WHITEPAPER

OCPP & IEC 61850: a winning team

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LIST OF ABBREVIATIONS

ACSI	Abstract Communication Service Interface
BP	Business Process
CPO	Charge Point Operator
CSO	Charging Station Operator
CS	Charging Station
CSMS	Charging Station Management System
DER	Distributed Energy Resources
DERMS	Distributed Energy Resources Management System
DSO	Distribution System Operator
eMSP	e-Mobility Service Provider
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GOOSE	Generic Object-Oriented Substation Event
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
JSON	JavaScript Object Notation
MMS	Manufacturing Message Specification
OCPP	Open Charge Point Protocol
OCPI	Open Charge Point Interface
OSI	Open Systems Interconnection
RfG	Requirements for Generators
SCADA	Supervisory Control and Data Acquisition
SoC	State of Charge
TCP/IP	Transmission Control Protocol/Internet Protocol
TSO	Transmission System Operator
UC	Use Case

1 EXECUTIVE SUMMARY

In the coming years, utilities will see more and more electric vehicles connecting to their electricity grid. Cars, busses, vans, trucks, ships and airplanes will charge their batteries drawing energy from the grid. In some cases, these vehicles will also discharge their batteries and feed energy back into the grid, effectively becoming a Distributed Energy Resource (DER). It means that utilities will work together with new customers, systems and use cases. To integrate DERs safely into the grid, information exchange and control is needed. The IEC 61850 protocol for electricity grid control and OCPP for charging infrastructure control combine to ensure that the charging and discharging of vehicles takes place whilst ensuring grid stability and meeting the customers' needs and expectations.

Even though both protocols were developed by different industry groups in different periods of time, the combination of these two protocols can fulfil all requirements that utilities might have to control electric vehicles acting as DERs. The paper list use cases that a utility might use to control a DER, and shows for each use case which IEC 61850 settings to use and how these settings will be transferred to the charging station via OCPP.

This paper aims to help the industry better understand both protocols and help with the implementation of the combination of IEC 61850 and OCPP in charging station management systems.

2 INTRODUCTION

Electric vehicles (EVs) and charging stations will be able to supply power back into the grid soon. This is called vehicle-to-grid (V2G) technology. It is currently only occurring on a small scale and mostly in pilot projects, but this is expected to become applicable on a large scale in the foreseeable future. It can then be used to help balance the electricity demand and supply in an electricity grid. EVs can act as generators, and this creates virtual power plants from the grid's perspective. In that case, the combination of EV and charging station must follow the Requirements for Generators (RfG) network code just like other distributed energy resources (DERs) and therefore must be able to control their electrical power output and withstand grid faults.

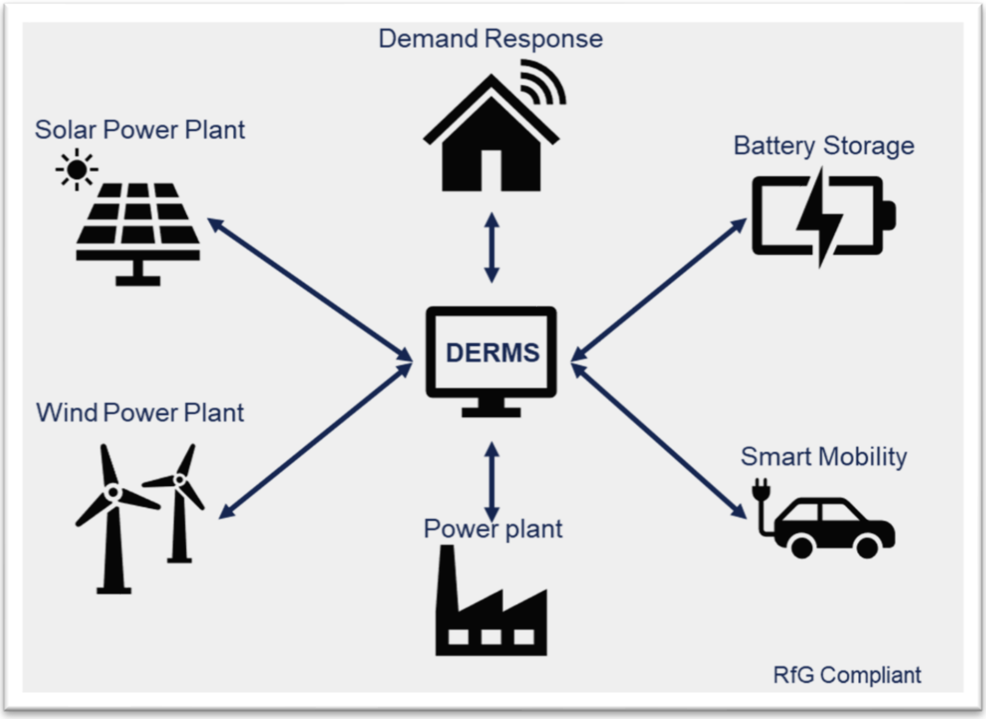

Figure 1 DERMS controllable assets

At this point in time there are several different views on how utilities and grid operators would interact with EVs as ‘Generators’: (1) directly with the EV, or (2) directly with the Charging Station (CS) via a Smart Meter, Energy Management System or (3) Grid Connection Point Controller, etc. This paper focusses on the topology where the utility/grid operator interacts with the EVs via the Charge Point Operator (CPO).

A network of charging stations is controlled by a CPO. When such a network (or part thereof) acts as a DER, the CPO will act as an aggregator of this DER towards the utility. Utilities control DERs via the IEC 61850 protocol (industry standard), so the CPO will need the capability to translate the IEC 61850 instructions to instructions that are understood by charging stations.

OCPP is the common standardized protocol between CPO and charging stations. This white paper describes how the OCPP protocol can be used to convey IEC 61850 instructions for DERs to the charging stations.

This paper starts with a brief description of OCPP and IEC 61850. The applicable use cases from network code requirements perspective are described, followed by an explanation of the IEC 61850 information that is conveyed via OCPP.

Recently work has started on a new IEC standard, IEC 63460 architecture and use cases for EVs to provide grid support functions. This is still ongoing work, in the future we will harmonize and align the use cases.

2.1 Role of Charge Point Operators

Utilities will need to communicate with CPOs for power quality, congestion management and compliance to grid codes. Utilities can get insights in the charging stations through the CPOs, being the owners of the charging infrastructures.

The utilities and CPOs have similar goals of uptime, availability and quality and will need to be able to communicate to achieve these goals effectively and proactively. IEC 61850 can be the communication bridge between utilities and CPO.

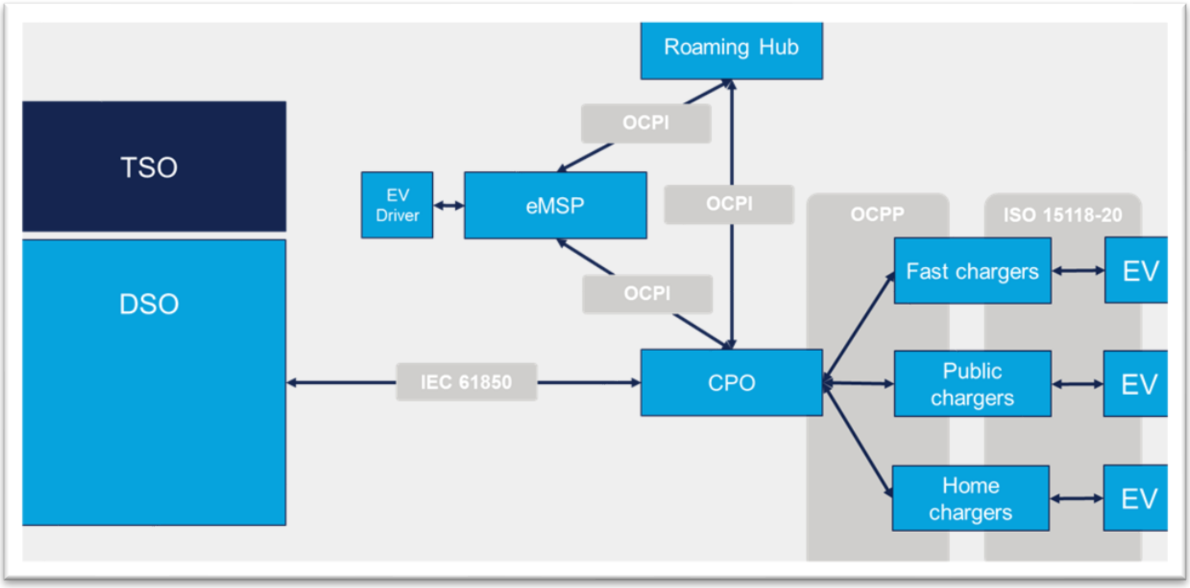

Figure 2 CPO in context

2.2 What is OCPP?

Electric Vehicles (EVs) are becoming the new standard for mobility all over the world. This development is only possible with a good coverage of charging stations. To advance the roll out of charging infrastructure, open communication standards play a key role: to enable switching from charging network without necessarily replacing all the charging stations, to encourage innovation and cost effectiveness and to allow many and diverse players participate in this new industry.

Additionally, the EV charging infrastructure is part of the Smart Grid, a larger and still evolving ecosystem of sensors, actors, protection and control devices, and protocols. In this Smart Grid ecosystem, open communications standards are key enablers for two-way power flows, real time information exchange, automation, demand control and eMobility services.

The Open Charge Point Protocol (OCPP) is the industry-supported de facto standard for communication between a Charging Station and a Charging Station Management System (CSMS) and is designed to accommodate any type of charging technique. OCPP is an open standard with no cost or licensing barriers for adoption. OCPP2.0.1 was released in 2020. OCPP2.1 will be released in 2024 and will be backwards compatible in the sense that all OCPP 2.0.1 functionality will continue to function, and only new features are added in OCPP 2.1. As of the version OCPP2.1, OCPP will support bi-directional power flow and grid support function in a standardized way.

2.3 What is IEC 61850?

IEC 61850 is the international standard for power utility automation system design, application engineering, testing, communication protocols to achieve vendor independent, cost efficient and interoperable protection, automation, and control systems.

IEC 61850 was published in 2003 for the first time with the validity of the first edition until 2005, extended to 2010. IEC 61850 is now a worldwide standard for communication networks and systems in substations. Since the publication of the first edition of IEC 61850, experts have been working on an updated edition to further improve the standard and ensure compliance to the points above. All parts of the IEC 61850 standard have been revised or updated and have been published as the second edition or amended since 2012. With the second edition communication outside the substation and the traditional power domain are added. Edition 2 changed the title to power utility automation and includes now extensions related to other domains such as DER, Wind- and solar parcs and electric vehicles.

Power utility automation which engages IEC 61850 provides:

1. Uniformity of protection and automation design
2. Improved power system functionality and performance requirements
3. Higher interoperability between substation electronic devices
4. Improvement in substation reliability
5. Alignment with peer utility substation designs and technological trends.

IEC 61850 compliant devices provide a uniform way of communication between the devices to support multi-vendor systems which will meet functional, technical and performance requirements, while also being future proof. It is a common misunderstanding that IEC 61850 is only about data communication and just a protocol. The key concepts for data modelling, engineering and universal configuration language are equally important.

The development of IEC 61850 is a continuous effort by a large group of international experts from manufacturers, utilities, and consultancy companies. Extensions and updates based on practical international experiences in implementation projects are released annually.

3 USING IEC 61850 AND OCPP FOR DER CONTROL

IEC 61850 is a widely accepted standard that enables seamless communication and interoperability in power utility automation and control of DERs. OCPP is widely accepted as the de facto standard protocol for communication between charging stations and management systems. When both standards are used together, it becomes possible to treat bi-directional charging stations as DERs.

3.1 Topology for DER control

The CPO controls the charging stations and acts as an aggregator for DER control towards the utility. It is quite likely that groups of charging stations will be treated as a single DER. For example, all chargers of a single charging plaza might be treated as one DER.

The utility sends a command to set certain parameters for a specific DER (see par. 3.30) to the CPO. This DER represents a controllable cluster of charging stations. Depending on the type of parameters and the state of the charging stations (e.g., idle, charging, discharging), the CPO will configure the chargers such that the behavior of the group conforms to the specified DER parameters.

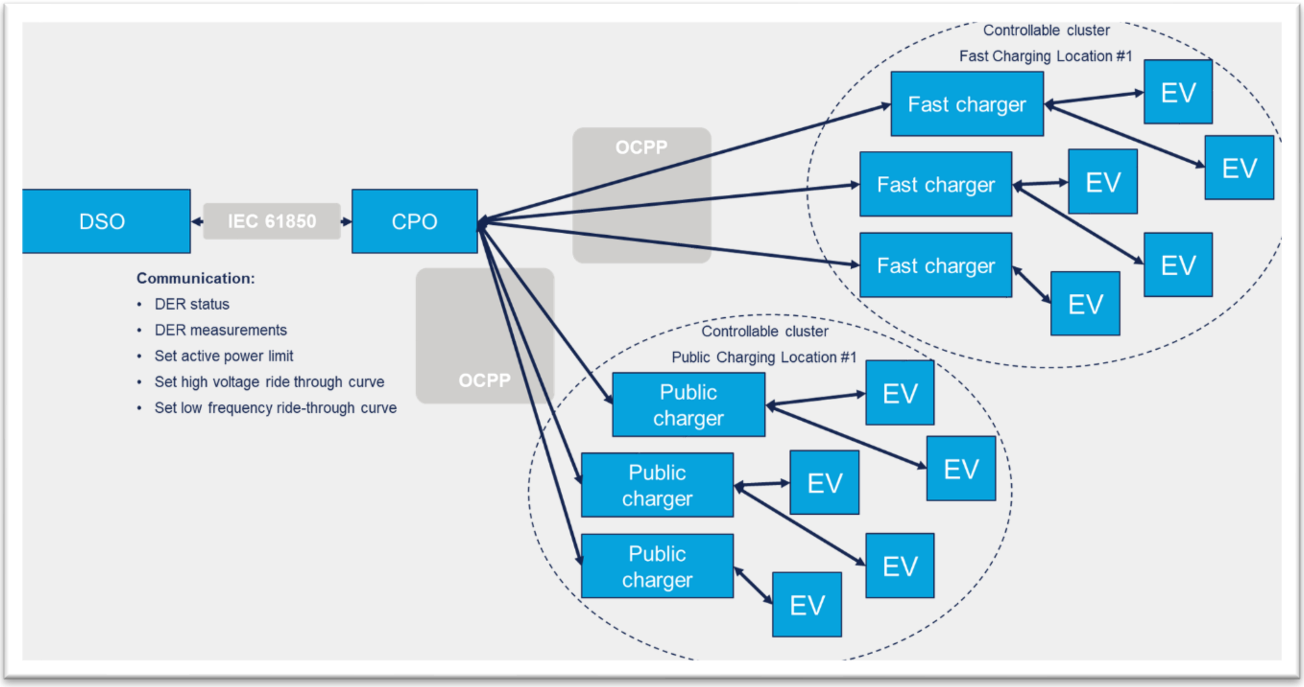

Figure 3 Topology for DER control via CPO

It is up to the CPO in its role as aggregator, to handle the logic of mapping parameters for a single DER to individual charging stations in a cluster. As part of this process the CPO will have to translate the IEC 61850 parameters to corresponding OCPP 2.1 messages. If the EV is connected to an AC charging station, then some additional messaging via ISO 15118-20 may be required. This is discussed in more detail in the next section.

The following figure shows the chain of protocols that are involved in DER control from utility to EV.

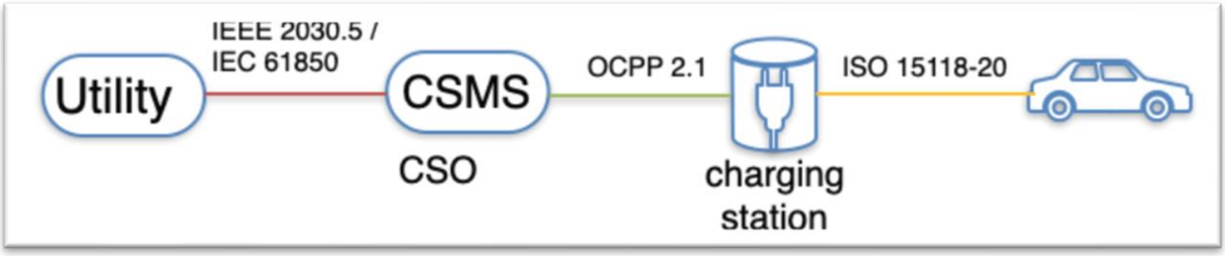

Figure 4 Protocol chain for DER control

Many CPOs operate internationally and in areas serviced by multiple utilities. Since unfortunately not all utilities require identical grid codes, CPOs will need to adhere to multiple DER control settings. However, the mechanism for DER control is universal and the CPO can activate curves and settings depending on the location of the charging station.

3.2 AC and DC charging stations

There are two main flavors for charging stations: AC and DC. An AC charging station is nothing more than a fancy outlet – the current from the grid is simply passed on to the EV. A DC charging station on the other hand, converts the AC current from the grid to a DC current, which is then provided to the EV.

Whether connecting to an AC or DC charging station, the battery of an EV needs to be charged with a DC current. When connected to an AC charger, in order to convert the AC current from the electrical grid to a DC current, the EV uses a so-called on-board inverter. A vehicle that is capable of discharging energy back into the grid, has a bi-directional inverter that can convert the DC current back to AC for the grid. Typically, the rated power of such a converter is less than 11 or 22 kW. In the case of a DC charger, the inverter is located in the charging station. Such a stationary inverter is capable of much higher power levels ranging from 50 kW to 350 kW.

The actual device that is injecting power into the electricity grid is the inverter that converts the DC power from the battery to AC power. The DER control functions target the inverter. In case of a DC charging station the inverter is housed in the charging station and can therefore be controlled by the CPO via OCPP messages.

In case of an AC charging station, the inverter is on board the EV. The CPO cannot directly address the EV via OCPP messages. A dedicated protocol is used between charging station and EV: ISO 15118-20. (See Figure 4). Unfortunately, ISO 15118-20 does not provide a mechanism to allow manipulation of inverter parameters yet. Work is ongoing in ISO to add these support functions. At the time of writing, there is no way to transmit, for example, a high frequency trip curve to the on-board inverter, yet, but it is possible to control the output of the inverter many times per second. This allows the charging station to fulfill DER control functions for an on-board inverter by sending it the exact commands that are required to implement the specific function.[1]

[1] A task force has recently been started with the goal of extending the AC-BPT part of ISO 15118-20 before end of 2023 with additional capabilities to control the on-board inverter.

3.3 IEC 61850 Logical Nodes for DER control

The following table provides a non-exhaustive overview of DER control functions and the corresponding Logical Nodes in IEC 61850 and objects in OCPP. The DER functions were selected based upon existing work done in IEEE 1547:2018.

Table 1 Overview of DER, IEC 61850, OCPP

DER Function (IEEE 1547)	IEC 61850 Logical Node	OCPP Object	Use Case
Constant Power Factor	DFPF	SetPointPFInject	10
Voltage – Reactive Power	DVVR	VoltVar	11
Active Power – Reactive Power	DWVR	WattVar	13
Constant Reactive Power	DVAR	ChargingProfile	3
Voltage – Active Power	DVWC	VoltWatt	12
High Voltage Trip Curve	DHVT	HVTrip	5
Low Voltage Trip Curve	DLVT	LVTrip	6
High Frequency Trip Curve	DHFT	HFTrip	7
Low Frequency Trip Curve	DLFT	LFTrip	8
Frequency-Droop (HF)	DHFW	FreqDroop	9
Frequency-Droop (LF)	DLFW	FreqDroop	9
Enter Service	DCTE	EnterService	14
Limit Active Power	DWMX	ChargingProfile	4

3.4 OCPP 2.1 messages for DER control

It is important to realize that the OCPP messages do not provide one-to-one replacement of IEC 61850 messages. It is assumed that the CPO performs an aggregator role towards the utility. The utility connects with the CSMS of the CPO, using IEC 61850. (Other protocols, like IEEE 2030.5 might also be used for this purpose, but that is out of scope for this document). CSMS will then forward the appropriate information to the impacted charging stations.

The burden of scheduling and prioritizing of messages lies mostly with CSMS. For example, a utility can schedule a series of events with a start time and duration for a DER. A DER can be part of multiple groups, and one group can have a higher priority than another group. CSMS will receive these events and construct a timeline of events in which higher priority events supersede events with lower priority. CSMS will then send the appropriate OCPP messages to the affected charging station.

In case of AC (dis)charging, the charging station uses ISO 15118-20 to control the inverter in the vehicle such that it adheres to the DER controls.

3.4.1 DER control settings in OCPP

The behavior of a DER (i.e., charging station or EV inverter) can be controlled by so-called DER Controls. These are settings with parameters to control active or reactive power, other settings, such as power factor and ramp rates, and curves that control behavior.

Power settings

If a utility wishes to state (reactive) power setpoints or limits, this can be achieved via the CPO. Setting of active or reactive power setpoints via CSMS is already supported by OCPP charging profiles. No new messages towards charging station are needed to support this. Instead, a power setpoint or limit will be translated to an OCPP charging profile towards the stations.

Parameter settings

Other control settings, such as a fixed power factor, frequency droop, are transferred to the charging station via a SetDERControlRequest message. The settings can be scheduled with a start time and duration.

The following settings can be set via SetDERControlRequest

- Fixed power factor setpoint when absorbing active power
- Fixed power factor setpoint when injecting active power
- Frequency-Watt parameterized mode
- Enter service after trip (default only)
- Ramp rate (default only)
- Soft-start ramp rate (default only)

Curves

DER curves describe the behavior that a charging station must perform ***autonomously*** in case of a grid anomaly. Such curves are configured on the charging station via the OCPP SetDERControlRequest messages with a curve type.

While only one curve per curve-type can be active at the same time, different curve-types can be active at the same time if they do not conflict. These curves are used to provide autonomous control in a predictable fashion. For example, assuming a volt-watt curve is active; if the inverter senses an over-voltage situation a volt-watt curve would direct the inverter to lower its power output during discharging.

Likewise, in an under-voltage situation, the same curve would likely direct the DER to increase its output during discharging.

Trip curves

The following curves describe when a DER must trip or pause in case of a frequency or voltage anomaly:

- High Frequency Trip
- Low Frequency Trip
- High Voltage Trip
- Low Voltage Trip

Volt and Watt curves

The following is a list of (reactive) power curves based on the measured frequency, voltage or power:

- Frequency-Power curve, P(F)
- Voltage-Reactive Power curve, Q(U)
- Voltage-Power curve, P(U)
- Power-Power Factor curve, Pf(P)
- Power-Reactive Power curve, Q(P)

Signaling and alarms

When a charging station starts to deviate from normal behavior, because it is forced to follow a DER curve or setting, then this will be signaled to CSMS, such that the CPO is aware of this situation. Similarly, the charging station will send a signal when this event has ended.

This is supported via the OCPP NotifyDERTakingOverRequest message.

When a charging station needs to shut down or restart due to an error condition, this is reported via a NotifyDERAlarmRequest message.

3.4.2 OCPP 2.1 DER control messages

This section lists the OCPP 2.1 DER control messages. For details about the object types, please see the OCPP 2.1 specification.

SetDERControlRequest

Set a DER control of a certain type. The *controlType* determines the type of control. Associated parameters are in one of the optional fields. *controlType* is one of: EnterService, FreqDroop, FreqWatt, HFTrip, HVTrip, LFTrip, LVTrip, RampRates, SetpointPFAbsorb, SetpointPFInject, VoltVar, VoltWatt, WattPF, WattVar.

Default	boolean	1..1
controlType	DERControlEnumType	1..1
setpointPFAbsorb	SetpointPFType	0..1
setpointPFInject	SetpointPFType	0..1
freqDroop	FreqDroopType	0..1
enterService	EnterServiceType	0..1
rampRates	GradientsType	0..1
curve	DERCurveType	0..1

SetDERControlResponse

status	DERControlStatusEnumType	1..1
statusInfo	StatusInfoType	0..1
controlId	Integer	0..1
supersededId	Integer	0..1

GetDERControlRequest

Get a list of all default or all scheduled controls of a certain type or Id.

default	boolean	1..1
controlType	DERControlEnumType	0..1
controlId	integer	0..1

GetDERControlResponse

setpointPFAbsorb	SetpointPFType	0..24
setpointPFInject	SetpointPFType	0..24
freqDroop	FreqDroopType	0..24
enterService	EnterServiceType	0..24
rampRates	GradientsType	0..24
curve	DERCurveType	0..24
status	DERControlStatusEnumType	1..1
statusInfo	StatusInfoType	0..1

ClearDERControlRequest

Clear all default or all scheduled controls of a certain type or Id.

default	boolean	1..1
controlType	DERControlEnumType	0..1
controlId	integer	0..1

ClearDERControlResponse

status	DERControlStatusEnumType	1..1
statusInfo	StatusInfoType	0..1

NotifyDERStartStopRequest

Notify CSMS of the starting or stopping of a scheduled DER control.

controlId	integer	1..1
started	boolean	1..1
timestamp	dateTime	1..1
supersededId	integer	0..24

NotifyDERStartStopResponse

No fields

NotifyDERTakingOverRequest

Notify CSMS that a DER control has started (or stopped) to cause charging station deviate from normal behavior.

controlType	DERControlEnumType	1..1
takeOverStarted	boolean	1..1
timestamp	dateTime	1..1

NotifyDERTakingOverResponse

No fields.

NotifyDERAlarmRequest

Notify CSMS of a fault that requires a shutdown or restart of the charging station.

alarmType	DERAlarmEnumType	1..1
alarmStarted	boolean	1..1
timestamp	dateTime	1..1

NotifyDERAlarmResponse

No fields.

3.4.3 ISO 15118-20 DER control messages for AC-BPT

At the time of writing of this paper, ISO 15118-20 does not support specific messages to change the settings of an on-board inverter so that it can independently perform the DER functions from Table 1 Overview of DER, IEC 61850, OCPP. Instead, the EVSE will have to use the AC_ChargeLoop messages, which are exchanged several times a second, to control inverter behavior in a way that that it will obey to the DER setting that has been configured in the EVSE.

A task group within ISO 15118-20 is investigating an extension to the protocol for AC bi-directional charging (AC-BPT) to allow some or all DER functions to be configured for local execution by the on-board inverter. This is, however, not yet available, and therefore not considered in this paper.

3.5 Business Processes

For utilities using IEC 61850 and OCPP for DER control we have defined 3 business processes (BP) for a systematic and structured flow of information.

BP1 is defined for the initial connection between a utility and CPO, when information about the assets and its capabilities should be exchanged. If there are already known grid constraints initial limits, setpoints and curves could already be set. This could then be seen as the default operation.

BP2 is defined to set new limits, setpoints and curves based on new insights from the utilities network model calculations.

BP3 is a safe mode which should be considered in case the connection between utility and CPO is lost.

Within these business processes several use cases describe the getting and setting of the DER's different limits, setpoints and curves.

3.5.1 BP1: DER initial setup

No.	Type.	Description
1	Name	DER Initial setup
2	ID	BP1

No.	Type.	Description
3	Objective	First connection between DSO – CPO to exchange information and set limits, setpoints and curves.

No.	Type.	Description

4	Description	DSO wants to retrieve process image from the CPO per controllable cluster:
		- Measurements of:
		  o Active Power
		  o Reactive Power
		  o Phase-Neutral Voltage for all 3 phases
		  o Actual current of all 3 phases
		- Generator status (Controllable cluster info)
		- Device information (CPO interface info)
		
		Based on DSO network model calculation the following limits, setpoints and curves are set:
		- Active Power
		- Reactive Power
		- Voltage ride-through upper and lower limits
		- Frequency ride-through upper and lower limits
		- Frequency Droop
		- Fixed Power factor
		- Voltage-Reactive Power V-var
		- Voltage-Active Power V-W
		
		The DSO will also set the reason for the set limits per controllable cluster.

	Actors	DSO, CSMS, CS
	Scenario description	DSO uses UC1 and UC2 to establish the connection with the DER and learn the DER capabilities. DSO uses UC3, UC4, UC5, UC6, UC7, UC8 UC9, UC10, UC11, UC12, UC13 & UC14 if supported to set the different limits, setpoints and curves.
	Alternative scenarios	
5	Prerequisites	Communication channel between DSO and CPO is available and active.
6	Post condition	Limits based on DSO network model calculations are set at CPO controllable clusters.
7	Error Handling	
8	Remarks	

3.5.2 BP2: Change in network model calculations.

No.	Type.	Description
1	Name	Change in network model calculations
2	ID	BP2

No.	Type.	Description
3	Objective	When a DSO calculates a change for their network model the limits, setpoint and curves will need to be updated at the CPO controllable cluster.
4	Description	Based on DSO network model calculation and DER controllable cluster capabilities the following limits, setpoints and curves are changed: - Active Power - Reactive Power - Voltage ride-through upper and lower limits - Frequency ride-through upper and lower limits - Frequency Droop - Fixed Power factor - Voltage-Reactive Power V-var - Voltage-Active Power V-W The DSO will also set the reason for the set limits per controllable cluster
	Actors	DSO, CSMS, CS
	Scenario description	DSO uses UC3, UC4, UC5, UC6, UC7, UC8, UC9, UC10, UC11, UC12, UC13 & UC14 if supported to set the different limits, setpoints and curves.
	Alternative scenarios	
5	Prerequisites	Communication channel between DSO and CPO is available and active.
6	Post condition	Based on the latest DSO network model calculations limits, setpoints and curves are updated at CPO controllable clusters.
7	Error Handling	
8	Remarks	

3.5.3 BP3: Safe mode

In case the IEC61850 communication between DSO and CPO cannot be established. The CPO should configure their charging stations limits and curves in safe mode to make sure the grid is protected.

3.6 Use cases

The following 14 use cases are defined to read from the DER and set the different limits, setpoints and curves.

3.6.1 UC1: DER registration

Initial setup of communication between DSO and CPO. Exchange of information about controllable asset clusters and parameters. The data exchanged contains all data needed to identify the DER and needs to be initiated after powering up and initiation of the data communication. The utility and CPO need to align on the IEC61850 communication and the desired information, the following Logical Nodes can be used: LPHD, LLN0, DGEN. This use case is not related to OCPP.

3.6.2 UC2: DER reading

No.	Type.	Description
1	Name	Configure reactive power
2	ID	UC2
3	Objective	Utility receives meter values from CPO.
4	Description	Utility receives meter values from CPO of a defined charging station or group of charging stations as defined in UC1.
	Actors	Utility, CSMS, CS
	Logical Nodes	DGEN, MMXU
	Scenario description	This scenario assumes the amount of reactive power is controlled by setting a power factor. 1. CPO sends DGEN to inform about the DER. a. DEROpSt.StVal(DERStateKind) to inform about the status. b. WMaxRtg.setMag to inform about the active power rating. c. InRef.setSrcRef to refer to the charging station or group of charging stations. 2. CPO send MMXU to inform about the measurements. a. TotW.mag for total active power (Power.Active.Export & Power.Active.Import) b. TotVAr.mag for total reactive power (Power.Reactive.Export & Power.Reactive.Import) c. TotPF.mag for average power factor (Power.Factor) d. Hz.mag for frequency (Frequency) e. PNV.phs(A, B,C) for phase voltage (Voltage) f. A.phs(A, B,C) for phase current (Current.Export & Current.Import) 3. CSMS receives MeterValues(Timestamp, SampledValues) from the desired charging stations.
	Alternative scenario description	
5	Prerequisites	
6	Post condition	Utility is aware of desired measurements at location.
7	Error Handling	
8	Remarks	Other desired meter values could be defined is supported.

3.6.3 UC3: Configure reactive power level

No.	Type.	Description
1	Name	Configure reactive power
2	ID	UC3
3	Objective	Set reactive power.
4	Description	Utility requests CPO to set reactive power in a charging station or group of charging stations.
	Actors	Utility, CSMS, CS
	Logical Nodes	DVAR, GGIO
	Scenario description	This scenario assumes reactive power amount is controlled by setting a power factor. 1. Utility send GGIO Iscso1.stVal to inform about the reason. 2. Utility send DVAR to set reactive power in a certain area. a. Either VArTgtSpt.mxVal or VArTgtSptPct.mxVal for percentage or value limit. b. Set Mod.StVal to 1 (On) to enable the setpoint. c. ModPrio.StVal to set a priority if desired. d. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. CSMS sends SetDERControlRequest(setpointPFInject, displacement, excitation) commands to affected charging stations. 4. In case of AC charging charging station sets required reactive power in AC_ChargeLoop message to EV.
	Alternative scenario description	This scenario assumes reactive power is set as part of a charging schedules for charging stations. 1. Utility send GGIO Iscso1.stVal to inform about the reason. 2. Utility send DVAR to set reactive power in a certain area. a. Either VArTgtSpt.mxVal or VArTgtSptPct.mxVal for percentage or value limit. b. Set Mod.StVal to 1 (On) to enable the setpoint. c. ModPrio.StVal to set a priority if desired. d. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. CSMS sends SetChargingProfileRequest with a setpointReactive attribute for reactive power.
5	Prerequisites	
6	Post condition	Affected charging stations have updated charging profiles to stay within requested power limit.

No.	Type.	Description
7	Error Handling	
8	Remarks	If the requested power limit is negative, i.e. is about discharging, then only charging stations that are currently involved in discharging, need to receive a new charging profile.

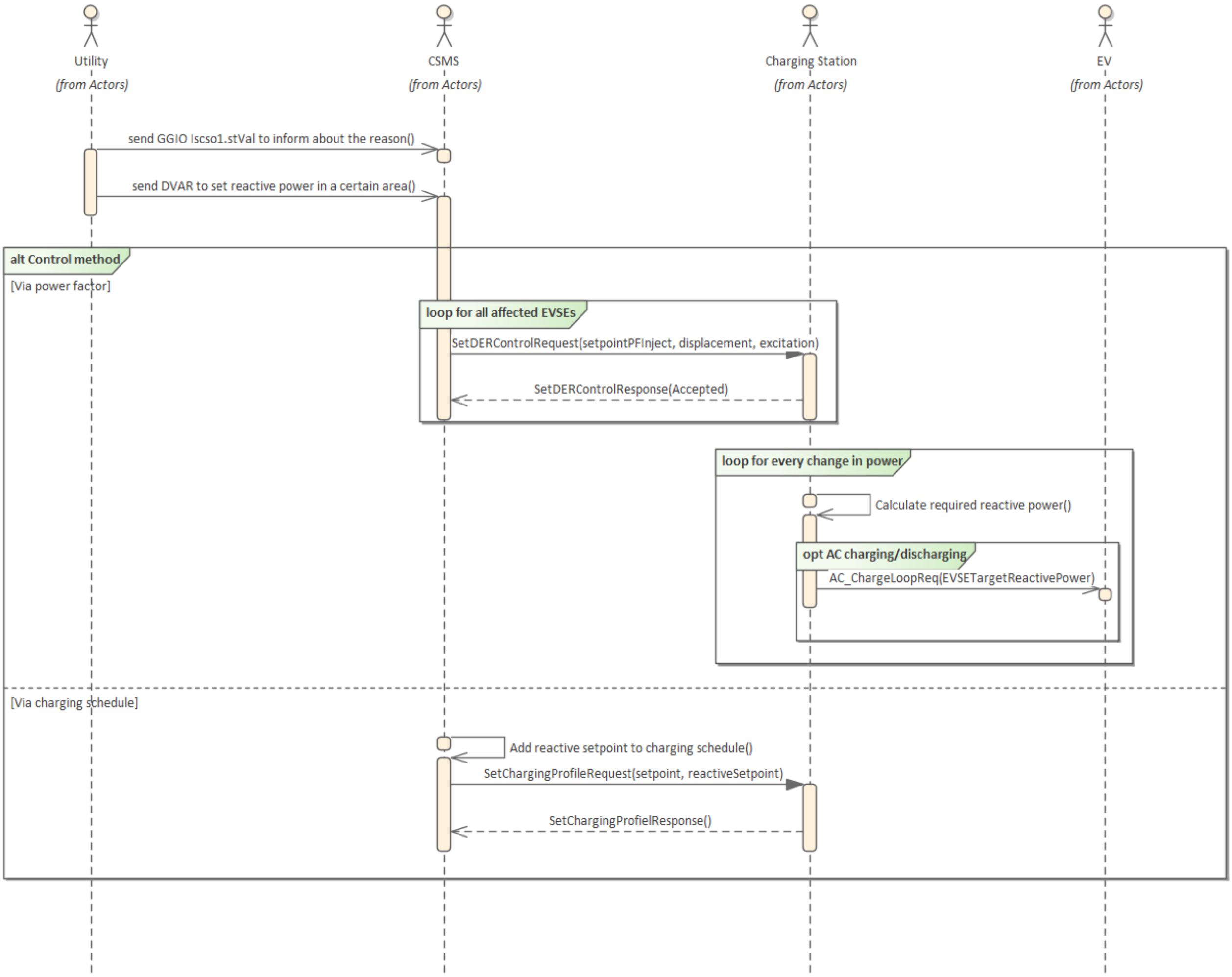

Figure 5 Configure reactive power level

3.6.4 UC4: Configure limit active power level

No.	Type.	Description
1	Name	Configure limit active power
2	ID	UC4, UC.DER.01 of RFC Adding DER Control to OCPP
3	Objective	Limit active power for charging or discharging, e.g. in case of grid congestion.
4	Description	Utility requests CPO to limit active power in a charging station or group of charging stations.
	Actors	Utility, CSMS, CS
	Logical Nodes	DWMX, GGIO
	Scenario description	1. Utility sends GGIO Iscso1.stVal to inform about the reason. 2. Utility sends DWMX to limit active power in a certain area. a. Either WMaxSptPct.mxVal or WMaxSpt.mxVal for percentage or value limit. b. Set Mod.StVal to 1 (On) to enable the limit. c. ModPrio.StVal to set a priority if desired. d. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. CSMS sends a SetChargingProfileRequest with limits for each affected charging station.
5	Prerequisites	
6	Post condition	Affected charging stations have updated charging profiles to stay within requested power limit.
7	Error Handling	
8	Remarks	If the requested power limit is negative, i.e. is about discharging, then only charging stations that are currently involved in discharging, need to receive a new charging profile.

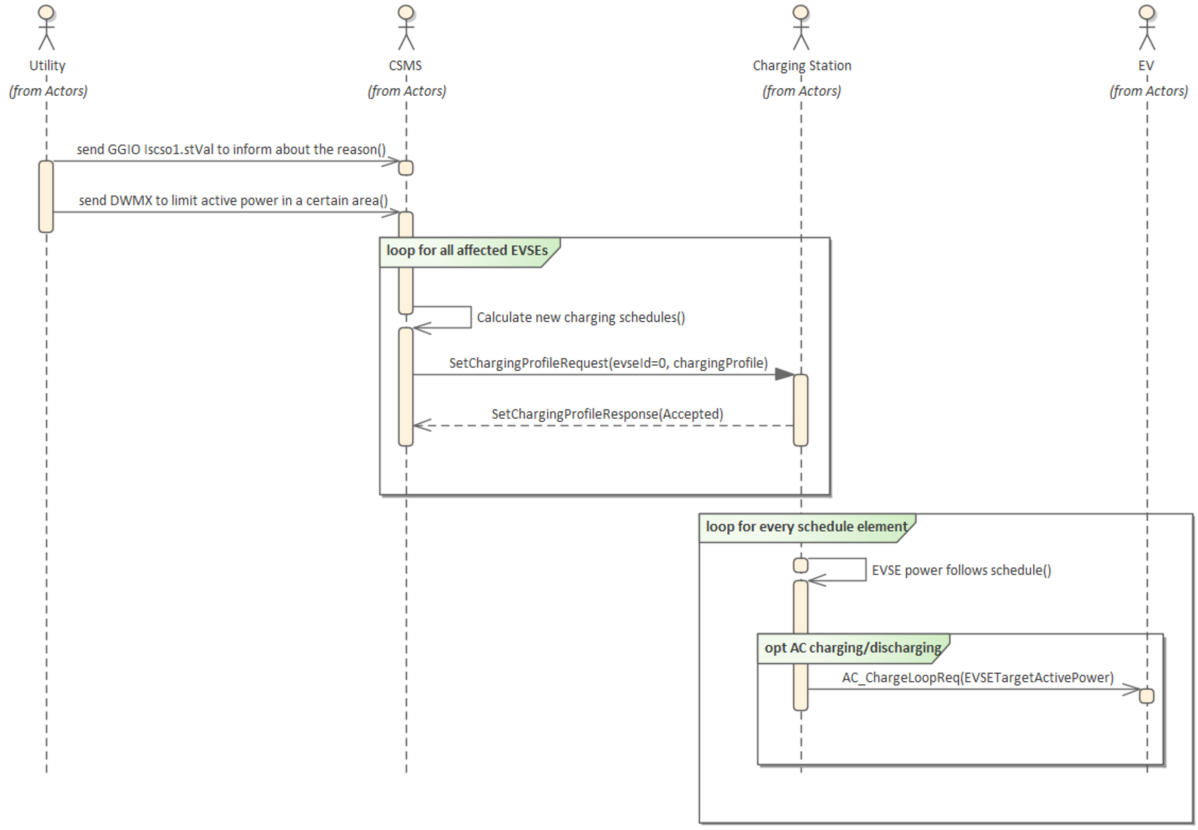

Figure 6 Configure limit active power

3.6.5 UC5: Configure high voltage ride-through

No.	Type.	Description
1	Name	Configure high voltage ride-through curve
2	ID	UC5
3	Objective	A default high voltage ride-through curve is configured to control trip behavior during over voltages.
4	Description	CPO receives a new high voltage trip curve from utility
	Actors	Utility, CSMS, CS
	Logical Nodes	DHVT, PTOV, GGIO
	Scenario description	1. Utility send GGIO Iscso1.stVal to inform about the reason. 2. Utility send DHVT to enable the curve in a certain area. a. Set Mod.StVal to 1 (On) to enable the curve. b. ModPrio.StVal to set a priority if desired. c. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. Utility send PTOV TmVCrv.CURVE for high voltage ride-through curve settings, voltage value on the y-axis and time value on the x-axis with a maximum of 10 curve settings. 4. CSMS send the high voltage ride-through curve settings via SetDERControlRequest(HVTrip, <curve>) to the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated high voltage ride-through curve to stay within the voltage bandwidth.
7	Error Handling	
8	Remarks	

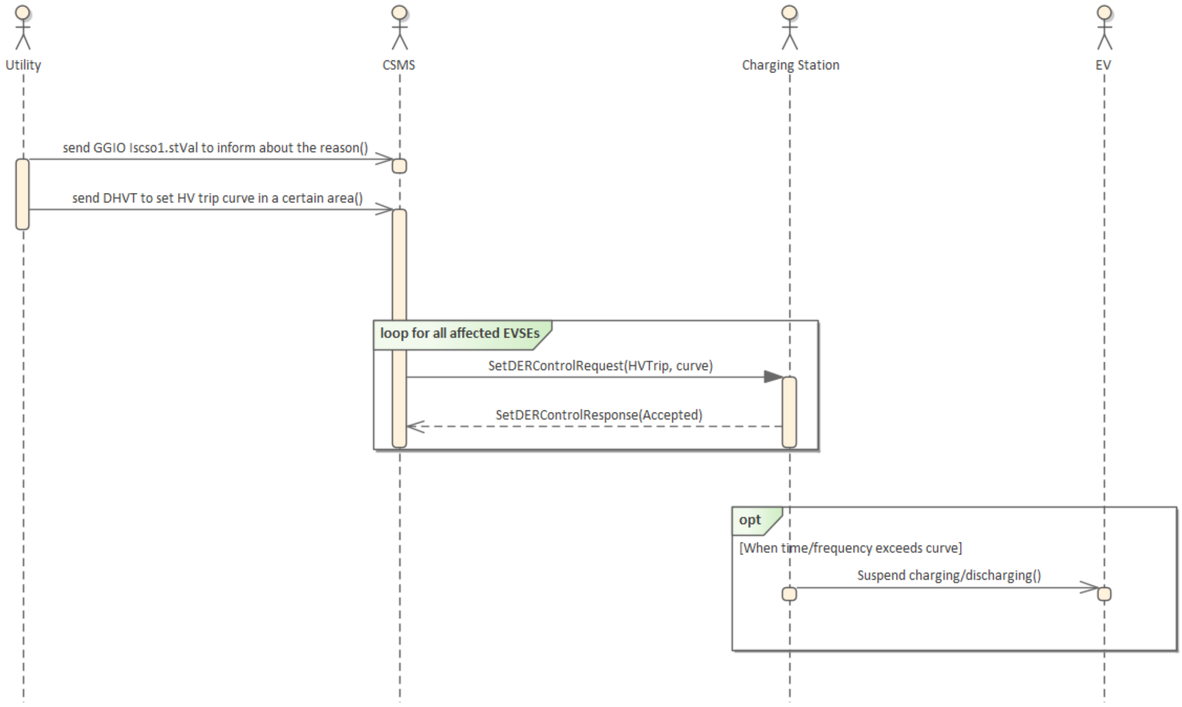

Figure 7 Setting a high voltage trip curve

3.6.6 UC6: Configure low voltage ride-through

No.	Type.	Description
1	Name	Configure low voltage ride-through curve
2	ID	UC6
3	Objective	A default low voltage ride-through curve is configured to control trip behavior during over voltages.
4	Description	CPO receives a new low voltage trip curve from utility
	Actors	Utility, CSMS, CS
	Logical Nodes	DLVT, PTUV, GGIO
	Scenario description	1. Utility send GGIO Iscso1.stVal to inform about the reason. 2. Utility send DLVT to enable the curve in a certain area. a. Set Mod.StVal to 1 (On) to enable the curve. b. ModPrio.StVal to set a priority if desired. c. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. Utility send PTUV TmVCrv.CURVE for low voltage ride-through curve settings, voltage value on the y-axis and time value on the x-axis with a maximum of 10 curve settings. 4. CSMS send the low frequency ride-through curve settings via SetDERControlRequest(LVTrip, <curve>) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated low voltage ride-through curve to stay within the voltage bandwidth.
7	Error Handling	
8	Remarks	

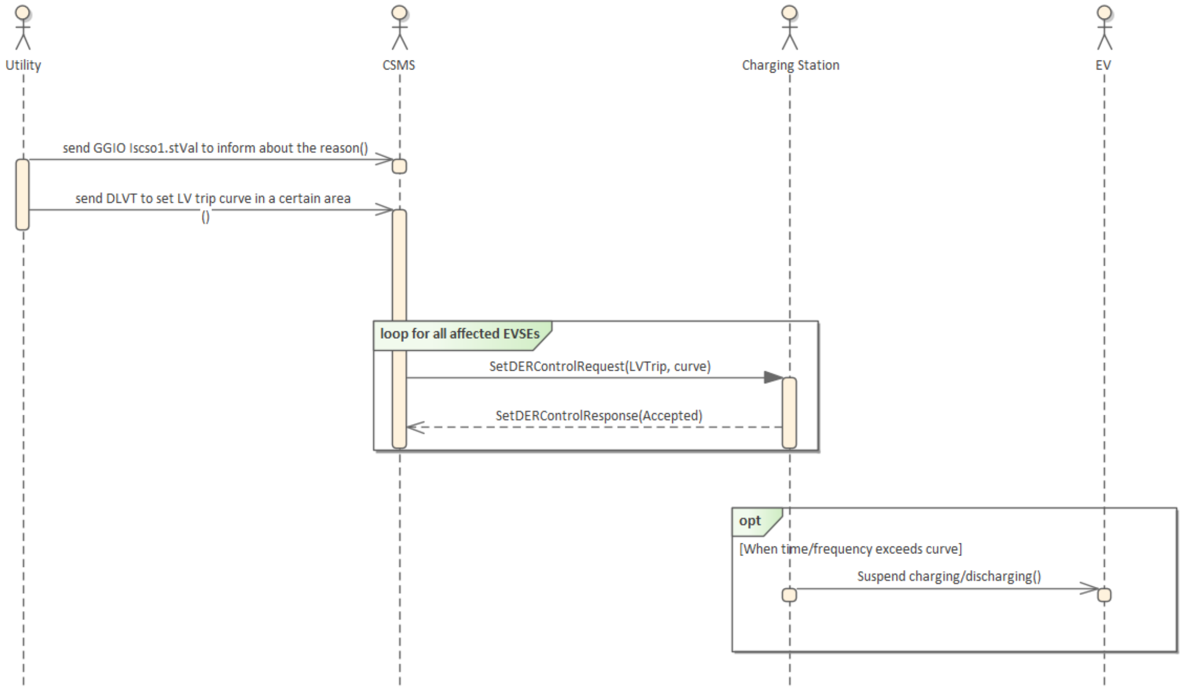

Figure 8 Setting a low voltage trip curve

3.6.7 UC7: Configure high frequency ride-through

No.	Type.	Description
1	Name	Configure high frequency ride-through curve
2	ID	UC7, UC.DER.03 of RFC Adding DER Control to OCPP
3	Objective	A default high frequency ride-through curve is configured to control trip behavior during over frequencies.
4	Description	CPO receives a new high frequency trip curve from utility
	Actors	Utility, CSMS, CS
	Logical Nodes	DHFT, PTOF, GGIO
	Scenario description	1. Utility send GGIO Iscso1.stVal to inform about the reason. 2. Utility send DHFT to enable the curve in a certain area. a. Set Mod.StVal to 1 (On) to enable the curve. b. ModPrio.StVal to set a priority if desired. c. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. Utility send PTOF for high frequency ride-through curve settings. Each PTOF represents a curve, with a maximum of 10. a. StrVal.setMag for frequency value on the y-axis b. OpDlTmms.setVal for the time value on the x-axis 4. CSMS send the low frequency ride-through curve settings via SetDERControlRequest(HFTrip, <curve>) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated high frequency ride-through curve to stay within the frequency bandwidth.
7	Error Handling	
8	Remarks	

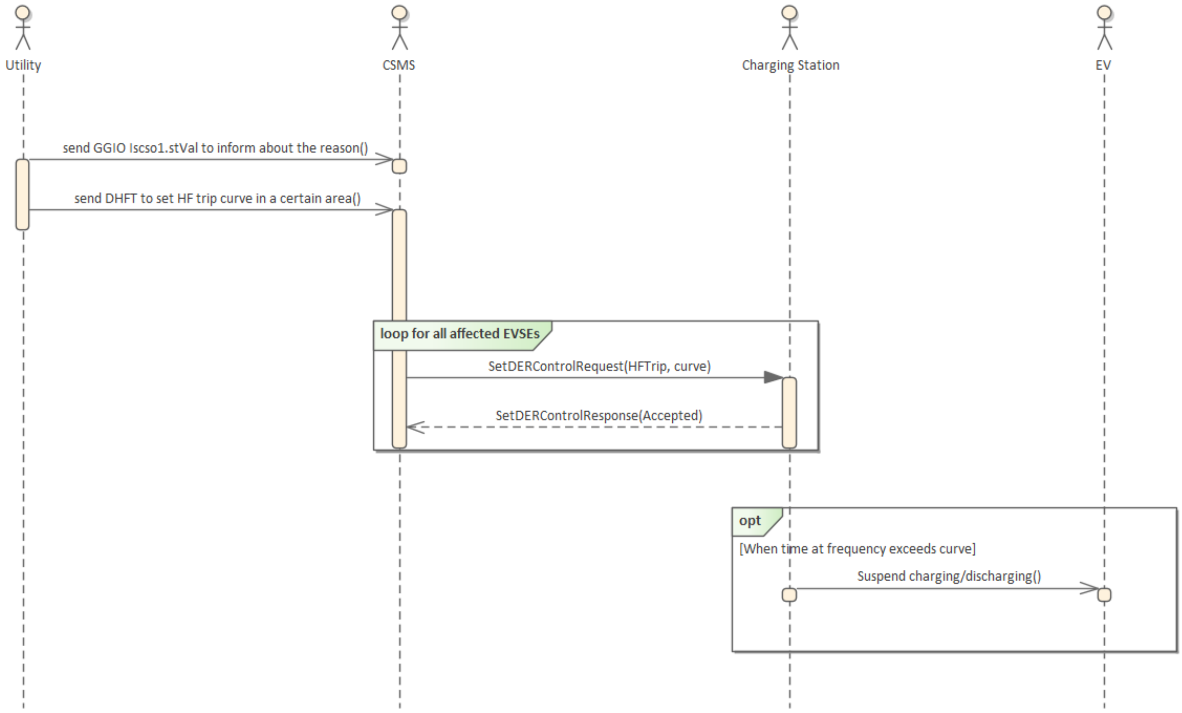

Figure 9 Setting high frequency trip curve

3.6.8 UC8: Configure low frequency ride-through

No.	Type.	Description
1	Name	Configure low frequency ride-through curve
2	ID	UC8
3	Objective	A default low frequency ride-through curve is configured to control trip behavior during over frequencies.
4	Description	CPO receives a new low frequency trip curve from utility
	Actors	Utility, CSMS, CS
	Logical Nodes	DLFT, PTUF, GGIO
	Scenario description	1. Utility send GGIO Iscso1.stVal to inform about the reason. 2. Utility send DLFT to enable the curve in a certain area. a. Set Mod.StVal to 1 (On) to enable the curve. b. ModPrio.StVal to set a priority if desired. c. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. Utility sends PTUF for low frequency ride-through curve settings. Each PTUF represents a curve, with a maximum of 10. a. StrVal.setMag for frequency value on the y-axis b. OpDITmms.setVal for the time value on the x-axis 4. CSMS send the low frequency ride-through curve settings via SetDERControlRequest(LFTrip, <curve>) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated low frequency ride-through curve to stay within the frequency bandwidth.
7	Error Handling	
8	Remarks	

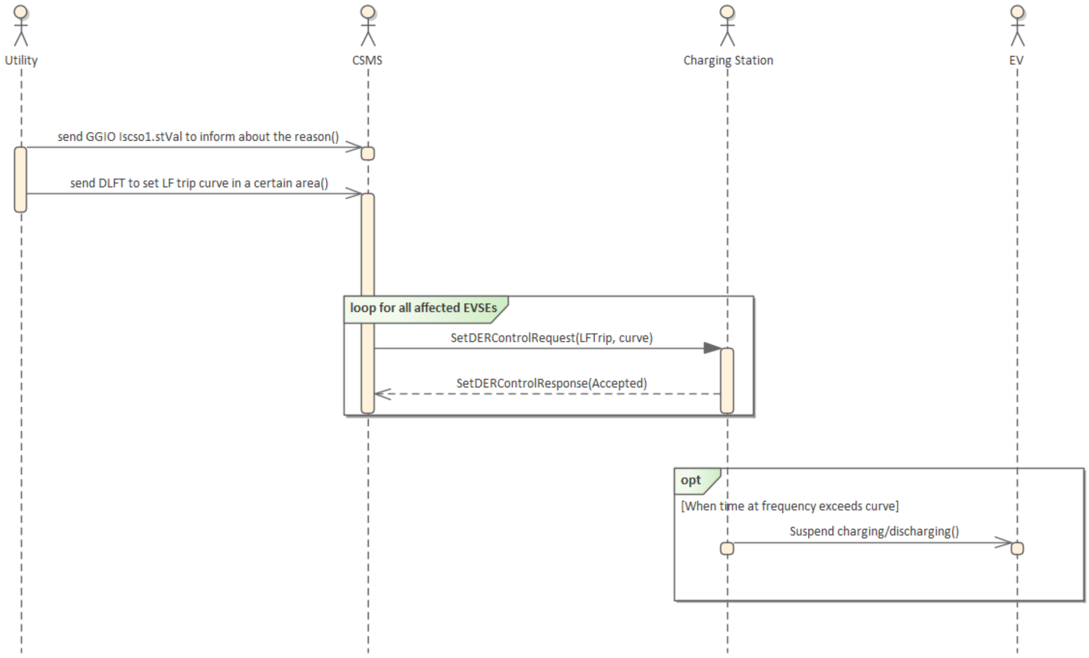

Figure 10 Set low frequency trip curve

3.6.9 UC9: Configure frequency droop

No.	Type.	Description
1	Name	Configure frequency droop
2	ID	UC9, UC.DER.02 of RFC Adding DER Control to OCPP
3	Objective	Configure frequency droop parameters to aid in stabilizing the net frequency when it deviates from nominal value.
4	Description	Utility sends parameters for a frequency droop curve to adjust charging/discharging rate when frequency deviates from nominal value.
	Actors	Utility, CSMS, CS
	Logical Nodes	DHFW, DLFW, GGIO
	Scenario description	1. Utility send GGIO Iscso1.stVal to inform about the reason. 2. Utility send DHFW for high settings. a. HzStr.setMag for over frequency (overFreq) b. WGra.setMag for droop (overDroop) c. OplTmsMax.setVal for open loop response time (responseTime) d. Set Mod.StVal to 1 (On) to enable the curve. e. ModPrio.StVal to set a priority if desired. f. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. Utility sends **Error! Reference source not found.** for low settings. a. HzStr.setMag for under frequency (underFreq) b. WGra.setMag for droop (underDroop) c. OplTmsMax.setVal for open loop response time (responseTime) d. Set Mod.StVal to 1 (On) to enable the curve. e. ModPrio.StVal to set a priority if desired. f. InEcpRef.setSrcRef to refer to the charging station or group of charging stations. 4. CSMS send the low frequency ride-through curve settings via SetDERControlRequest(FreqDroop, overFreq, underFreq, overDroop, underDroop, responseTime) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated charging profiles to stay within requested power limit.
7	Error Handling	
8	Remarks	

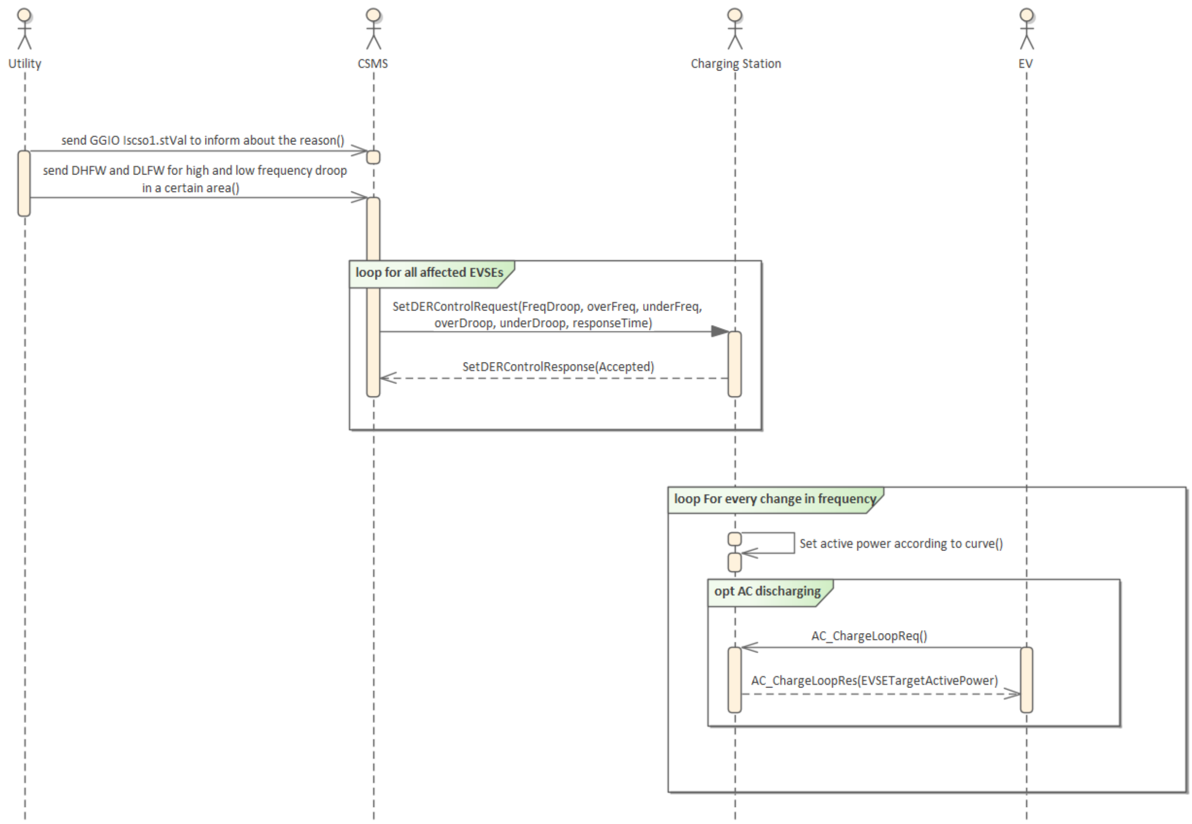

Figure 11 Set frequency droop

3.6.10 UC10: Configure fixed power factor

No.	Type.	Description
1	Name	Configure fixed power factor
2	ID	UC10
3	Objective	Configure fixed power factor for both generating or consuming.
4	Description	Utility sends setpoint for the fixed power factor.
	Actors	Utility, CSMS, CS
	Logical Nodes	DFPF, GGIO
	Scenario description	1. Utility sends GGIO Iscso1.stVal to inform about the reason. 2. Utility sends DFPF for high settings. a. Either PFGnTgtSpt.mxVal or PFLodTgtSpt.mxVal to set fixed power factor for generating or consuming b. Set Mod.StVal to 1 (On) to enable the setpoint. c. ModPrio.StVal to set a priority if desired. d. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. CSMS sends SetDERControlRequest(setpointPFInject) message to affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated power factor setpoint to reach.
7	Error Handling	
8	Remarks	

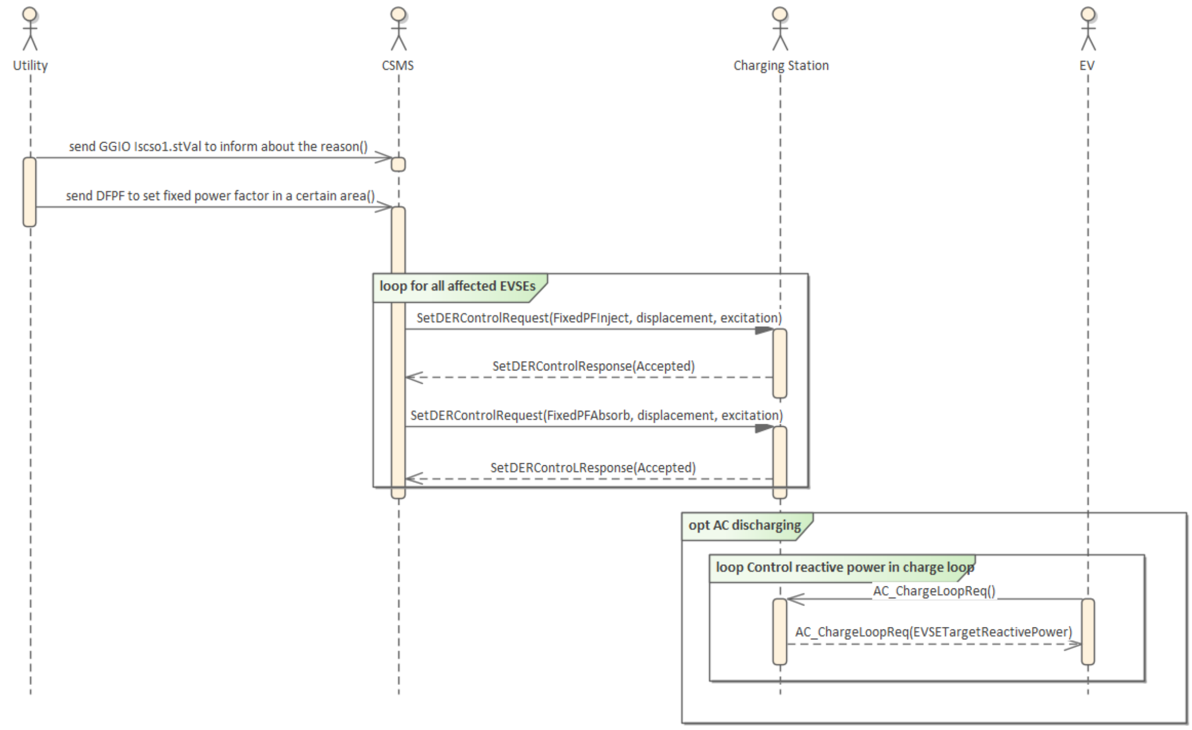

Figure 12 Set fixed power factor

3.6.11 UC11: Configure Voltage-Reactive Power V-var

No.	Type.	Description
1	Name	Configure voltage-reactive power V-var curve
2	ID	UC11, UC.DER.04 of RFC Adding DER Control to OCPP
3	Objective	A default VoltVar curve is configured to stabilize grid voltage.
4	Description	CPO receives a new VoltVar curve from utility, that describes how much reactive power the charging station must inject when voltage deviates from nominal.
	Actors	Utility, CSMS, CS
	Logical Nodes	DVVR, GGIO
	Scenario description	1. Utility sends GGIO Iscso1.stVal to inform about the reason. 2. Utility sends DVVR to limit active power in a certain area. a. VVArCrv.crvPts to define an array of points for the curve, with a maximum of 10. b. OplTmsMax.setVal for open loop response time (responseTime) c. Set Mod.StVal to 1 (On) to enable the curve. d. ModPrio.StVal to set a priority if desired. e. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. CSMS sends the low frequency ride-through curve settings via SetDERControlRequest(VoltVar, <curve>) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated VoltVar curve to stabilize grid voltage.
7	Error Handling	
8	Remarks	

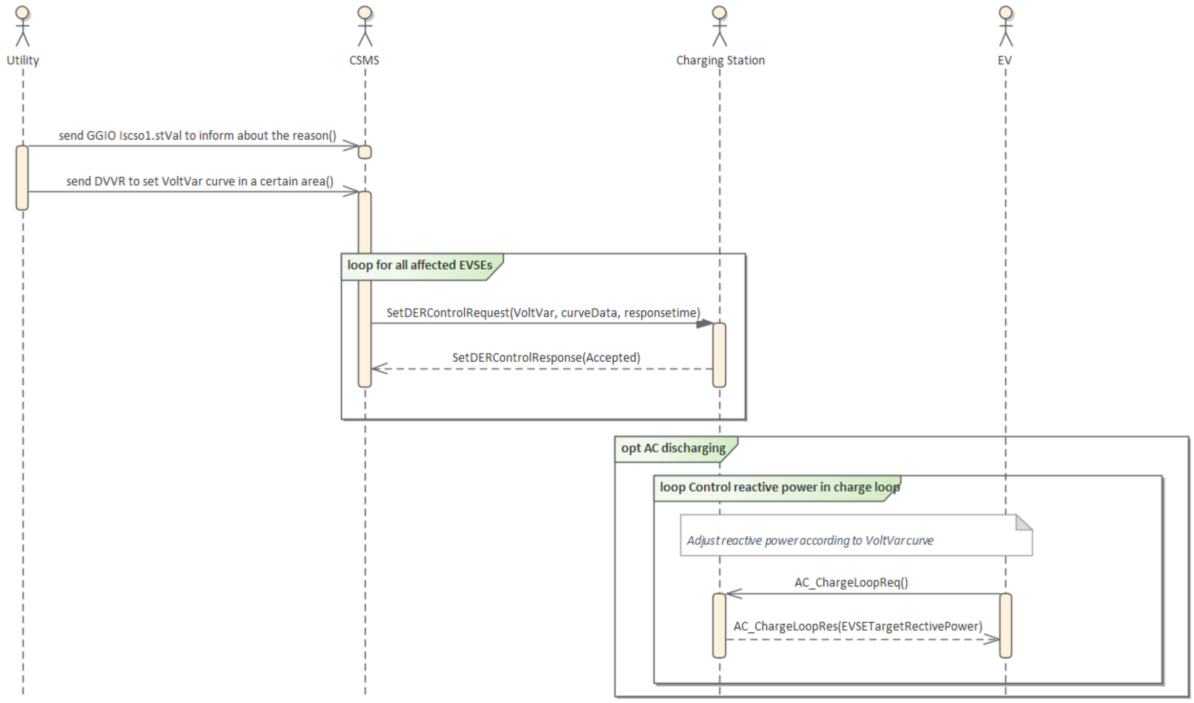

Figure 13 Set VoltVar curve

3.6.12 UC12: Configure Voltage-Active Power (V-W)

No.	Type.	Description
1	Name	Configure voltage-actisve power V-W curve
2	ID	UC12
3	Objective	A default V-W curve is configured to stabilize grid voltage.
4	Description	CPO receives a new VoltVar curve from utility, that describes how much reactive power the charging station must inject when voltage deviates from nominal.
	Actors	Utility, CSMS, CS
	Logical Nodes	DVWC, GGIO
	Scenario description	1. Utility sends GGIO Iscso1.stVal to inform about the reason. 2. Utility sends DVWC to limit active power in a certain area. a. VWCrv.crvPts to define an array of points for the curve, with a maximum of 10. b. OplTmsMax.setVal for open loop response time (responseTime) c. Set Mod.StVal to 1 (On) to enable the curve. d. ModPrio.StVal to set a priority if desired. e. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. CSMS sends the low frequency ride-through curve settings via SetDERControlRequest(VoltWatt, <curve>) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated V-W curve to stabilize grid voltage.
7	Error Handling	
8	Remarks	

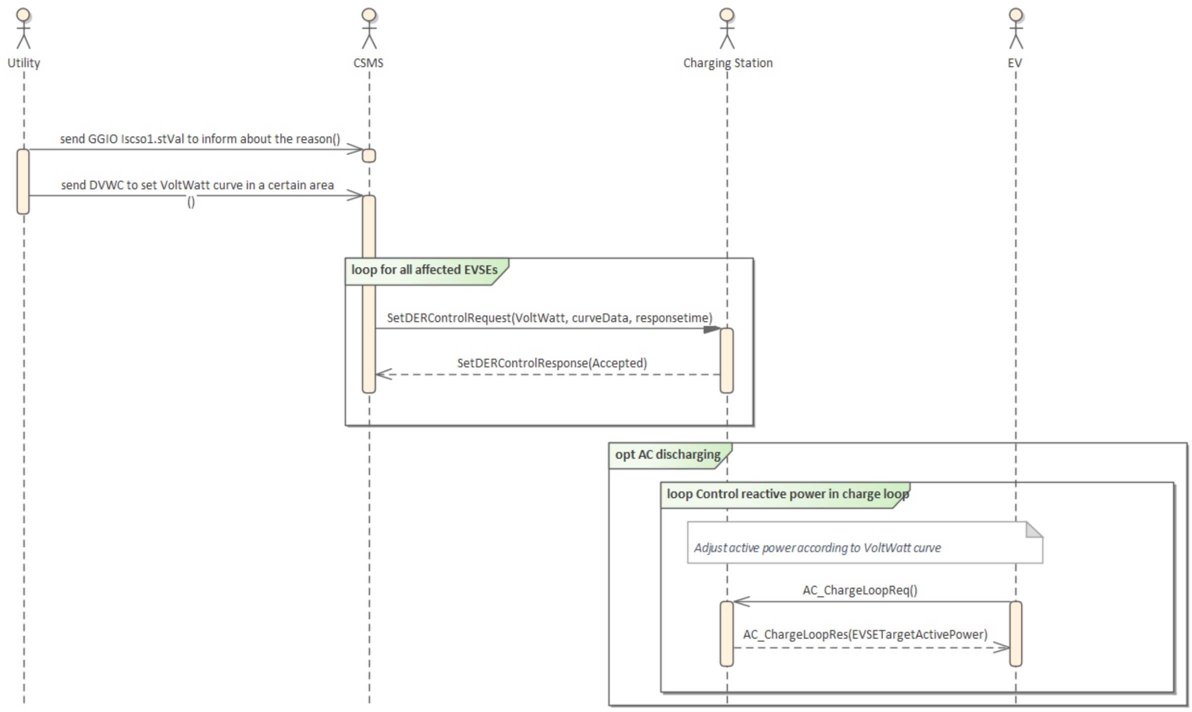

Figure 14 Set VoltWatt curve

3.6.13 UC13: Configure Active Power Reactive Power (W-Var)

No.	Type.	Description
1	Name	Configure Active power Reactive Power W-Var curve
2	ID	UC13
3	Objective	A default W-Var curve is configured to stabilize grid voltage.
4	Description	CPO receives a new WattVar curve from utility, that describes how much reactive power the charging station must inject when voltage deviates from nominal.
	Actors	Utility, CSMS, CS
	Logical Nodes	DWVR, GGIO
	Scenario description	1. Utility sends GGIO Iscso1.stVal to inform about the reason. 2. Utility sends DWVR to limit active power in a certain area. a. WVArCrv.crvPts to define an array of points for the curve, with a maximum of 10. b. OplTmsMax.setVal for open loop response time (responseTime) c. Set Mod.StVal to 1 (On) to enable the curve. d. ModPrio.StVal to set a priority if desired. e. InRef.setSrcRef to refer to the charging station or group of charging stations.

No.	Type.	Description
		3. CSMS sends the low frequency ride-through curve settings via SetDERControlRequest(WattVar, <curve>) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have updated W-Var curve to stabilize grid voltage.
7	Error Handling	
8	Remarks	

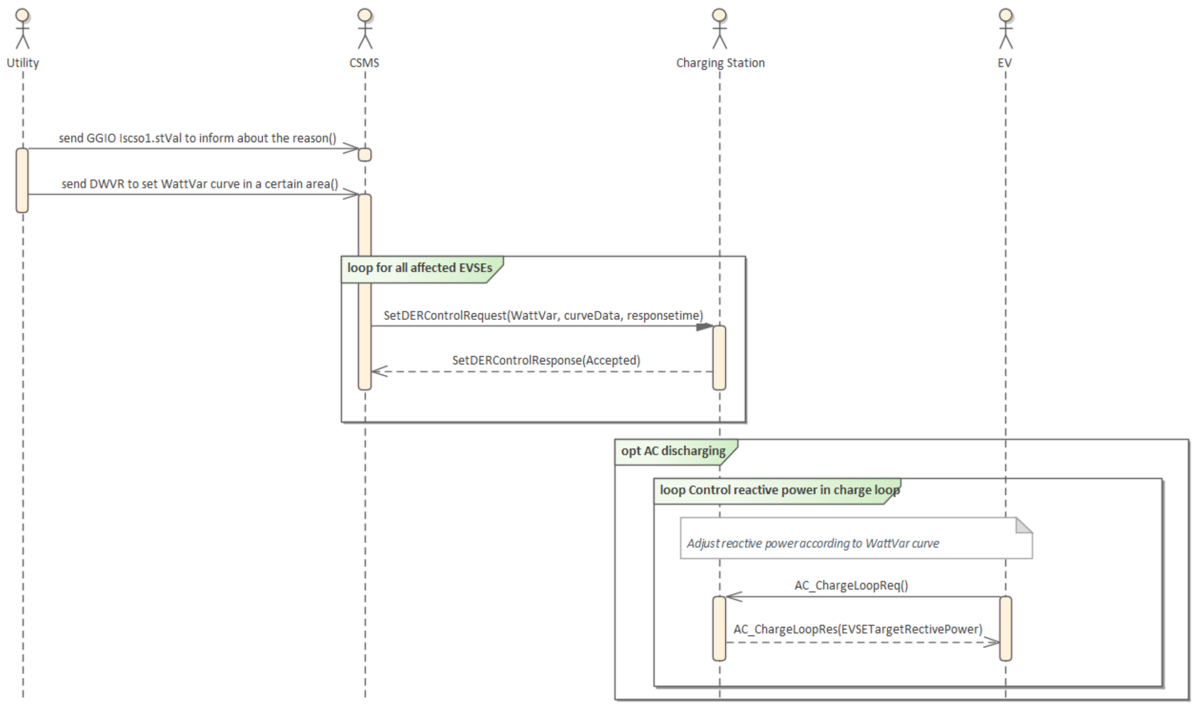

Figure 15 Set WattVar curve

3.6.14 UC14: Configure Reenter service

No.	Type.	Description
1	Name	Parameters for entering service
2	ID	UC14
3	Objective	
4	Description	To set parameters that describe the conditions when and how a device can enter service.
	Actors	Utility, CSMS, CS
	Logical Nodes	DCTE, GGIO

No.	Type.	Description
	Scenario description	1. Utility sends GGIO Iscso1.stVal to inform about the reason. 2. Utility sends DCTE to set parameters in a certain area. a. VHiLim.setMag for high voltage (highVoltage) b. VLoLim.setMag for low voltage (lowVoltage) c. HzHiLim.setMag for high frequency (highFreq) d. HzLoLim.setMag for low frequency (lowFreq) e. RtnDlTmms.setVal for delay (delay) f. RtnRmpTmms.setVal for ramp rate (rampRate) g. WinTms.setVal for a random delay before enabling (randomDelay) h. Set Mod.StVal to 1 (On) to enable the function. i. ModPrio.StVal to set a priority if desired. j. InRef.setSrcRef to refer to the charging station or group of charging stations. 3. CSMS sends the reenter service settings via SetDERControlRequest(EnterService, highVoltage, lowVoltage, highFreq, lowFreq, delay, rampRate) for the affected charging stations.
5	Prerequisites	
6	Post condition	Affected charging stations have entered service parameters.
7	Error Handling	
8	Remarks	

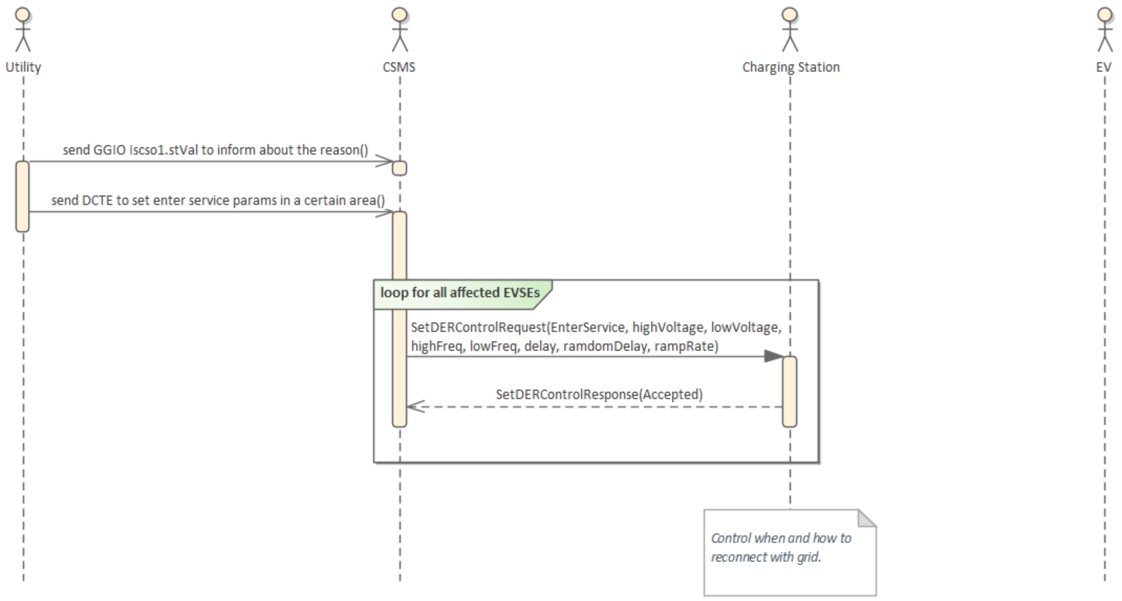

Figure 16 Set Enter Service parameters

4 CONCLUSIONS

Utilities consider a charging station (or group of charging stations) that is performing bi-directional charging/discharging as a Distributed Energy Resource (DER). A DER needs to adhere to the local grid codes that govern how it should react in case of grid anomalies. This is controlled by a range of settings and curves that determine how to respond to frequencies and/or voltages that are too high or too low.

IEC 61850 is an international standard defining data exchange between intelligent electronic devices at electricity substations and for distributed energy resources. It is a logical choice for utilities to use the communication protocols within IEC 61850 towards a charge point operator to set or update grid control settings for the (groups of) charging stations that can act as a DER.

The addition of DER support in OCPP 2.1 makes it possible to convey this information to charging stations. When in the near future bi-directional charging is being adopted at a large scale, this may become a vital instrument for utilities to protect the grid.

APPENDIX A
What is IEC 61850?

The need for a reliable electrical infrastructure drove the transition from electro-mechanical devices to integrated circuits, which in turn led to the massive use of advanced, fast, and relatively cheap microprocessors. The introduction of microprocessors in the substation automation world has caused a revolution, instead of having dedicated devices to perform one function there is now the option of combining several functions in so called Intelligent Electronic Devices (IEDs). These IEDs perform the required protection, monitoring and local/remote control functions with the same ease and comfort as the traditional digital relays. To utilize the IEDs in an efficient way the need for a uniform communication and configuration protocol become crucial for the success of these modern devices. Then the unique manufacturer specific way of communication and configuration became undesirable and too costly.

It became clear that a new substation automation standard had to be developed to consider a truly uniform way of communication between the devices to support multi-vendor systems and that will meet functional, technical and performance requirements while also be future proof. The standard must support all current power utility automation functions but cannot force to use functions in a certain way. The standard must use open, standardized communication and data modelling standards and needs to be future proof, meaning to be self-descriptive and provide options to extend and enhance the standard in the future. Around 1995 an IEC project was started with 60 experts from different countries, organized in three working groups and worked out the concerns and objectives for a future proof substation automation standard and created IEC 61850. The standard is based upon the following building blocks:

- “A single communication protocol for complete substation automation including modelling of different data required for substation automation, protection & control.
- Definition of basic services required to transfer data so that the entire mapping to communication protocol can be made future proof.
- Promotion of high inter-operability between systems from different vendors.
- A common method/format for storing complete data.
- Define complete testing required for the equipment which conforms to the standard”.

The main aim of the IEC 61850 substation automation standard is to provide interoperability between all devices in a substation and beyond the substation. IEC 61850 was published in 2003 for the first time with the validity of the first edition until 2005. However according to IEC, the stability date was 2010, stating the standard’s validity was extended. Since the publication of the first edition of IEC 61850, the experts have been working on an updated edition to further improve the standard and ensure compliance to the points above. All edition 1 parts of the IEC 61850 standard have been revised or updated and published as the second edition since 2012. Edition 2 core parts have been reworked as amendment 1 between 2020-2022.

The development of IEC 61850 is still done by a large group of international experts from manufacturers, utilities, and consultancy companies. In the meantime, the standard has been reviewed and new parts are added every year. IEC 61850 is now a worldwide standard for communication networks and systems in substations and since its 2nd edition also for communication outside the substation and the traditional power domain. With the release of edition 2 the title was changed to power utility automation.

It is a common misunderstanding that IEC 61850 is only about data communication. The key concepts for data modelling and the universal configuration language are often considered less important, while the opposite is true. Without proper data modelling and configuration there is even no data communication possible.

Power utility automation which engages IEC 61850 provides:

1. Uniformity of protection and automation design
2. Improved power system functionality and performance requirements
3. Higher interoperability between substation devices
4. Improvement in substation reliability
5. Alignment with peer utility substation designs and technological trends.

A successful transition from the present methods of designing, implementing, testing, and commissioning of substations to fully engage IEC 61850 power utility automation will require:

1. Detailed planning and a phased approach
2. Training, testing and simulation
3. Changes to some business practices
4. Re-skilling resources at utilities and/or acquiring new resources with required competence
5. Stakeholder engagement including management, asset owners and operations.

The aim of a generic and standardized power utility automation approach with IEC 61850 is to set out clearly all objectives and provide a foundation for going forward given the upcoming electricity distribution network augmentation. The clear benefit of IEC 61850 is around standardized configuration methods, with IEC 61850 a single tool can be used to configure the system. The need for vendor specific tools is eliminated. When replacing an IED no new tools or method must be learned. The standardized IEC 61850 engineering and configuration tool is responsible for the configuration of the whole system and not for individual IEDs and to provide overall system documentation. A true IEC 61850 configuration tool supports devices from different manufacturers and is using the same methodology, procedures to achieve the final system configuration.

Protection and automation IEDs are specialized and purpose build computers in the electricity distribution and/or transmission network. They control and protect the primary assets during normal operation and during abnormal system conditions. The correct functioning of IEDs is key to the security of supply inside an electric system. Failure to operate will have disastrous consequences for the electrical network and human safety. On the other hand, if an IED operates when it is not intended to operate it may have large economic consequences.

With the introduction of IEC 61850, utility communication will be used for power utility automation and for protection purposes within and between substations. Measured values and trip signals will be transmitted digitally over high-speed communication networks.

A positive side effect of the introduction of IEC 61850 is the introduction of Ethernet and TCP/IP based Local and Wide Area Networks (LAN/WAN) which will introduce additional benefits in terms of (direct and fast) access to systems and data inside the substation from a remote location. The migration from legacy protocols and communication architecture to a future proof and vendor independent Ethernet network architecture will reduce costs in terms of maintenance and support. The upgrade to an all-IP fiber infrastructure in the entire system will improve the reliability and availability of the connected digital assets. This improves the usability of the SCADA system when more relevant data becomes available. Having direct and remote access to (fault) data in the connected IEDs and other assets inside the power utility domain together with access to current settings will save time in fault analysis in case of serious events.

Generally, automation functions should be provided in a common configurable environment using selected IEDs which can deliver the maximum number of functions reducing the overall number of common IED types. The advantages of IEC 61850-enabled systems have been clearly demonstrated but the caution exercised by utilities for full adoption has been related to an apprehension about the effort required to carry out the programming, configuration and testing of the final system.

IEC 61850 – Parts 1-4

IEC 61850 parts 1-4 give an introduction and overview of the standard and act as a reading guideline for the standard. It provides a glossary of the used terms, abbreviations, and general requirements. Environmental and EMC aspects are also explained together with project and system lifecycle management aspects.

IEC 61850 – Part 5

Part 5 is dedicated to the communication requirements for functions and device models for substations.

Chapter 1 specifies the scope of the standard as applicable to substation automation systems. Normative references are listed in chapter 2, while terms and definitions as well as list of abbreviation are given in chapters 3 and 4.

Chapter 5 is dedicated to power utility automation system functions, and it is describing logical and physical allocation of functions and interfaces, as well as the role of the interfaces. Clause 5.3 zooms in on other application domains such as renewables and distributed energy resources (DER) and distribution automation.

Chapter 6 is dedicated to the goal and the requirements of the standard. It states that acceptable overall transfer data shall be defined and guaranteed in any situation, however without giving any requirements regarding those times and focusses on the approach to an interoperable system and the requirements for conformance testing.

The rules for function description are stated in chapter 7, and functions are categorized in chapter 8 and detail the use of the specific logical nodes used for different applications and the exchange of information. Chapter 9 clarifies the application concept for logical nodes. Chapter 10 describes the system description and introduces the system configuration description and the data exchange between tools and devices.

Chapter 11 deals with system performance requirements regarding time synchronization, message exchange in and between IEDs together with performance criteria for the communication system. According to it, the broad range of transfer times reflects the individual needs of the functions together with the requirements for data integrity and the methods to prove that dynamic performance requirements will be met, and chapter 12 concludes the standard with some additional requirements for the data model.

IEC 61850 – Part 6

Part 6 specifies the Substation Configuration Language (SCL) for the configuration of IEC 61850 equipment. It is used to describe the configurations of IED and communication systems according to IEC 61850-5 and IEC 61850-7. The main purpose of the configuration language is to exchange data in a standardized way between different manufacturers of IEC 61850 compliant equipment.

The generic engineering process is described in chapter 5 and 6. The chapter describes a universal and thus standardized top-down engineering of a complete power utility automation system instead of individual configuration of devices with proprietary tools. According to this document a device can only be considered compliant to IEC 61850 when:

1. It is accompanied either by an SCL file describing its capabilities, or by a tool, which can generate this file from the IED.
2. It can directly use a system SCL file to set its communication configuration, as far as setting is possible in this IED (i.e., as a minimum, its needed addresses), or it is accompanied by a tool which can import a system SCL file to set these parameters to the IED.

In addition, this part describes in detail the different configuration models for IEC 61850 compliant substations. Chapters 5 and 6 explain the concepts and inter-relations between communication functions and data models.

Chapter 7 describes the differences between the existing SCL files and explains which SCL file is used where in the engineering process while chapter 8 describes the contents and the semantics of the SCL syntax together with the way on how object references in the data-model are generated. Chapter 9 explains in detail the contents of the different SCL syntax elements. Chapter 10 deals with the different SCL tools and project engineering rights imposed by the SCL syntax.

IEC 61850 – Part 7

The 7-series documents describe the communication and data modelling services that form the foundation of the standard. By following these documents carefully interoperability will be reached.

Part 7-1 provides an overview of the architecture for communication and interactions between substation devices such as protection devices, breakers, transformers, substation hosts etc. This document is part of a set of specifications which details layered power utility communication architecture. This architecture has been chosen to provide abstract definitions of classes (representing hierarchical information models) and services such specifications are independent of specific protocol stacks, implementations, and operating systems. The goal of the IEC 61850 series is to provide interoperability between the IEDs from different suppliers or, more precisely, between functions to be performed in a substation but residing in equipment physical devices) from different suppliers. Interoperable functions may be those functions that represent interfaces to the process (for example, circuit breaker) or application functions such as protection and control. This part of the IEC 61850 series uses simple examples of functions to describe the concepts and methods applied in the IEC 61850 series.

Part 7-2 describes in an abstract way the communication services for IEC 61850 compliant IEDs. This is done in such a way that the communication services are independent of the used operations systems, specific protocol stacks or even physical communication methods. The so-called Abstract Communication Service Interfaces (ACSI) are independent of the underlying communication technology and provide an interface to common read; write functions of data objects and attributes inside the IED. The specific mapping to communication protocols or services are done in IEC 61850-8-x and IEC 61850-9-x.

Where in 7-1 and 7-2 the abstract definitions and concepts are described in relation to substation functions and communication services, part 7-3 describes the commonly used data types and data classes for use inside the substation. These Common Data Classes (CDC) are the building blocks for the correct use automation, control, and protection applications.

In part 7-4 the foundation is laid for interoperability by using standardized names and function definitions for power utility automation functions. To reach interoperability, all data in the data model need a strong definition about syntax and semantics. The semantics of the data are mainly provided by names assigned to logical nodes and data they contain, as defined in this part. Interoperability is only achieved by clear and detailed utility specifications where all required data is outlined as mandatory data objects and attributes. Because of different philosophies and technical features, settings were declared as optional in this edition of the standard. The Logical Node Names and Data Names defined in part 7-4 are part of the class model introduced in IEC 61850-7-1 and further defined in IEC 61850-7-2. The names defined in part 7-4 are used to build the hierarchical object references applied for communicating with IEDs. The naming conventions of IEC 61850-7-2 are applied in this part. To avoid private and incompatible extension rules this part specifies normative naming rules for multiple instances and private extensions of Logical Node (LN) Classes and Data Names.

Part 7-420 is dedicated to the use of Distributed Energy Resources (DER) and includes not only renewables but also includes Electric Vehicles (EV). From the perspective of IEC 61850 an EV is like a combined storage and generator device which consumes and produces electrical energy. The most recent version of part 7-420 includes mandatory operational functions for the use of DER devices. In Appendix B a more detailed description can be found of the EV specifics.

IEC 61850 – Part 8

This part of the IEC 61850 standard focuses on communication inside the substation and outside the substation, for both time critical data and non-time-critical data. The most common part in referenced in this series, is the IEC 61850-8-1. Substation communication is achieved by the mapping of the abstract communication services as defined in part 7-2 onto the MMS protocol and on Ethernet. The mapping of ACSI to MMS in part 8-1 defines how the concepts and services of the ACSI are to be implemented using MMS concepts, objects, and services. This mapping allows interoperability across functions implemented by different manufacturers. Part 8-1 also specifies the definition of time-critical information directly mapping onto Ethernet frames. The communication services described in this part of the IEC 61850 standard are referred to station-bus-communication in many documents. Part 8-2 describes the mapping of ACSI services and MMS messages onto webservices. The document details the usage of XMPP, and the details of the actual implementation and the features used in the mapping together with means to secure the communication end to end. The use of XMMP makes IEC 61850 ready for the use over non trusted and/or third-party communication networks and is considered a game-changer for the implementation of IEC 61850 communication in DER environments.

APPENDIX B

IEC 61850 in the EV domain

Electrical networks are changing from a unidirectional power flow to a multi directional power flow; the use of distributed energy resources (DER) is crucial for this transition. To standardize not only communication but also data modelling IEC 61850 is extended with dedicated object models for DER.

One of the goals of IEC 61850 was for numerous years to create a communication infrastructure that will allow seamless integration of systems into one communication architecture. An architecture that is vendor independent and will allow devices and systems to work together. IEC 61850 was developed for communication inside the substation when it was released as Edition 1 in 2005. With the introduction of Edition 2, communication in the non-real-time domain was extended to outside the substation such as communication with centralized SCADA systems.

IEC 61850 is an object-oriented approach to substation automation and modelling and is designed for an automatic transmission of data between IEDs and other systems making process data available everywhere in the automation system. The standard defines the communication protocols for both the real-time and the non-real-time domain inside the substation.

As described in Appendix A the IEC 61850 standard is a very comprehensive standard which exists of multiple parts with relevance to the EV domain. To implement IEC 61850 for EV the following latest revisions are in scope for communication: part 7-2, 8-1 and for data modelling: part 6, 7-3, 7-4, 7-420.

Communication in the non-real-time domain is done via the Manufacturing Messaging Specification (MMS) protocol. MMS utilizes TCP/IP and is therefore suitable for transport and routing over wide area networks. The difference between the GOOSE and MMS is depicted in the picture below.

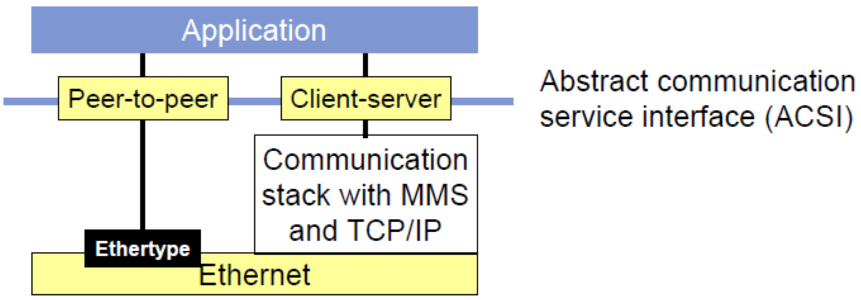

Figure 17 GOOSE and MMS

For communication between IEDs in the real-time-domain GOOSE is the way forward. GOOSE stands for Generic Object-Oriented Substation Event. The GOOSE message replaced the conventional hardwired connections between IEDs and process equipment and is often referred to as peer-to-peer communication. Upon detecting events in the process, the task of an IED is to inform all other IEDs of this change by sending updated process information instantly to all subscribers on the network.

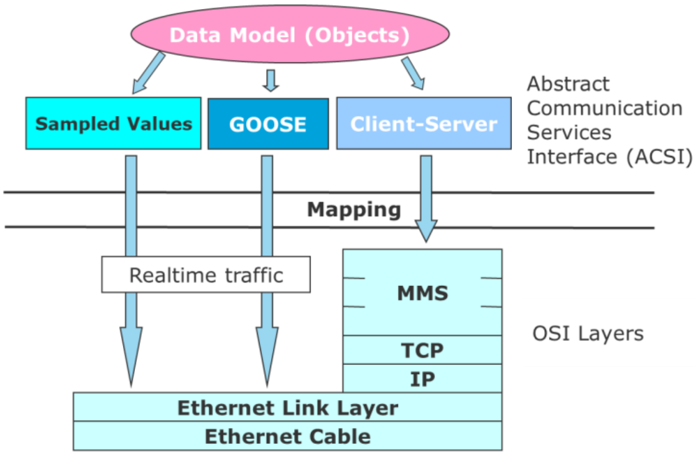

Figure 18 GOOSE mapping on Ethernet

As seen in the above picture GOOSE is directly on mapped onto Ethernet and the broadcast nature of GOOSE makes it only suitable within the scope of one Ethernet collision domain. GOOSE is not routable without special operational and security measures. MMS uses TCP/IP and is therefore routable.

MMS is defined in the ISO 9506 and is originally developed for factory automation and provides a messaging system for real time process data between devices or applications. One of the benefits for IEDs is the easy configuration; remote clients only need to know the IP address of a device. After setting up a connection, MMS provides a set of services to retrieve the complete hierarchal data model including all the relevant data points and values. The first version of MMS was developed in 1986 and published as an international standard in 1990 for use on Open Systems Interconnection (OSI) networks. Boeing revised MMS in 1999 and added support for TCP/IP. The revised 2000 version is used for IEC 61850 and is still the only standard which meets all performance and flexibility criteria defined by IEC 61850.

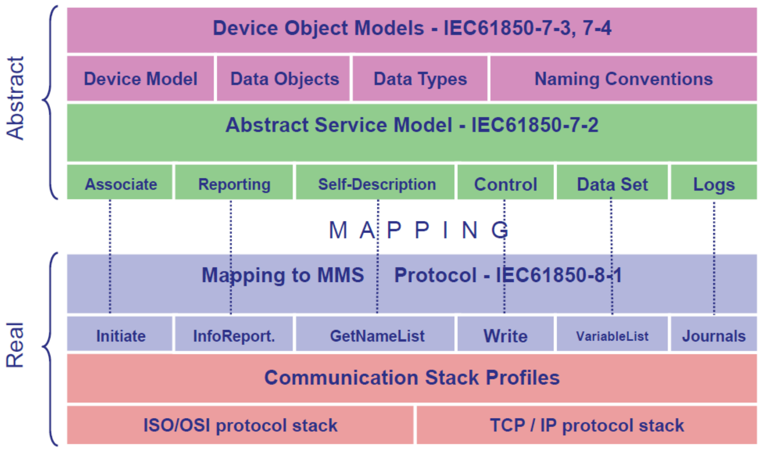

Figure 19 Mapping of abstract services onto MMS

By using MMS and a shared common naming convention and communication services, devices, or applications independent from any manufacturer will work together. IEC 61850-7-2 describes the abstract communication services such as Reporting, Control. The mapping of the abstract services to MMS services is arranged in IEC 61850-8-1, for example Reporting maps on infoReport and Control on Write.

APPENDIX C

Terminology and definitions

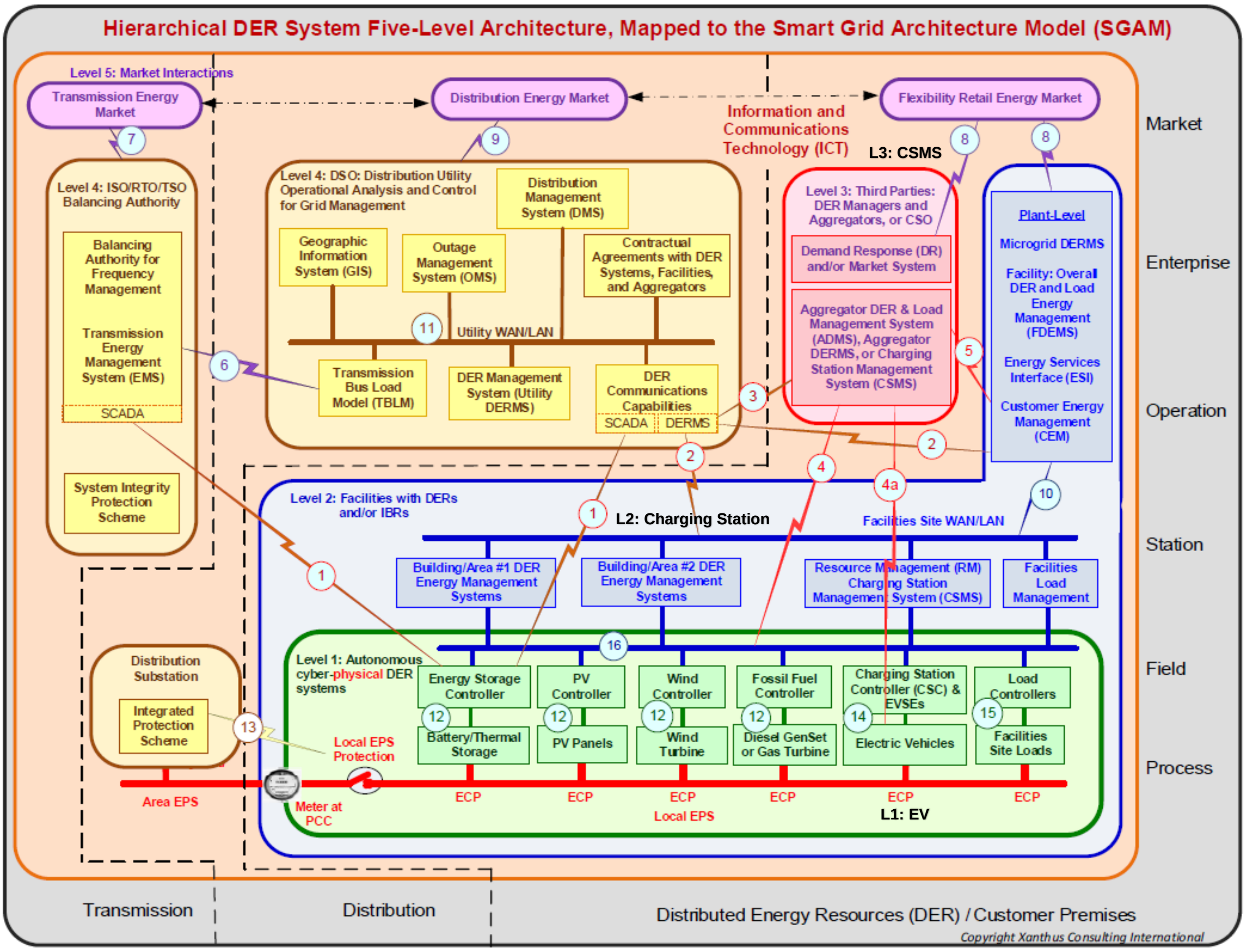

Figure 20 Conceptual hierarchical architecture of DER information interactions with other entities including OCPP mapping (Source: IEC 61850-7-420 (2021))

Table 2 Terminology and definitions comparison

OCPP 2.0.1 PART 2 – SPECIFICATION SECTION 2. CONVENTIONS, TERMINOLOGY AND ABBREVIATIONS		IEC 61850-7-420 (2021) SECTION 3. TERMS, DEFINITIONS AND ABBREVIATED TERMS AND ACRONYMS	
Definition	Description	Definition	Description
Charging Station	The Charging Station is the physical system where EVs can be charged. A Charging Station has one or more EVSEs.	DER Level 2	Distributed Energy Resource, Level 2 is a facility DER management system (facility DER MS) manages the operation of the Level 1 DERs. This facility DER MS may be managing one or two DERs.
CSMS	Charging Station Management System. The system that manages Charging Stations and has the information for authorizing Users for using its Charging Stations	DER Level 3	Distributed Energy Resource, Level 3 are market-based aggregators and retail energy providers (REP) who request or even command DERs (either through the facility's facility DER MS or via aggregator-provided direct communication links) to take specific actions, such as turning on or off, setting or limiting output, providing ancillary services (e.g. volt-var control), and other grid management functions.
EV	Electric Vehicle, distributed energy resource with a remote battery and socket	DER Level 1	Distributed Energy Resource, Level 1 is the lowest level and includes the actual cyber-physical DERs themselves. These DERs will be interconnected to local grids at Electrical Connection Points
Connector	The term Connector, refers to an independently operated and managed electrical outlet on a Charging Station. In other words, this corresponds to a single physical Connector.	ECP	Electrical Connection Point
Charging cable	Cable assembly equipped with a, by the EV accepted, plug, intended to be used for the connection between an EV and an EVSE. One side may be permanently attached to the EVSE, or also be equipped with a plug that is accepted by the EVSE.	N/A	
EVSE	An EVSE is considered as an indepen-dently operated and managed part of the Charging Station that can deliver energy to one EV at a time. In some cases an EVSE may have multiple physical socket types and/or tethered cable/Connector Arrangements (i.e. Connectors) to facilitate different vehicle types.	ECP	Electrical Connection Point
EV Driver	The Driver of an EV who wants to charge the EV at a Charging Station.	N/A	
State of charge (SoC)	State of charge of charging vehicle in percentage	SoC	State of charge of storage solution.
TxStartPoint	Defines when the Charging Station starts a new transaction. The sequence diagrams are using the configuration EVConnected.	MMS Communication	This autonomous operation can be modified by DER owner preferences, pre-set parameter, and commands issued by utilities and aggregators.
TxStopPoint	Defines when the Charging Station ends a transaction. The sequence diagrams are using the configuration EVConnected.	MMS Communication	This autonomous operation can be modified by DER owner preferences, pre-set parameter, and commands issued by utilities and aggregators.

APPENDIX D

Data Model of used IEC 61850 Logical Nodes

DCTE: Cease-to-energize

Data Object Name	Attribute	Explanation
VHiLim	setMag	The voltage high limit of the normal voltage range. The measured voltage must be below this high limit before the DER may be allowed to return to service.
VLoLim	setMag	The voltage low limit of the normal voltage range. The measured voltage must be above this low limit before the DER may be allowed to return to service.
HzHiLim	setMag	The frequency high limit of the normal frequency range. The measured frequency must be below this high limit before the DER may be allowed to return to service.
HzLoLim	setMag	The frequency low limit of the normal frequency range. The measured frequency must be above this low limit before the DER may be allowed to return to service.
RtnDlTmms	setVal	Time delay (ms) before returning to service in order to ensure that both the frequency and voltage are within their high and low limits
RtnRmpTmms	setVal	Return to service duration (ms) that is a time for ramping up that must not be exceeded. Active power shall increase linearly, or in a stepwise linear ramp, with an average rate-of-change not exceeding the DER nameplate active power rating divided by this return to service duration.
WimTms	setVal	Time window within which to randomly initiate the actions specified by the enabled mode. If the time window is zero, the mode will be initiated immediately.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DFPF: Set Fixed Power Factor

Data Object Name	Attribute	Explanation
PFGnTgtSpt	mxVal	Target power factor setpoint when generating. PFSign (in MMXU) defines what convention is in use. The power factor target is a number between -1 and 1 and is used in conjunction with PFGnExtSet to indicate whether it to set it over or under excited. Its mxVal attribute reflects the value of the setpoint that is requested.
PFLodTgtSpt	mxVal	Target power factor setpoint when acting as a load (consuming, charging). PFSign (in MMXU) defines what convention is in use. The power factor target is a number between -1 and 1 and is used in conjunction with PFLodExtSet to indicate whether it to make it over or under excited. Its mxVal attribute reflects the value of the setpoint that is requested.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DGEN: DER generating unit

Data Object Name	Attribute	Explanation
DEROpSt	stVal (DERStateKind)	Current State of operation of the distributed energy resource
WMaxRtg	setMag	Nameplate maximum active generation power rating at unity power factor

```
<EnumType id="DERStateKind">
  <EnumVal ord="1">on but disconnected and not ready</EnumVal>
  <EnumVal ord="2">starting up</EnumVal>
  <EnumVal ord="3">disconnected and available</EnumVal>
  <EnumVal ord="4">disconnected and authorized</EnumVal>
  <EnumVal ord="5">synchronizing</EnumVal>
  <EnumVal ord="6">running</EnumVal>
  <EnumVal ord="7">stopping and disconnecting under emergency conditions</EnumVal>
  <EnumVal ord="8">stopping</EnumVal>
  <EnumVal ord="9">disconnected and blocked</EnumVal>
  <EnumVal ord="10">disconnected and in maintenance</EnumVal>
  <EnumVal ord="11">failed</EnumVal>
  <EnumVal ord="98">Not applicable or not known</EnumVal>
</EnumType>
```

DHFT: High Frequency ride-through

Data Object Name	Attribute	Explanation
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DHFW: High Frequency-Active Power

Data Object Name	Attribute	Explanation
HzRef	setMag	Reference frequency set for this function. This could be different from HzNom if the Area Control Error is being corrected.
WGra	setMag	(inherited from: FrequencyActivePowerLN) If curves are not used, this defines a single active decreasing (increasing) power gradient while generating or consuming in percent of WMax per Hz during a high (low) frequency condition
OplTmsMax	setVal	(inherited from: LowPassFilterOnFunctionOutputLN) Maximum (Fast-as-possible) open loop response time in seconds. The DER should reach OplPct (e.g. 90 % or 95 %) of the delta between its current value and the requested value by the end of this time period. It may go as fast as it can, while still respecting any limiting ramp rates. Is equivalent to 3 tau in case of a first order low pass filter and the target percentage is equal to 95 %.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DHVT: High Voltage ride-through

Data Object Name	Attribute	Explanation
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DLFT: Low Frequency ride-through

Data Object Name	Attribute	Explanation
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DLFW: Low Frequency-Active Power

Data Object Name	Attribute	Explanation
HzRef	setMag	Reference frequency set for this function. This could be different from HzNom if the Area Control Error is being corrected.
WGra	setMag	(inherited from: FrequencyActivePowerLN) If curves are not used, this defines a single active decreasing (increasing) power gradient while generating or consuming in percent of WMax per Hz during a high (low) frequency condition
OplTmsMax	setVal	(inherited from: LowPassFilterOnFunctionOutputLN) Maximum (Fast-as-possible) open loop response time in seconds. The DER should reach OplPct (e.g. 90 % or 95 %) of the delta between its current value and the requested value by the end of this time period. It may go as fast as it can, while still respecting any limiting ramp rates. Is equivalent to 3 tau in case of a first order low pass filter and the target percentage is equal to 95 %.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DLVT: Low Voltage ride-through

Data Object Name	Attribute	Explanation
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.

Data Object Name	Attribute	Explanation
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DVAR: Set reactive power level

Data Object Name	Attribute	Explanation
VArTgtSpt	mxVal	Target reactive power setpoint as absolute value. Its mxVal attribute reflects the value of the setpoint that is requested.
VArTgtSptPct	mxVal	Target reactive power setpoint expressed as percent as indicated by VArSetRef. Its mxVal attribute reflects the value of the setpoint that is requested.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DVVR: Voltage-Reactive Power V-var

Data Object Name	Attribute	Explanation
VVArCrv	crvPts	Paired array of independent and dependent variables For crvPts: xVal = percent of nominal voltage (with increasing abscissas first optionally followed by decreasing abscissas for hysteresis) yVal = Percent of reactive power, either % of active power WMax, or % of reactive power VArMax or VArAvl, as set in ReactivePowerReferenceKind
OplTmsMax	setVal	(inherited from: LowPassFilterOnFunctionOutputLN) Maximum (Fast-as-possible) open loop response time in seconds. The DER should reach OplPct (e.g. 90 % or 95 %) of the delta between its current value and the requested value by the end of this time period. It may go as fast as it can, while still respecting any limiting ramp rates. Is equivalent to 3 tau in case of a first order low pass filter and the target percentage is equal to 95 %.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DVWC: Voltage-Active Power (V-W)

Data Object Name	Attribute	Explanation
VWCrv	crvPts	Paired array of independent and dependent variables For crvPts: xVal = voltage at the referenced ECP of this operational function yVal = active power or percent of WMax (ChaWMax), set by DepRef Maximum power curve delineating the limits for 4 zones – High voltage generating gradients – Low voltage generation gradients – High voltage consuming gradients

Data Object Name	Attribute	Explanation
		– Low voltage consuming gradients
OplTmsMax	setVal	(inherited from: LowPassFilterOnFunctionOutputLN) Maximum (Fast-as-possible) open loop response time in seconds. The DER should reach OplPct (e.g. 90 % or 95 %) of the delta between its current value and the requested value by the end of this time period. It may go as fast as it can, while still respecting any limiting ramp rates. Is equivalent to 3 tau in case of a first order low pass filter and the target percentage is equal to 95 %.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DWMX: Limit Maximum Active Power operational function

Data Object Name	Attribute	Explanation
WMaxSptPct	mxVal	Setpoint reflecting the maximum of active power as a percentage of Maximum Active Power capability at the Referenced ECP. Its mxVal attribute reflects the value of the setpoint that is requested. If the value is negative, power consumption is limited. If the value is positive, power generation is limited.
WMaxSpt	mxVal	Setpoint reflecting the maximum limit of active power. Its mxVal attribute reflects the value of the setpoint that is requested. If the value is negative, power consumption is limited. If the value is positive, power generation is limited.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

DWVR: Active Power-Reactive Power (W-Var)

Data Object Name	Attribute	Explanation
WVArCrv	crvPts	Paired array of independent and dependent variables For crvPts: xVal = Percent of WMax (with increasing abscissas first optionally followed by decreasing abscissas for hysteresis) yVal = Percent of VArMax or VArAvl Hysteresis path shall be described by adding points with decreasing abscissas at the end of the list of the points describing the initial path
OplTmsMax	setVal	(inherited from: LowPassFilterOnFunctionOutputLN) Maximum (Fast-as-possible) open loop response time in seconds. The DER should reach OplPct (e.g. 90 % or 95 %) of the delta between its current value and the requested value by the end of this time period. It may go as fast as it can, while still respecting any limiting ramp rates. Is equivalent to 3 tau in case of a first order low pass filter and the target percentage is equal to 95 %.
Mod	stVal (BehaviourModeKind)	Operating mode of the domain logical node that may be changed by operator. Processing of the quality status ('q') of the received data is the prerequisite for correct interpretation of the operating mode.
ModPrio	stVal	Priority relation of this mode (0..n) with higher numbers superseding lower numbers shall be a positive value, with the default as 0.
InRef	setSrcRef	Object reference of data object bound to the input n.

GGIO: Generic IO

Data Object Name	Attribute	Explanation
Iscso1	stVal	Integer status controllable status output. To elaborate on the reasoning for the send DER controls.

LLN0: Logical node zero

Data Object Name	Attribute	Explanation
NamPlt	Vendor swRev	Name plate

All LLN0 data objects are inherited by all the other logical nodes.

LPHD: Physical device information

Data Object Name	Attribute	Explanation
PhyNam	Vendor serNum location name owner	Physical device name plate

MMXU: Measurement

Data Object Name	Attribute	Explanation
TotW	mag	Total active power
TotVAr	mag	Total reactive power
TotPF	mag	Average power factor
Hz	mag	Frequency
PNV	phs(A,B,C)	Phase to neutral voltage
A	phs(A,B,C)	Phase current)

PTOF: Time Over Frequency Protection

Data Object Name	Attribute	Explanation
StrVal	setMag	Start value (frequency)
OpDlTmms	setVal	Operate delay time

PTOV: Time Over Voltage Protection

Data Object Name	Attribute	Explanation
TmVCrv	CURVE	Curve characteristic for protection operation of the form: y = f(x), where x = V (voltage) and y = Tm (time).

PTUF: Time Under Frequency Protection

Data Object Name	Attribute	Explanation
StrVal	setMag	Start value (frequency)
OpDlTmms	setVal	Operate delay time

PTUV: Time Under Voltage Protection

Data Object Name	Attribute	Explanation
TmVCrv	CURVE	Curve characteristic for protection operation of the form: y = f(x), where x = V (voltage) and y = Tm (time).