessation parameters as defined in Chapter 10.6.7 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 14 below. Note that instead of a curve, individual start values and operate delays are used.

Table 14 Management information for momentary cessation

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
HV Momentary Cessation Curve Points	High-voltage momentary cessation curve points	Cea1PTOV.StrVal Cea1PTOV.OpDlTmms
LV Momentary Cessation Curve Points	Low-voltage momentary cessation curve points	Cea3PTUV.StrVal Cea3PTUV.OpDlTmms

B.3.8. Frequency Trip

The management information required for frequency trip parameters as defined in Chapter 10.6.8 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 15 below. Note that instead of a curve, individual start values and operate delays are used.

Table 15 Management information for frequency trip

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
HF Trip Curve Points	High frequency shall trip curve points	Tr1PTOF.StrVal Tr1PTOF.OpDlTmms Tr2PTOF.StrVal Tr2PTOF.OpDlTmms
LF Trip Curve Points	Low frequency shall trip curve points	Tr1PTUF.StrVal Tr1PTUF.OpDlTmms Tr2PTUF.StrVal Tr2PTUF.OpDlTmms

B.3.9. Frequency Droop

The management information required for frequency droop mode as defined in Chapter 10.6.9 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 16 below.

Table 16 Management information for frequency droop

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Overfrequency Droop dbOF	Frequency droop deadband for overfrequency conditions	DHFW.HzStr
Underfrequency Droop dbUF	Frequency droop deadband for underfrequency conditions	DLFW.HzStr
Overfrequency Droop kOF	Frequency droop per unit frequency change for overfrequency conditions corresponding to 1 per unit power output change	DHFW.WGra
Underfrequency Droop kUF	Frequency droop per unit frequency change for underfrequency conditions corresponding to 1 per unit power output change	DLFW.WGra
Open Loop Response Time	The duration from a step change in control signal input until the output changes by 90% of its final change, before any overshoot	DHFW.OpnLoopMax DLFW.OpnLoopMax

B.3.10. Enter Service After Trip

The management information required for enter service after trip as defined in Chapter 10.6.10 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 17 below.

Table 17 Management information for enter service after trip

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Permit service	Able to enter or stay in service	DCTE.RtnSrvAuth
ES Voltage High	Enter service voltage high	DCTE.VHiLim
ES Voltage Low	Enter service voltage low	DCTE.VLoLim
ES Frequency High	Enter service frequency high	DCTE.HzHiLim
ES Frequency Low	Enter service frequency low	DCTE.HzLoLim
ES Delay	Enter service delay	DCTE.RtnDlTmms
ES Randomized Delay	Enter service randomized delay	Not available*
ES Ramp Rate	Enter service ramp rate	DCTE.RtnRmpTmms

**NOTE on IEEE 1547 and IEC 61850-7-420: It is unclear if the randomized delay shall be a separate parameter or rather a range within which the randomization shall happen. No DO is available in IEC 61850-7-420.*

B.3.11. Limit Maximum Active Power

The management information required for limit maximum active power as defined in Chapter 10.6.12 in IEEE 1547 with the mapping to the IEC 61850 data model is shown in Table 18 below.

Table 18 Management information for limit maximum active power

Parameter [1]	Description [1]	IEC 61850-7-4/420 Data Object [3, 4]
Limit Active Power Enable	Enable mode	DWMX.FctEna
Maximum Active Power	Maximum active power setting	DWMX.WLimPctSpt

Appendix C Considerations for Voltage Disturbance

C.1. Trip Delay

Table 13 in IEEE 1547 specifies the maximum disconnection time from fault inception, $T_{trip,max}$, for a Category III DER. The value of the disconnection time is given by the sum of the following parameters:

- The time for the PTUV or PTOV to start – this for most of today's devices is about 20 ms,
- The time delay setting OpDlTmms,
- The breaker tripping time – this is assumed to be about 80 ms for a 5-cycle breaker.

Therefore, the DER voltage trip function maximum time delay setting where an immediate trip is required shall satisfy:

- Tr2PTUV.OpDlTmms $\leq T_{trip,max}^{UV2} - (100\ ms)$.

An example for the must trip requirement for voltage disturbances is illustrated in Fig. 9. This illustration is based on Figure H.9 in IEEE 1547, which provides the requirements for voltage disturbances for a Category III DER [1]. The horizontal and vertical axes represent time and percent of rated voltage, respectively. The bounds that determine various under and over voltage regions are marked on the vertical axis. The maximum time interval between fault inception and disconnection is marked along the horizontal axis for each under and over voltage region.

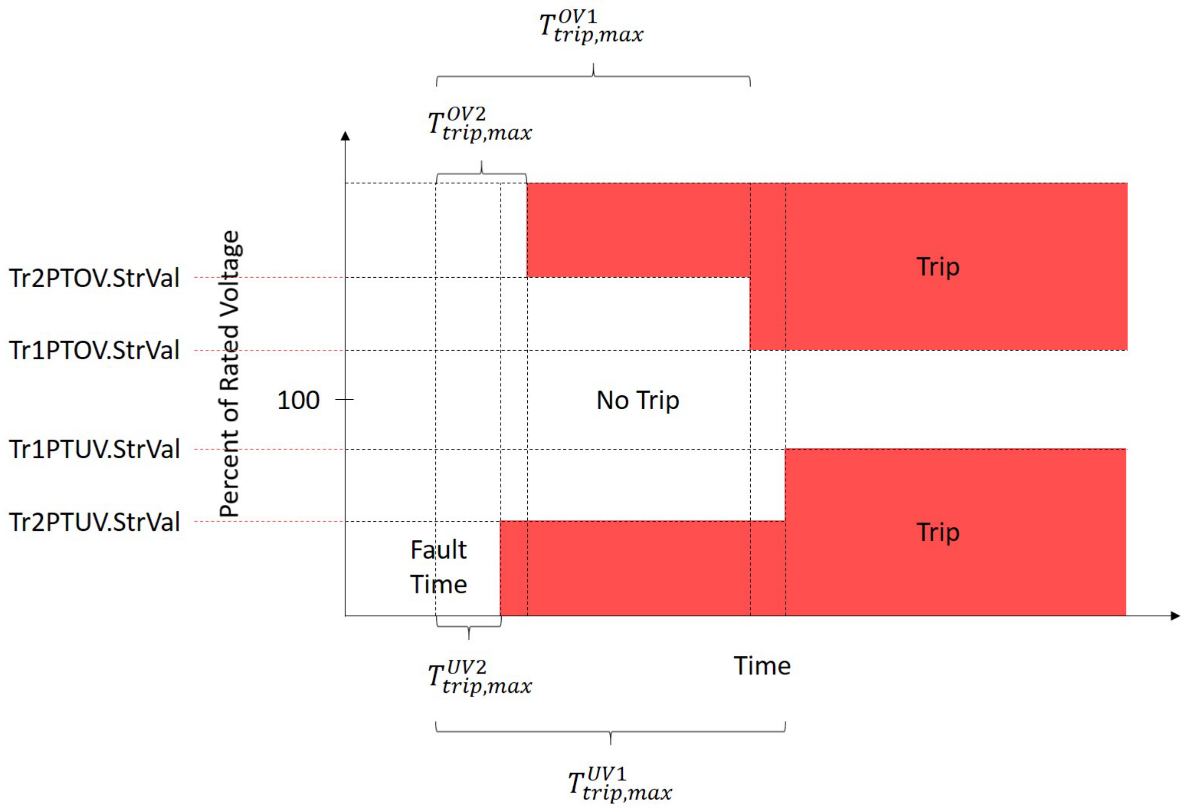

Fig. 9 Illustration of must trip requirements for voltage disturbances with different threshold values (based on Figure H.9 in IEEE 1547 [1])

C.2. Fault Patterns

During a single phase line-to-ground fault, it is possible to have simultaneously undervoltage in the faulted phase and overvoltage in the healthy phases. This is shown by the simulated waveform in Fig. 10. In this scenario, phase A faults at 0.5 s and the healthy phases are B and C. Prior to the fault time, all of the three phases are sinusoidal signals with equal magnitude. After the fault, all of the three phases exhibit transient behavior for approximately 0.2 s; with under voltage in phase A and over voltage in phases B and C. At approximately 0.7 s, phase A is settled to an under voltage sinusoidal signal, and phases B and C are settled to over voltage sinusoidal signals.

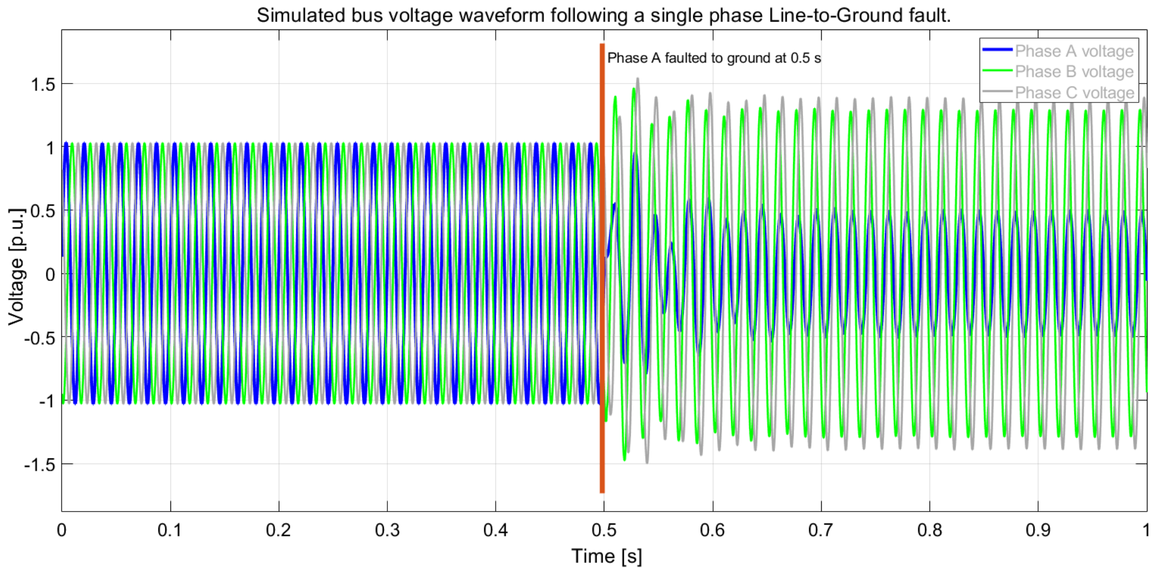

Fig. 10 Simulated voltage waveform for single phase line-to-ground fault

As a result, depending on the values of the rms voltage measurements, the following may be applicable:

- Va < Tr2PTUV.StrVal
- Tr1PTOV.StrVal < Vb < Tr2PTOV.StrVal
- Tr1PTOV.StrVal < Vc < Tr2PTOV.StrVal

This condition will simultaneously start the timers for the corresponding undervoltage and overvoltage disturbance.

From the above analysis it is clear that the implementation of the PTOV and PTUV functions in a DER controller will require the monitoring of the rms values of the measured voltages in all three phases.

Appendix D Modeling of DER Resource

Table 19 Data objects of logical node DGEN as defined in [3]

DO	Description
EcpRef	Reference to the electrical connection point (ECP)
PhsConnTyp	Physical connection type
DERTyp	DER Type
DEROpSt	Operational status of DER
WSpt	The active power setpoint applied to the DER
VArSpt	The reactive power setpoint applied to the DER
WMaxRtg	Max Active power
VAMaxRtg	Max Apparent power
IvarMaxRtg	Maximum injected reactive power
AvarMaxRtg	Maximum absorbed reactive power
VMaxRtg	Maximum voltage
VMinRtg	Minimum voltage
WOvPFRtg	Active power rating at specified over-excite power factor
OvPFRtg	Specified over-excited power factor
WUnPFRtg	Active power rating at specified under-excite power factor
UnPFRtg	Specified under-excited power factor
SuscRtg	Reactive susceptance that remains connected
WMax	Max Active power – operational setting
VAMax	Max Apparent power – operational setting
IvarMax	Maximum injected reactive power – operational setting
AvarMax	Maximum absorbed reactive power – operational setting
VMax	Maximum voltage – operational setting
VMin	Minimum voltage – operational setting
RegClas	Regulatory class of DER (Could be used to document IEEE 1547 Normal Category B & Abnormal Category III)

Table 20 Data objects of logical node DPVC as defined in [3]

DO	Description
EEName	Nameplate of DER with vendor, model, serial number, hardware and software version identification
EEHealth	Condition of PV equipment

Appendix E Modeling of Electrical Reference Point

Table 21 Data objects of logical node DPCC as defined in [3]

DO	Description
EcpIsldSt	ECP islanded state
PhsConnTyp	Type of circuit phases
GndSys	Grounding system at the electrical reference point
VRefSet	Default reference voltage for functions using voltage at this ECP as input. It may be overridden by VRef setpoints in specific operational functions.
ElcMsRef	Reference to electrical measurement function, typically MMXU or MMDC
EcpVRtg	Voltage rating at ECP
VMax	Setpoint for maximum voltage
VMin	Setpoint for minimum voltage
DERMsIncl	Indication whether the active power from the DER referencing this ECP is included in the measurements coming from the ECP. This is important for managing Generation and Load Following, as well as Peak Power Limiting functions.
EcpIsldAuto	Islanded state autonomously determined. If true, islanded state is autonomously determined; if false, islanded state is provided by external data.

Table 22 Data objects of logical node MMXU (data objects except for PhVAngChg are as defined in [4])

DO	Description
TotW	Total real power in a three-phase circuit [W].
TotVAr	Total reactive power in a three-phase circuit [VAr].
TotVA	The total apparent power in a three-phase circuit [VA].
TotPF	Average power factor in a three-phase circuit.
Hz	Frequency [Hz].
PhV	Phase to ground (line) voltages.
A	Phase to ground/phase to neutral three phase currents.
MaxPhVPhs	Maximum magnitude of phase to reference voltage of the 3 phases: max(PhVa, PhVb, PhVc). (Only needed in rmsMMXU)
MinPhVPhs	Minimum magnitude of phase to reference voltage of the 3 phases: min(PhVa, PhVb, PhVc). (Only needed in rmsMMXU)
HzRte	ROCOF [Hz/s].
ClcTotVA	Calculation method used for total apparent power 'TotVA'.
PFSign	Sign convention for power factor 'PF' (and reactive power 'VAr').
PhVAngChg	Phase voltage angle change between two consecutive calculations. (Only needed in rmsMMXU) ***New DO suggested – see Section 6.2.3.5***

Table 23 Data objects of logical node MSQI (data objects except for SeqVAngChg are as defined in [4])

DO	Description
SeqA	Absolute measured values of positive, negative and zero sequence components of the current (its sequence type 'seqT'='pos-neg-zero').
SeqV	Absolute measured positive, negative and zero sequence voltage components (its sequence type 'seqT'='pos-neg-zero').
DQ0Seq	Direct, quadrature, and zero axis quantity (its sequence type 'seqT'='dir-quad-zero').
ImbA	Deviation from the average phase to ground/phase to neutral current.
ImbNgA	Imbalance negative sequence current (I2 / I1).
ImbNgV	Imbalance negative sequence voltage (V2 / V1).
ImbPPV	Deviation from the average phase-to-phase voltage.
ImbV	Deviation from the average phase to neutral voltage.
ImbZroA	Imbalance zero sequence current (I0 / I1).
ImbZroV	Imbalance zero sequence voltage (V0 / V1).
MaxImbA	Maximum deviation from the average current: max('ImbA.phsA', 'ImbA.phsB', 'ImbA.phsC').
MaxImbPPV	Maximum deviation from the average phase-to-phase voltage: max('ImbPPV.phsAB', 'ImbPPV.phsBC', 'ImbPPV.phsCA').
MaxImbV	Maximum deviation from the average phase-to-neutral voltage: max('ImbV.phsA', 'ImbV.phsB', 'ImbV.phsC').
SeqVAngChg	Sequence voltage angle change between two consecutive calculations ***New DO suggested – see Section 6.2.3.5***

Table 24 Data object of logical nodes XCBR and XSWI as defined in [4]

DO	Description
Pos	The position of the switch

Table 25 Data objects of logical node MMXN as defined in [4]

DO	Description
Amp	Non-phase-related AC rms current.
Vol	Non-phase-related AC rms voltage.
Watt	Non-phase-related AC real power.
VolAmpr	Non-phase-related AC reactive power.
VolAmp	Non-phase-related AC apparent power.
PwrFact	Non-phase-related AC power factor.
Hz	Frequency [Hz].

Appendix F Modeling of Power Management Function

Table 26 Data objects of logical node DPMC as defined in [3]

DO	Description
ReqTotW	Active power requested by the power management function
ReqTotVAr	Reactive power requested by the power management function
DERRef	Reference to a DER resource LN
EcpRef	Reference to ECP LN
WSpt	Active power setpoint received from an operational function
VArSpt	Reactive power setpoint received from an operational function
PFSpt	PF setpoint received from an operational function
CeaEngzCtl	Cease to energize request
FctRef	Reference to an operational function LN

Table 27 Setpoints and associated FctRef for logical node DPMC

Setpoint	Associated FctRef	Value of FctRef
WSpt01	FctRef01	@HzDst/DHFW
WSpt02	FctRef02	@HzDst/DLFW
WSpt03	FctRef03	@VWCtrl/DVWC
WSpt04	FctRef04	@OperFct/DWMX
VArSpt05	FctRef05	@VVarCtrlr/DVVR
VArSpt06	FctRef06	@VVarCtrl/DWVR
VArSpt07	FctRef07	@VVarCtrl/DVAR
PFSpt08	FctRef08	@VVarCtrl/DFPF
CeaEngzCtl09	FctRef09	@VDst/PTRC.Op
CeaEngzCtl10	FctRef10	@VDst/mayPTRC.Op
CeaEngzCtl11	FctRef11	@VDst/DHVT.CeaZnSt
CeaEngzCtl12	FctRef12	@VDst/DLVT.CeaZnSt
CeaEngzCtl13	FctRef13	@HzDst/PTRC.Op
CeaEngzCtl14	FctRef14	@HzDst/mayPTRC.Op

Appendix G Modeling of Operational Functions from IEEE 1547

G.1. Modeling of Voltage Disturbances

Table 28 Data objects used for logical nodes DHVT and DLVT to indicate the disturbance event (data objects except for MayRtSt are as defined in [3])

DO	Description
TrZnSt	Status indicating that the voltage is in the trip zone
CeaZnSt	Momentary cessation is occurring
ModRtSt	Ride through event is occurring
MayRtSt	Status indicating that the voltage is in the "may ride-through or may trip zone". ***Proposed extension to LN DHVT and DLVT***.

The DOs for LN DHVT are determined as follows:

```
// shall trip
DHVT.TrZnSt.stVal := Tr2PTOV.Op.general OR Tr1PTOV.Op.general;
// may ride-through or may trip which means not in shall trip but beyond
   cease to energize
DHVT.MayRtSt.stVal := NOT DHVT.TrZnST.stVal AND Cea1PTOV.Op.general;
// Cease to energize which means not in shall trip and Cea1PTOV started
   but did not yet operate
DHVT.CeaZnSt.stVal := NOT DHVT.TrZnSt.stVal AND Cea1PTOV.Str.general AND
   NOT Cea1PTOV.Op.general;
// no ride through requirement in HV
DHVT.ModRtSt.stVal := FALSE;
```

The DOs for LN DLVT are determined as follows:

```
// shall trip
DLVT.TrZnSt.stVal := Tr2PTUV.Op.general OR Tr1PTUV.Op.general;
// may ride-through or may trip which means not in shall trip, but
// any of the ride through elements has operated
DLVT.MayRtSt.stVal := NOT DLVT.TrZnSt.stVal AND (Cea3PTUV.Op.general OR
   Rt2PTUV.Op.general OR Rt1PTUV.Op.general);
// Cease to energize, which means neither in shall trip nor in MayRt but
   Cea3 started
DLVT.CeaZnSt.stVal := NOT (DLVT.TrZnSt.stVal OR DLVT.MayRtSt.stVal) AND
   Cea3PTUV.Str.general;
// must ride through which means none of the previous but Rt1 or Rt2
   started
DLVT.ModRtSt.stVal := NOT (DLVT.TrZnSt.stVal OR DLVT.MayRtSt.stVal OR
   DLVT.CeaZnSt.stVal) AND (Rt2PTUV.Str.general OR Rt1PTUV.Str.general);
```

Table 29 Proposed new logical node DVRT for voltage ride-through

DO Name	Common Data Class (CDC)	Explanation	Presence Condition
DstDurTmm	Integer status (INS)	Timer measuring the time window for new count of disturbance sets	O (Optional)
Str	Directional protection activation information (ACD)	Indication that a first ride through disturbance has occurred and the timer DstDurTmm has been started	M (Mandatory)
Op (T*)	Protection activation information (ACT)	Indication that the maximum number of ride-through has been exceeded before the time window for a new count expired	O
MaxDstEvt	Integer setting (ING)	Setting for the maximum number of ride-through disturbance sets	O
SetDstDurTmm	ING	Setting for the time window for new count of disturbance sets	O

*Indicates that the DO is transient.

The DOs for LN PTRC and LN mayPTRC are determined as follows:

```
PTRC.Tr.general := Tr2PTOV.Op.general OR Tr1PTOV.Op.general OR
   Tr2PTUV.Op.general OR Tr1PTUV.Op.general;
PTRC.Op.general := PTRC.Tr.general;
mayPTRC.Tr.general := Cea1PTOV.Op.general OR Rt1PTUV.Op.general OR
   Rt2PTUV.Op.general OR Cea3PTUV.Op.general OR DVRT.Op.general;
mayPTRC.Op.general := mayPTRC.Tr.general;
```

G.2. Modeling of Frequency Disturbances

Table 30 Data objects used for logical nodes DHFT and DLFT to indicate shall trip and ride-through events and settings for rate of change of frequency ride-through (data objects except for MayRtSt are as defined in [3])

DO	Description
TrZnSt	Status indicating that the voltage is in the trip zone
ModRtSt	Ride through event is occurring
MayRtSt	Status indicating that the voltage is in the “may ride-through or may trip zone”. ***Proposed extension to LN DHFT and DLFT***.

The DOs for the LN DHFT are determined as follows:

```
// shall trip
DHFT.TrZnSt.stVal := Tr2PTOF.Op.general OR Tr1PTOF.Op.general;
// may ride-through or may trip which means not in shall trip but beyond
   mandatory operation
DHFT.MayRtSt.stVal := NOT DHFT.TrZnST.stVal AND (Rt2PTOF.Op.general OR
   Rt1PTOF.Op.general);
// ride through which means not in shall trip or MayRt, but start of Rt1
DHFT.ModRtSt.stVal := NOT DHFT.TrZnSt.stVal AND NOT DHFT.MayRtSt.stVal AND
   Rt1PTOF.Str.general;
```

The DOs for the LN DLFT are determined as follows:

```
// shall trip
DLFT.TrZnSt.stVal := Tr2PTUF.Op.general OR Tr1PTUF.Op.general;
// may ride-through or may trip which means not in shall trip but beyond
   mandatory operation
DLFT.MayRtSt.stVal := NOT DLFT.TrZnST.stVal AND (Rt2PTUF.Op.general OR
   Rt1PTUF.Op.general);
// ride through which means not in shall trip or MayRt, but start of Rt1
DLFT.ModRtSt.stVal := NOT DLFT.TrZnSt.stVal AND NOT DLFT.MayRtSt.stVal AND
   Rt1PTUF.Str.general;
```

The DOs for LN PTRC and LN mayPTRC are determined as follows:

```
PTRC.Tr.general := Tr2PTOF.Op.general OR Tr1PTOF.Op.general OR
   Tr2PTUF.Op.general OR Tr1PTUF.Op.general;
PTRC.Op.general := PTRC.Tr.general;
mayPTRC.Tr.general := Rt2PTOF.Op.general OR Rt2PTOF.Op.general OR
   Rt2PTUF.Op.general OR Rt1PTUF.Op.general OR PFRC.Op.general OR
   PhVRPAC.Op OR SeqVRPAC.Op;
mayPTRC.Op.general := mayPTRC.Tr.general;
```

Table 31 Data objects of logical node PFRC for rate of change of frequency ride-through as defined in [4]

DO	Description	Value
Str	Start	True / False
Op	Operate	True / False
StrVal	Start value (Hz/s)	Table 21 in IEEE 1547 [1]
OpDlTmms	Operate delay (ms)	0

Table 32 Data objects of logical node RPAC for angle change detection

DO	Description	Value PhVRPAC	Value SeqVRPAC
Str	Start	True / False	True / False
Op	Operate	True / False	True / False
StrVal	Start value (degree)	Chapter 6.5.2.6 in IEEE 1547 [1]	Chapter 6.5.2.6 in IEEE 1547 [1]
OpDlTmms	Operate delay (ms)	0	0

Table 33 Data objects of logical nodes DHFW and DLFW as defined in [3]

DO	Description	Value	Range
ReqW	Active power requested by the function (valid when function is active)		
WGra	Gradient (p.u. droop gain)	Table 24 in IEEE 1547 [1]	Table 24 in IEEE 1547 [1]
HzRef	Reference frequency (Hz)	60.0 (Assumed as nominal for illustration here.)	
HzStr	Frequency (Hz), where droop starts (DHFW)	60.0 + (HF deadband) (Table 24 in IEEE 1547) [1]	Table 24 in IEEE 1547 [1]
HzStr	Frequency (Hz), where droop starts (DLFW)	60.0 - (LF deadband) (Table 24 in IEEE 1547) [1]	Table 24 in IEEE 1547 [1]
OpnLoopMax	Open loop delay time (s)	Table 24 in IEEE 1547 [1]	Table 24 in IEEE 1547 [1]

G.3. Modeling of Return to Service After Trip

Table 34 Data objects of logical node DCTE as defined in [3]

DO	Description	Value
FctEna	Enable / Disable the function	True / False
RtnSrvAuth	Automatic return to service authorized ***Revised semantic****	True (can be set to false)
VHiLim	Upper limit for voltage range (pU)	Table 4 in IEEE 1547 [1]
VLoLim	Lower limit for voltage range (pU)	Table 4 in IEEE 1547 [1]
HzHiLim	Upper limit for frequency (Hz)	Table 4 in IEEE 1547 [1]
HzLoLim	Lower limit for frequency (Hz)	Table 4 in IEEE 1547 [1]
RtnDlTmms	Minimum delay to enter service	Chapter 4.10.3 in IEEE 1547 [1]
RtnRmpTmms	Enter service time (determines ramp)	Chapter 4.10.3 in IEEE 1547 [1]

*LN DCTE has two attributes whose usage is unclear regarding the permit service requirement. IEC 61850-7-420 provides the following information:

- RtnSrvAuth: "Authorization setting that permits the DER to return to service. True = authorized; false = not authorized. If true, the DER may or may not initiate the return to service process, depending on other factors. The CeaEngz command sets this setting to false [3]."
- RtnSrvAuto: "If true, the DER is authorized to automatically return to service; if false, the DER must wait until an external RtnSrvAuth is received to allow it to return to service [3]."

NOTE on IEC 61850-7-420: It is recommended to remove RtnSrvAuto and use RtnSrvAuth only with a changed semantic, to indicate permit service. If true, and the conditions are met, DER will return to service.

G.4. Modeling of Voltage and Reactive Power Control

Table 35 Data objects of logical node DFPF as defined in [3]

DO	Description
ReqPFExt	PF setpoint excitation information requested by function (valid when function is active)
ReqPF	Requested power factor (valid when function is active)
PFGnTgtSpt	Setpoint for power factor
PFGnExtSet	PF setpoint excitation information; if true - overexcited

Table 36 Data objects of logical node DVVR as defined in [3]

DO	Description
FctEna	Enable / Disable the function
VRefEsp	The reference voltage used by the function
ReqVAr	Reactive power requested by the function (valid when function is active)
VRefAdjEna	Enable autonomous reference voltage adjustment
VRefTmms	Time constant to adjust voltage
VArSetRef	Reference for the reactive power (may need to be formatted as reactive power in percent of VAMax)
VVArCrv	Setting of Volt Var curve
OpnLoopMax	Open loop response time (s) Table 8 in IEEE 1547, Category B DER [1]

Table 37 Definition of the voltage-reactive power curve for DVVR.VVArCrv

DA	Description	Value
crvPts (0)	Point VL / Q1 in IEEE 1547*	Shall Trip UV1 from Table 13 in IEEE 1547 / Table 8 in IEEE 1547, Category B DER [1]
crvPts (1)	V1 / Q1*	Table 8 in IEEE 1547, Category B DER [1]
crvPts (2)	V2 / Q2*	Table 8 in IEEE 1547, Category B DER [1]
crvPts (3)	V3 / Q3*	Table 8 in IEEE 1547, Category B DER [1]
crvPts (4)	V4 / Q4*	Table 8 in IEEE 1547, Category B DER [1]
crvPts (5)	VH / Q4*	Shall Trip OV2 from Table 13 in IEEE 1547 / Table 8 in IEEE 1547, Category B DER [1]
numPts	Number of valid points in the curve definition	6
maxPts	Maximum number of points available to define the curve	6 or more
xD	Description of x – axis	Voltage in pU
yD	Description of y – axis	Var in percentage of VAMax

*Notation from Table 8 in IEEE 1547 and Figure H.4 in IEEE 1547 is used for points defining the curve.

Table 38 Data objects of logical node DWVR as defined in [3]

DO	Description
FctEna	Enable / Disable the function
ReqVAr	Reactive power requested by the function (valid when function is active)
VArSetRef	Reference for the reactive power (may need to be formatted as reactive power in percent of VAMax)
WBarEna	Set to true (if true, value shall go to boundary; if false, interior)
WVArCrv	Setting of Volt Var curve

Table 39 Definition of the active power-reactive power curve for DWVR.WVArCrv

DA	Description	Value
crvPts (0)	First point on curve**	- 1.5 / Q'3*
crvPts (1)	P'3 / Q'3*	Table 9 in IEEE 1547, Category B DER [1]
crvPts (2)	P'2 / Q'2*	Table 9 in IEEE 1547, Category B DER [1]
crvPts (3)	P'1 (fraction of nameplate active power) / Q'1*	Table 9 in IEEE 1547, Category B DER [1]
crvPts (4)	P1 (fraction of nameplate active power) / Q1*	Table 9 in IEEE 1547, Category B DER [1]
crvPts (5)	P2 / Q2*	Table 9 in IEEE 1547, Category B DER [1]
crvPts (6)	P3 / Q3*	Table 9 in IEEE 1547, Category B DER [1]
crvPts (7)	Last point on curve**	1.5 / Q3*
numPts	Number of valid points in the curve definition	8
maxPts	Maximum number of points available to define the curve	8 or more
xD	Description of x – axis	Active power in PU
yD	Description of y – axis	Var in percentage of VAMax

**An active power value of 1.5WMax has been chosen for the first and last points on the curve; in principle it is infinite.

*Notation from Table 9 in IEEE 1547 and Figure H.5 in IEEE 1547 is used for points defining the curve.

Table 40 Data objects of logical node DVAR as defined in [3]

DO	Description
FctEna	Enable / Disable the function
ReqVAr	Reactive power requested by the function (valid when function is active)
VArSetRef	Reference for the reactive power definition
VArTgtPct Spt	Target setpoint for reactive power expressed as percentage of the reference defined with VArSetRef

G.5. Modeling of Voltage and Active Power Control

Table 41 Data objects of logical node DVWC as defined in [3]

DO	Description
FctEna	Enable / Disable the function
ReqW	Active power requested by the function (valid when function is active)
VWCrvRef	Reference for the active power definition (may need to be formatted as active power in percent of WMax)
VWCrv	Setting of Volt Watt curve
OpnLoopMax	Open loop response time (s) Table 10 in IEEE 1547 [1]

Table 42 Definition of the voltage-active power curve for DVWC.VWCrv

DA	Description	Value
crvPts (0)	First point on curve**	1 / P1*
crvPts (1)	V1 / P1*	Table 10 in IEEE 1547 [1]
crvPts (2)	V2 / P2*	Table 10 in IEEE 1547 [1]
crvPts (3)	Last point in curve	Shall Trip OV2 from Table 13 in IEEE 1547 / P2*
numPts	Number of valid points in the curve definition	4
maxPts	Maximum number of points available to define the curve	4 or more
xD	Description of x – axis	Voltage in pU
yD	Description of y – axis	Var in percentage of WMax

**A voltage value of 1 pU has been chosen for the first point on the curve.

*Notation from Table 10 in IEEE 1547 and Figure H.6 in IEEE 1547 is used for points defining the curve.

G.6. Modeling of Control Capability Requirements

Table 43 Data objects of logical node DWMX as defined in [3]

DO	Description
FctEna	Enable / Disable the function
WLimPctSpt	Maximum active power requested