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SYSTEMS REFERENCE DELIVERABLE

Architecture and use-cases for EVs to provide grid support functions

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ARCHITECTURE AND USE-CASES FOR EVS TO PROVIDE GRID SUPPORT FUNCTIONS

FOREWORD

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The text of this System Reference Document is based on the following documents:

Draft	Report on voting
SyCSmartEnergy/287/DTS	SyCSmartEnergy/288/RVDTS

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

The language used for the development of this System Reference Document is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

0.1 Objective

When electric vehicles (EVs) are interconnected to the electric power system, they are capable of providing grid support functions similar to other distributed energy resources (DER), particularly energy storage units, while still not impacting any more than necessary their primary purpose of charging their batteries in a timely manner. In aggregate, such as in fleets, in community aggregations, or in microgrids, EVs can not only benefit grid operations, but, if not managed well, cause grid problems.

This document provides various use cases as examples of how EVs might be used as DERs. Since regulations, EVs, charging stations, and power systems are vastly different across the world, this document does not attempt to define any specific mechanism for EVs to provide DER grid support functions, but rather draws on IEC 61850-7-420 that defines the data models for most of the DER grid support functions, including those described in electric power requirements in IEEE Std 1547™-2018 and EN 50549.

It is expected that IEC 61850-7-420 will utilize these use cases to develop EV-specific data models for "EV as DER" as needed, and that other standards such as the IEC 63110, ISO 15118, and the IEC 63382 series[1] will be revised or will otherwise accommodate the results of these "EV as DER" requirements.

Clearly contractual arrangements will need to be made with all relevant stakeholders on which EVs, under what conditions, with which functions, and when permitted. However, those contractual arrangements are outside the scope of this document, which addresses only the technical aspects of EVs as DER.

Cybersecurity for EVs as DER is important but is not in the scope of this document.

0.2 EVs, utilities, and charging

Utilities everywhere are concerned that the charging load for electric vehicles (EVs) will greatly increase the load on the power grids. In many places, the charging load could exceed the existing demand during peak hours from residential consumers. As more electric vehicle charging points are deployed, it becomes increasingly important to manage flexibility of both the power levels and the time of charging.

The concept adopted in the past has been that EV charging would be managed by charging stations similar to gas stations, but today it is clear that EV drivers often charge at home and use phone applications, cloud-based systems, and remote service providers to manage their charging. Although charging stations are still important, they are no longer the only way EVs are charged. This shift is also complicating the design of the EV standards.

In addition, the idea that EVs could be used to support the power grid used to be regarded as strange, technically difficult, and not likely to be supported by EV owners. That idea, too, has been overtaken by events, as more and more EV manufacturers are including the ability to discharge and many pilot projects have shown that "vehicle-to-home" would be very desirable by customers, and "vehicle-to-grid" would be very popular with EV fleets and charging stations if they want to take part in market operations. In some regions, such as California, if the EVs are capable of discharging, they are included in the definition of Distributed Energy Resources.

[1] Under preparation.

Two primary groups of use cases have been identified: those concerned with the market aspects of charging, and those concerned with the grid services related to the impact of charging on the power system. A few use cases address vehicle-to-grid. Figure 2 illustrates the IEC standards used for EV grid support and market-related charging management.

For many years, academic papers have proposed using EV batteries as a form of energy storage that can provide services to the power grid even if only charging. But now there are many research and pilot projects around the world that are deploying some form of bidirectional flow of energy (charging and discharging), either as vehicle-to-grid (V2G) or vehicle-to-home (V2H), with EVs able to sell power to the main grid and even support the energy management of microgrids. One of the driving ideas behind these projects is to provide a means of storing energy in the EV from variable renewable resources, like solar and wind, for use at other times. This implies that EVs can actually be viewed as just one type of distributed energy resources (DER).

0.3 EV standardisation efforts in the IEC

Within the IEC, various committees and working groups are collaborating to define standards and guidance on how these new types of EV-related equipment should be integrated into power systems. There are several technical groups that are concerned with the physical and safety aspects of different types of equipment and others that look at how the different types of EV-related equipment are integrated into the power system.

However, integrating EVs into power systems so that they do not overload the grid and can actually support grid reliability, requires understanding the electric utility perspective. Figure 1 shows the big picture with various types of systems relevant to DERs and EVs.

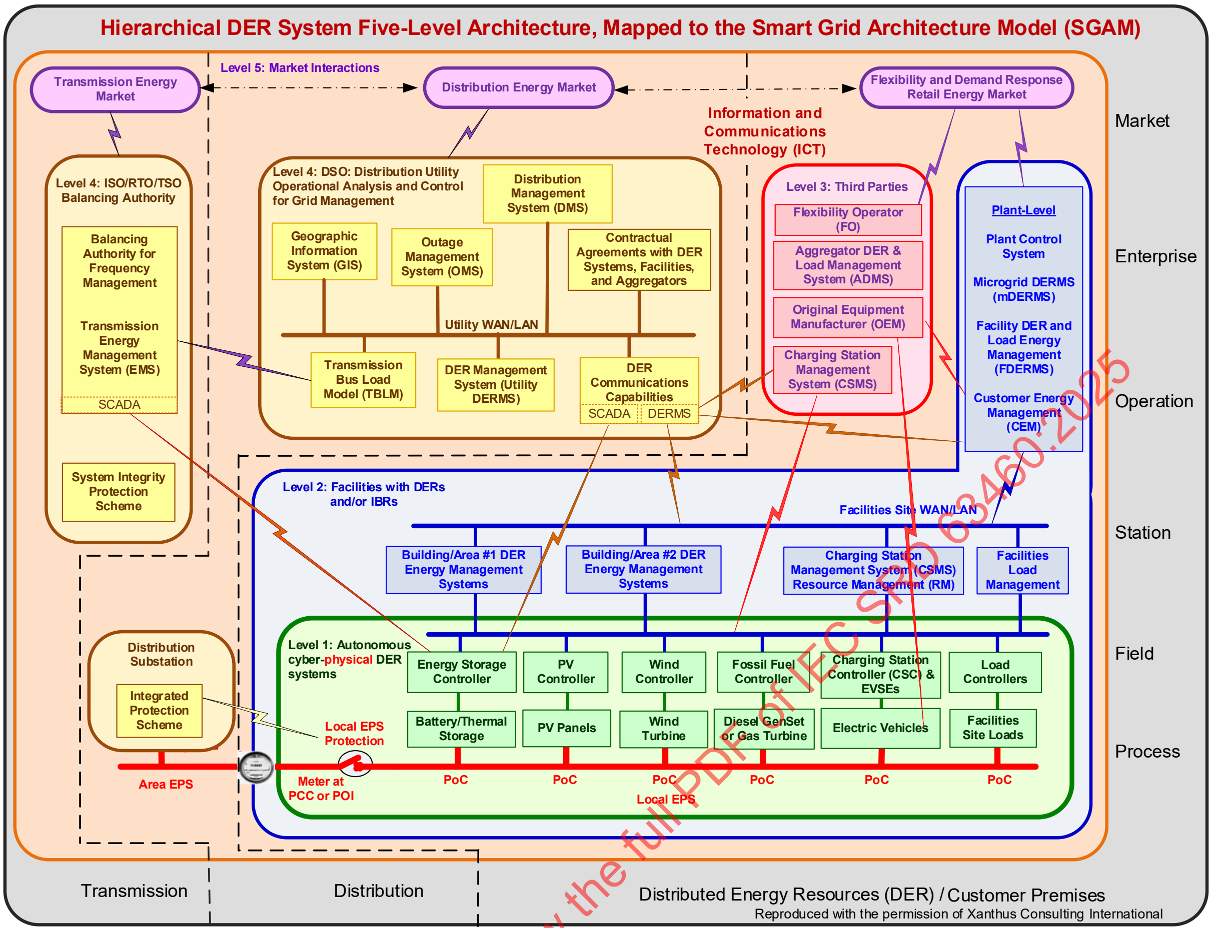


Figure 1 – EV as DER architecture within the larger grid environment

The IEC has many different groups addressing aspects of EVs and their charging from the grid. For the physical aspects, IEC TC 8 and its subcommittees work on the overall system aspects of electricity supply systems, and IEC TC 120 is responsible for standardization in the field of grid integrated energy storage systems. IEC TC 69 prepares publications related to electrical power/energy transfer systems for electrically propelled road vehicles, including some physical charger connection standards such as IEC 61851. TC 69 has also worked with the ISO to develop charging communication protocols such as the ISO 15118 series and has established joint working groups with other TCs to manage the higher-level charging infrastructure with use cases and communication protocols, currently developing the IEC 63110 series and the IEC 63382 series.

IEC TC 57 has that utility perspective and has developed sophisticated communication and automation standards for power systems control equipment and control centre systems. These standards include IEC 61850 for substations, distribution automation, and more recently DER. The common information model (CIM), covered in IEC 61968, the IEC 61970 series, IEC 62325, is focused on grid management applications and market interactions. In addition, IEC TC 65 has developed some standards describing energy management systems for industrial sites and IEC SC 23K is working on standards for energy management within residential and commercial premises. Complementing these energy standards is IEC TC13 who provides metering standards.

Figure 2 illustrates the different communication standards being applied in the EV domain.

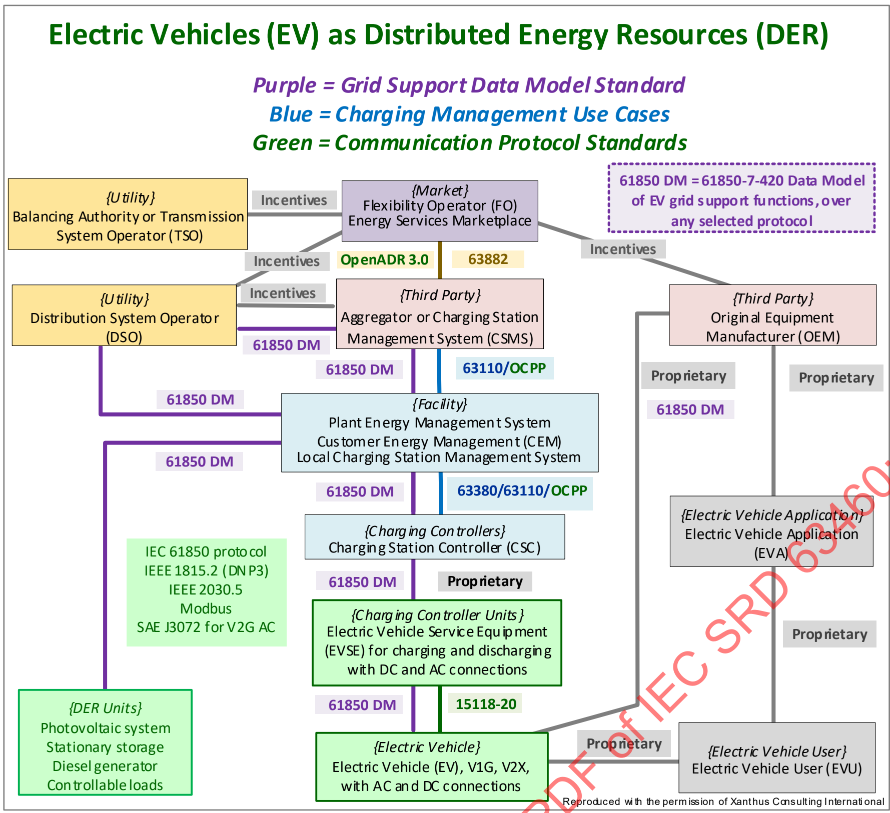


Figure 2 – IEC Standards for EV grid support and charging management

0.4 EV use cases

Many use cases have been developed that focus on the pricing and timing of energy management of charging electric vehicles. Typically, these energy management systems are concerned with optimising the cost of the energy used to charge the vehicles. These use cases rarely address the grid needs of distribution system operators who might need to impose constraints on the grid if the charging loads become too high. However, there is increasing awareness that these grid requirements also need to be take into account as more and more utility customers switch to electric vehicles. This dynamic juxtaposition of growing need for EV charging versus the strain that this charging puts on the grid is an area of growing concern around the world and will require sophisticated and flexible information and communication technologies. Different countries and regions will necessarily involve different business models, but all will need to reflect the challenges posed by such a shift in electrification requirements.

Other use cases and information models, developed more from the grid integration and grid management perspectives, have been developed related to the functions that distributed energy resources (DER) can provide. In particular, these use cases identify how these generation and storage systems can help manage grid voltage and frequency and can even ride through abnormal conditions to possibly avoid power outages. The information models were based on national grid codes originally developed for the integration of bulk generation resources, but now they have been extended to cover smaller distributed energy resources and battery storage. Thus, most of the use case development has already been done – they just need to be expanded to electric vehicle charging – and discharging – systems, thus converting EVs as uncontrolled loads to EVs-as-DERs.

0.5 Purpose of this document

This document describes the architecture and use-cases for EVs to provide grid support functions, or more familiarly called "EV-as-DER". Most of this document will be concerned with identifying realistic EV charging and discharging configurations, and the communication and control between the various actors, grid system operators, aggregators, premises energy management, and EV charging systems. The results from this document will hopefully help to take the grid-support capabilities of EVs into account as other standards are developed.

ARCHITECTURE AND USE-CASES FOR EVS TO PROVIDE GRID SUPPORT FUNCTIONS

1 Scope

The scope of this document is the assessment of how electric vehicles (EVs) can act as distributed energy resources (DER) when they are interconnected to the electric power system for charging or discharging, whether in the home, in an office complex, in shopping centres, or in EV charging stations. Although clearly the main purpose for EV interconnection to the grid is to charge their batteries, EVs can provide grid support functions while interconnected, and in some situations, can be mandated or incentivized to do so.

This document provides use cases as examples of how EVs might provide such DER functionality, based on the grid support functions defined in IEC 61850-7-420, IEEE Std 1547:2018, and EN 50549.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEEE Std 1547-2018, *IEEE Standard for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces*

IEEE Std 2800-2022, *IEEE Standard for interconnection and interoperability of inverter-based resources (IBRs) interconnecting with associated transmission electric power systems*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEEE Std 1547™ and IEEE Std 2800™ apply.

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

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

NOTE See Figure 3 for an illustration of some of the terms.

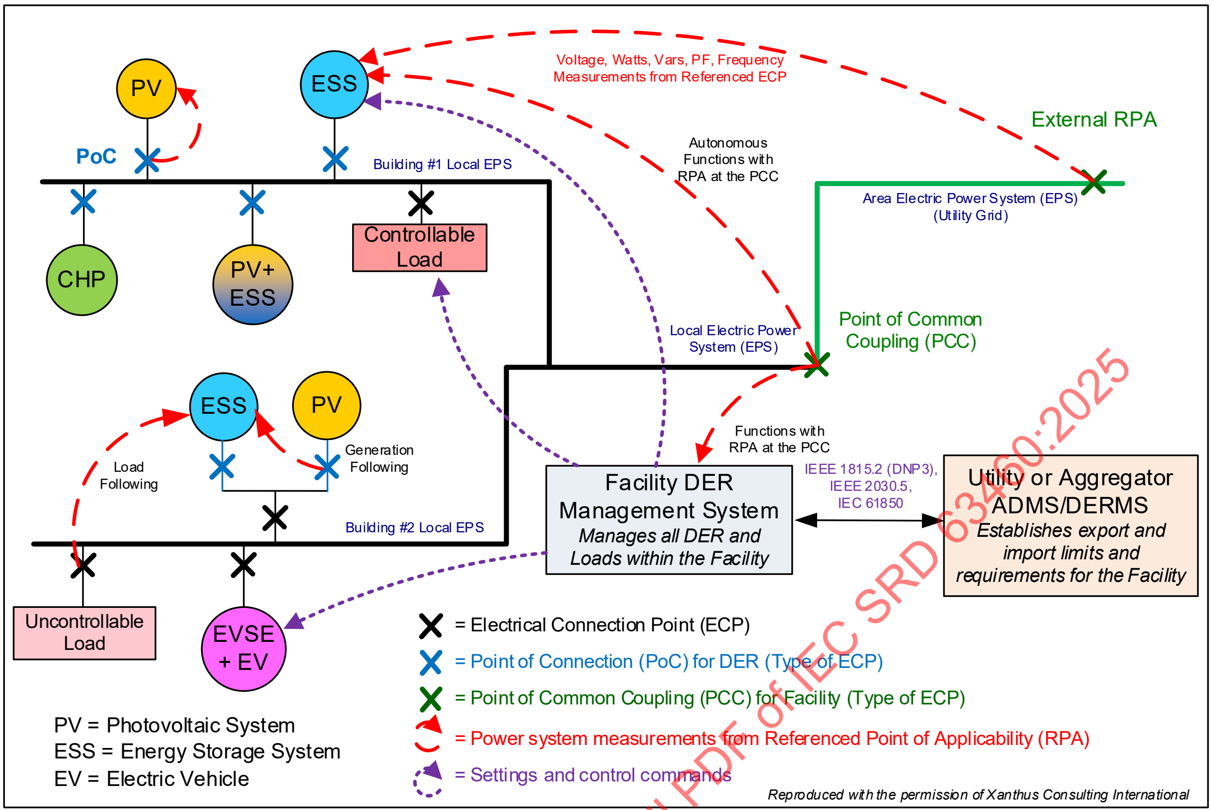


Figure 3 – Illustrations of ECP, PoC, PCC, RPA, local EPS, and area EPS

3.1.1
area electric power system
area EPS
EPS that serves local EPSs

3.1.2
business case
description of business objectives or purposes that could be provided through regulations, procedures, and/or technology

Note 1 to entry: Typically, business cases stay at a high level to focus on what or why a process is needed, but not how that process might be implemented.

3.1.3
cease to energize
cessation of active power delivery under steady-state and transient conditions and limitation of reactive power exchange

3.1.4
distributed energy resource
DER
source of electric power that is not directly connected to a bulk power system

Note 1 to entry: DER includes both generators and energy storage technologies capable of exporting active power to an EPS. An interconnection system or a supplemental DER device that is necessary for compliance with this document is part of a DER.

3.1.5
distributed energy resource system
DER system
grouping of DER units acting as a system

Note 1 to entry: See IEEE 1547:2018.

3.1.6
distributed energy resource unit
DER unit
individual DER device inside a group of DER that collectively form a system

3.1.7
distribution system operator
entity responsible for ongoing planning and operation of the distribution system

Note 1 to entry: In California, the DSO is the same as the distribution utility, e.g., an IOU.

3.1.8
export
active power going through the PCC from (i) the customer with a behind-the-meter (BTM) DER facility to the area EPS, or (ii) from an in-front-of-the-meter (IFM) DER facility to the area EPS

3.1.9
import
active power going through the PCC from the area EPS to (i) the customer with a BTM DER facility, or (ii) an IFM DER facility

3.1.10
island
portion of an area EPS energized solely by one or more local EPSs through the associated PCCs while that portion of the area EPS is electrically separated from the rest of the area EPS on all phases to which the DER is connected

Note 1 to entry: When an island exists, the DER energizing the island can be said to be "islanding".

3.1.11
load
devices and processes in a local EPS that use electrical energy for utilization, exclusive of devices or processes that store energy but can return some or all of the energy to the local EPS or area EPS in the future

3.1.12
local electric power system
local EPS
EPS contained entirely within a single premises or group of premises

3.1.13
point of common coupling
PCC
point of connection between the area EPS and the local EPS according to IEEE Std 1547:2018

Note 1 to entry: The PCC is also the transfer point for electricity between the electrical conductors of Distribution Provider and the electrical conductors of Producer (Rule 21).

3.1.14
point of connection
POC
point where the DER unit is electrically connected to an EPS

Note 1 to entry: In the case of BTM DER, the POC is the point where the DER unit is electrically connected to the customer equipment.

3.1.15
use case
description of technical methods for supporting the business cases

Note 1 to entry: The use cases might also be high level or might be detailed, but are focused on how the process might be implemented.

3.1.16
reference point of applicability
RPA
location where the interconnection and interoperability performance requirements specified apply

3.1.17
fast frequency response
FFR
active power injected to the grid in response to changes in measured or observed frequency during a frequency excursion event to decrease the rate-of-change of frequency

3.2 Abbreviated terms

ADMS	advanced distribution management system
area EPS	area electric power system
BTM	behind-the-meter
CPUC	California public utilities commission
DCC	demand connection code
DER	distributed energy resource
DER Facility	site with DER
DER Operator	generating facility operator
DERMS	distributed energy resource management system
DSO	distribution system operator
EMS	energy management system
ENTSO-E	European network of transmission system operators for electricity
EV	electric vehicle
EVSE	electric vehicle supply equipment
FTM	front-of-the-meter, equivalent to in-front-of-the-meter
IBR	inverter based resource (see IEEE 2800TM)
IFM	in-front of the meter, equivalent to front-of-the-meter
POI	point of interconnection
ISO	independent system operator
OCPP	Open charge point protocol
PCC	point of common coupling, also known as metering point or service point
POC	point of connection
RfG	requirements for generators

RPA	reference of point applicability
SGAM	smart grid architecture model
VGI	vehicle grid integration (includes v1g, v2g, v2h, v2x)
V1G	vehicle one-way to grid (charging only)
V2G	vehicle two-way to grid (charging and discharging)
V2H	vehicle to home
V2X	vehicle to everything

4 Overview of the DER environment and functions

4.1 DER Stakeholders

Clause 4 discusses the current situation for distributed energy resources (DER).

There are many types of stakeholders in the DER domain, with different purposes and information requirements. The key stakeholders are shown in Figure 4 and include the following.

- DER equipment and systems with their supporting controllers.
- Operators of the grid
  - DER operators, including facility energy management systems and aggregator management systems.
  - Distribution system operators, in charge of the distribution grid safety, reliability, and efficiency.
  - Independent system operators and transmission system operators, acting as the balancing authority for generation and load on the grid, as well as other safety and reliability measures.
  - Utility planners, in charge of assessing and planning for the impacts and benefits from interconnected DERs.
- Entities with primarily financial interests
  - DER owner, interested primarily in the financial and reliability benefits of having purchased the DER.
  - DER aggregator, interested in selling DER equipment and/or DER services to DER owners and to the grid operators (distribution and transmission).
  - Retail energy providers, interested in selling DER services.
  - Energy markets, which act as brokers for many different energy services transactions between stakeholders.
- Utility regulators, in charge of managing regulatory issues affecting electric power systems.
- Support services
  - DER maintenance and other DER equipment services, in charge of the health of DER equipment.
  - Distribution maintenance, in charge of maintaining the health of the grid equipment.
  - Metering and historical data collection.
- Manufacturers and implementors of DERs, in charge of developing and installing DERs.

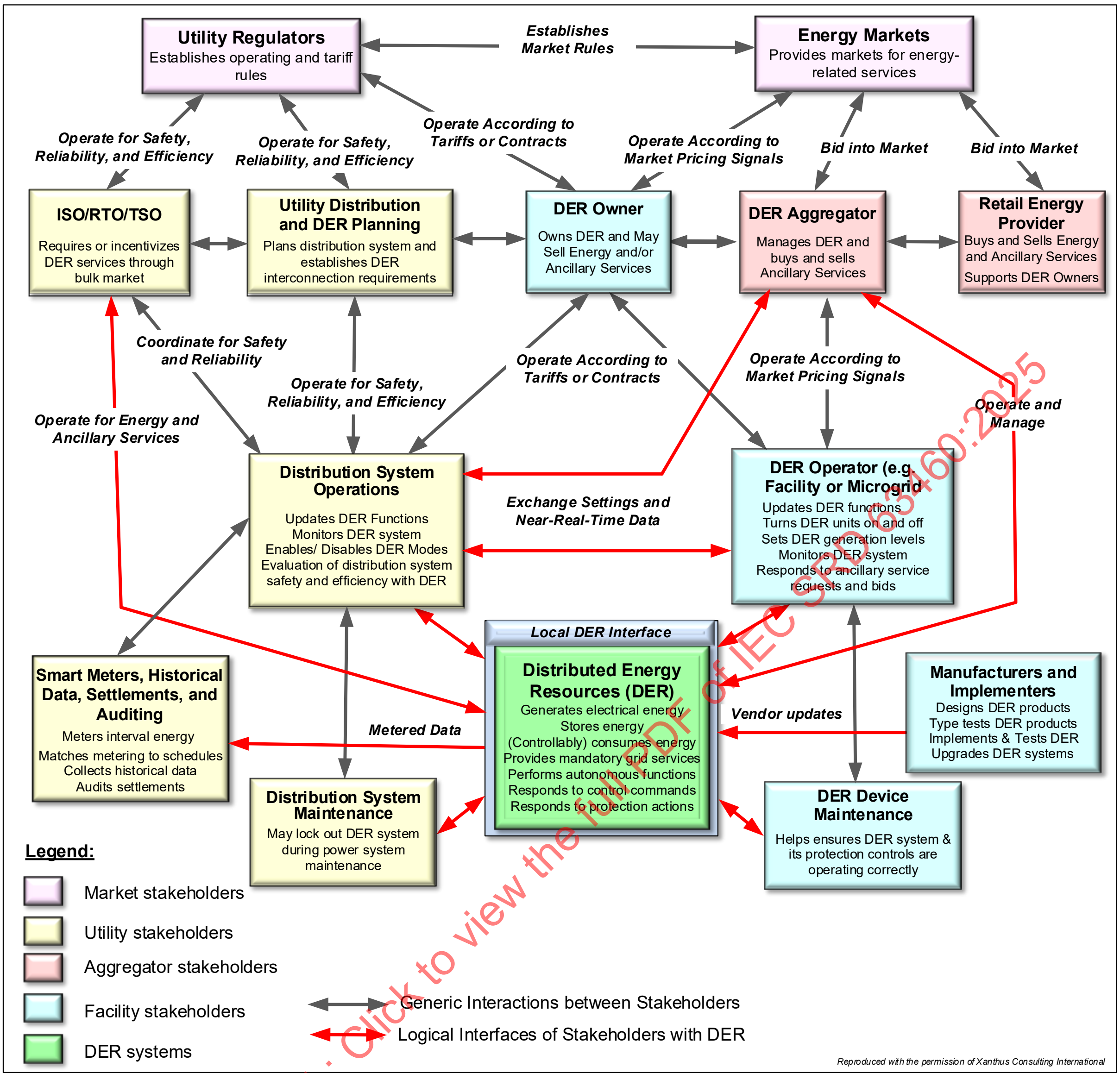


Figure 4 – Key DER stakeholders

4.2 DERs within a facility or microgrid

A basic architecture of DERs is shown in Figure 5, in which DERs (green level 1) are located within a facility (blue level 2). These facilities can be a simple residential house, a residential or office building, a university or office park campus, or a power plant. These facilities could be always grid-connected, or could be islandable as a microgrid, or could be permanently off-grid. In all these cases, some type of energy management system manages the moment-to-moment operation of each DER. For more complex facilities, a higher-level energy management or microgrid management system can coordinate the operations of all the DERs to meet overall goals of reliability, safety, and regulatory compliance.

DER management is not siloed but can consist of using the different capabilities of different types of DER to meet overall goals. For instance, energy arbitrage (the shifting of energy production from lower price to higher priced times, and the corresponding shifting of energy consumption from higher price to lower priced times) might be overall goal, and combinations of PV, distributed wind, battery storage, thermal storage, and EV battery management might all play a part in achieving this overall goal. A second example is meeting power system reliability requirements, where DER might be required to provide specific grid-support functions during different power grid situations.

Each type of DER has constraints: PV systems need sun, wind turbines need wind, batteries need to be recharged, and EVs need to meet their owner/operator mobility requirements. These constraints need to be factored into decision-making.

The circled numbers indicate logical interactions via communication protocols and are discussed in more detail in IEC 61850-7-420.

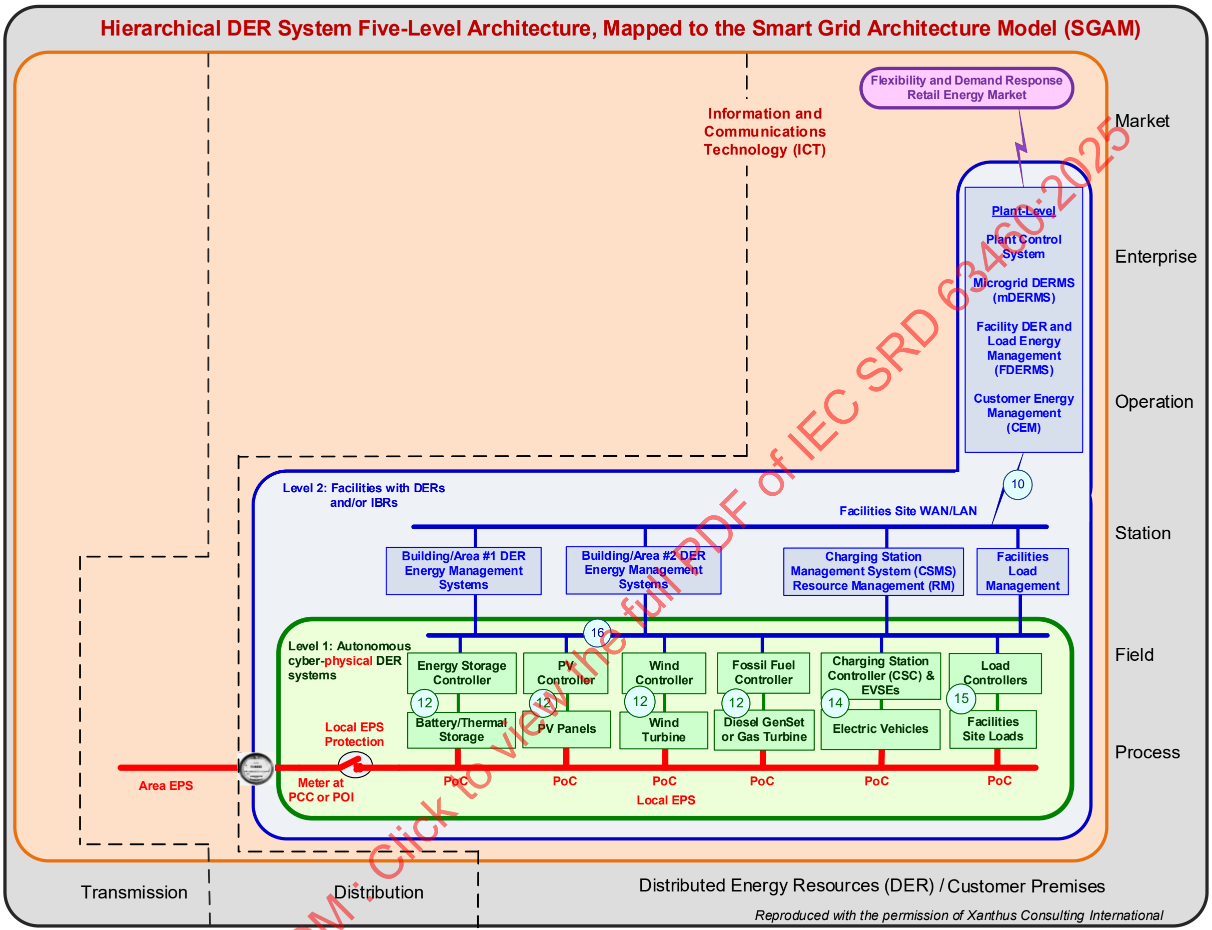


Figure 5 – DER within a facility: residence, campus, or plant, potentially as a microgrid, with flexibility market

4.3 Utility and aggregator interactions with DER facility

As shown in Figure 6, the DER facility usually needs to interact with aggregators (red, level 3) and/or utilities (yellow, level 4) in order to function in a safe and reliable manner. They might also interact directly or indirectly with the energy markets (purple, level 5) for financial purposes.

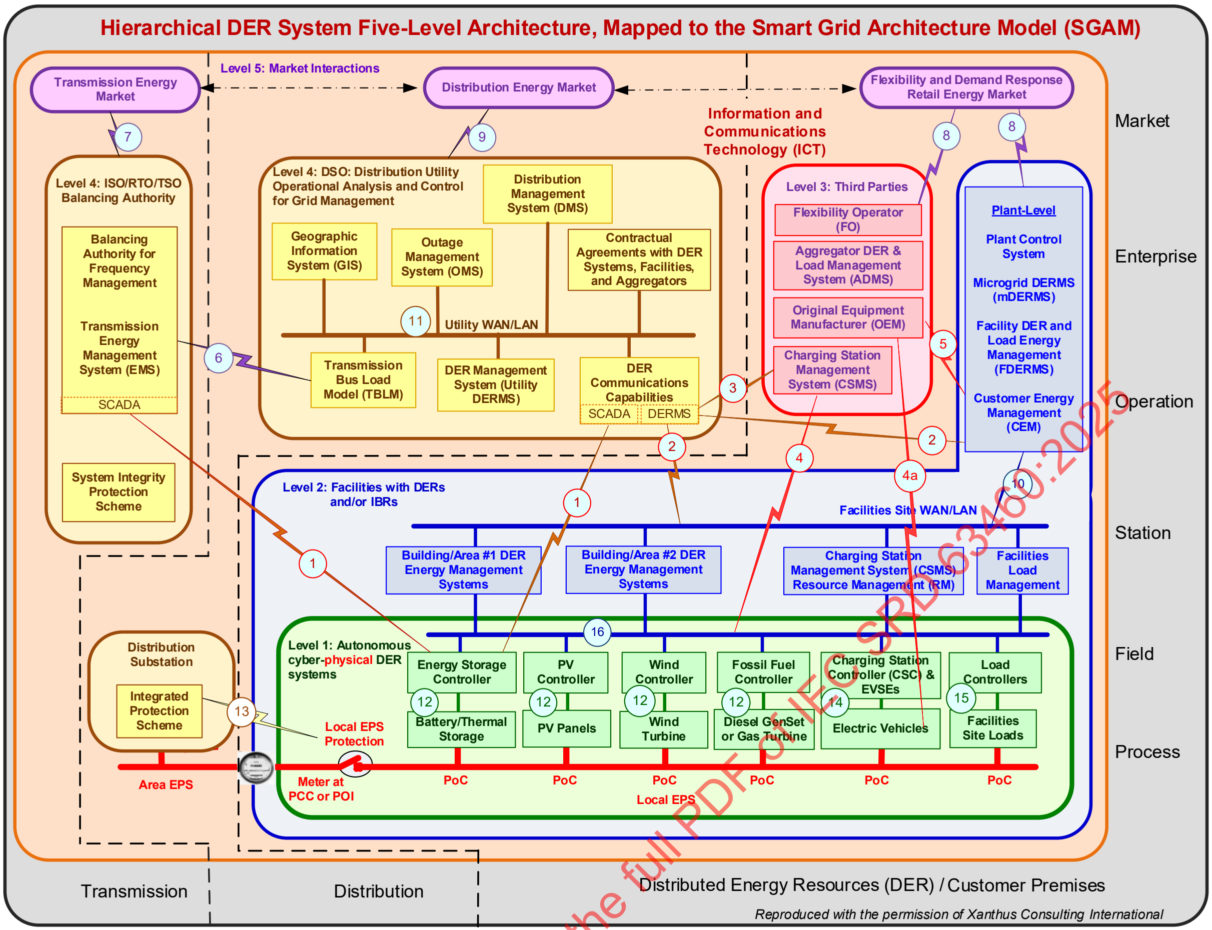


Figure 6 – Utility and aggregator interactions with DER facilities or directly with DERs

4.4 EV interactions within the DER environment

Using the broader DER diagrams as a basis but simplifying the utility functions, Figure 7 provides an architecture illustrating the EV roles within the DER environment.

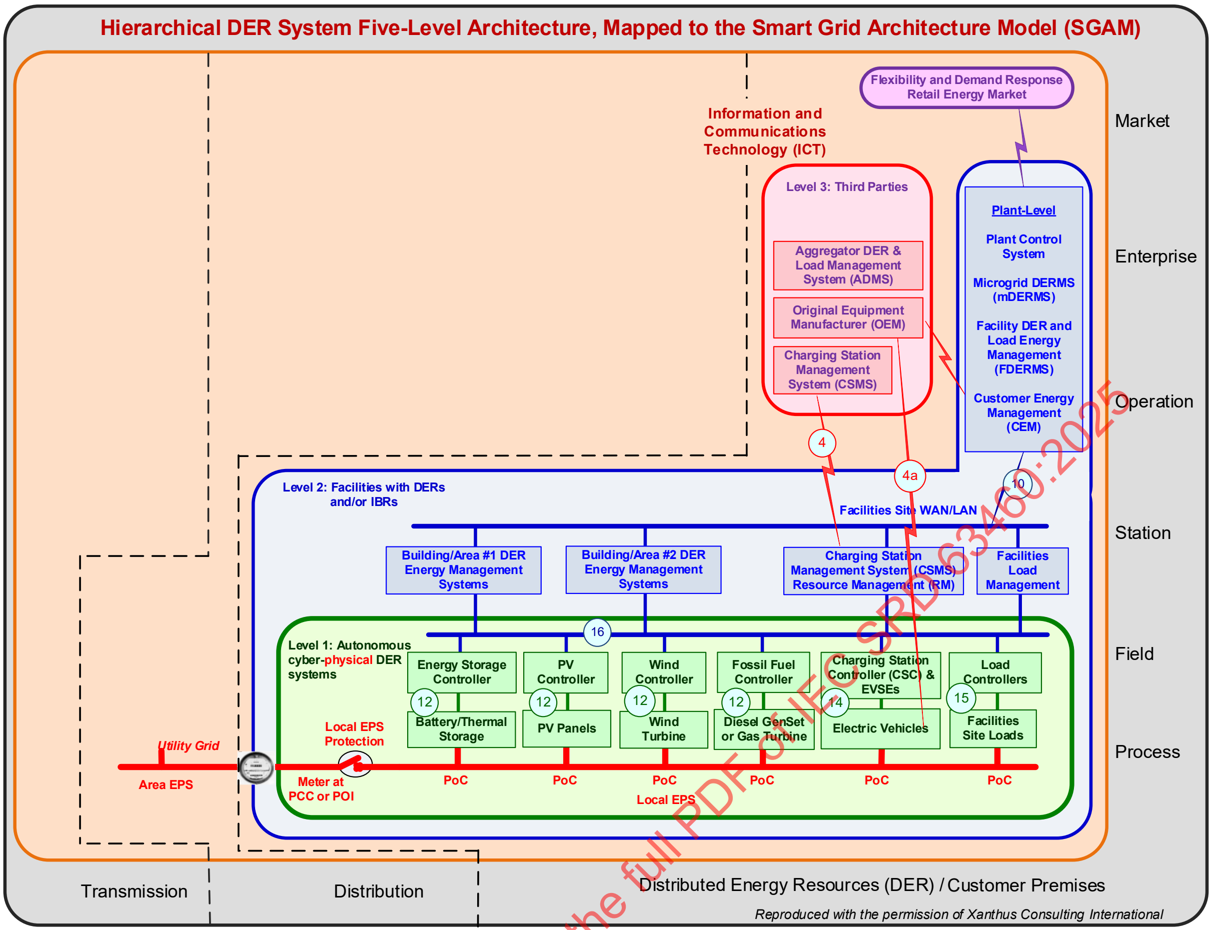


Figure 7 – DER architecture with a focus on charging stations

4.5 List of DER functions potentially applicable to EVs

Table 1 lists the most common functions that EV-as-DER might be able to provide.

Table 1 – DER functions for EV environment: roles and information exchanges

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
	Grid support functions				
1.	**Disconnect/connect function** Disconnect or connect the DER from the grid at its POC	The disconnect command initiates the galvanic separation (usually via switches or breakers) of the DER at its POC or at the PCC. There might be a time delay between receiving the command and the actual disconnect. The connect command initiates or allows the reconnection of the DER at its POC or at the PCC. A permission to reconnect might also be issued.	All types of DER For type A, only an interface is requested for disconnection	Either galvanic disconnect or cease to energize	Req. If the galvanic disconnect is at the EVSE, then all energy flow is zero. If the galvanic disconnect is at the PCC, then the energy flow at the PCC is zero, while internal energy flows might continue
2.	**Cease to energize and return to service** The DER ceases all active power output Allow active power output at the PCC	"Cease to energize" is a different function from disconnect/connect. The (draft) definition is "the DER shall not export active power during steady-state or transient conditions. Reactive power exchange (absorb or supply) shall be less than x % of nameplate DER rating and shall exclusively result from passive devices.". There might be a time delay between receiving the command and the actual cease to energize. "Return to service" allows current flow at the PCC. A permission to return to service might also be issued.	Type A and B only of DER – cease active power output within 5 s, following an instruction being received at the input port type A might disconnect randomly	Either galvanic disconnect or cease to energize at the PCC	Hi. If the cease to energize is at the EVSE, then power output is zero, but power input might continue. If the cease to energize is at the PCC, then the power output at the PCC is zero but power input might continue, while internal energy flows might continue
3.	**High/low voltage ride-through operational function** The DER rides through temporary fluctuations in voltage	The DER follows the utility-specified voltage ride-through parameters to avoid tripping off unnecessarily. The function would block tripping within the fault ride-through zones. Although normally enabled by default, this ride-through operational function might be updated, enabled, and disabled.	Fault ride-through is mandatory for all generators starting type B and larger generators.	H/LVRT is mandatory for all DER	Req

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
4.	**High/low frequency ride-through operational function** The DER rides through temporary fluctuations in frequency	The DER follows the utility-specified frequency ride-through parameters to avoid tripping off unnecessarily. The function would block tripping within the fault ride-through zones. Although normally enabled by default, this ride-through operational function might be updated, enabled, and disabled.	No mention, except the fact that facilities have to remain operational within an "extended" frequency range from 47 Hz to 52 Hz (exact range might depend on European synchronous zone)	H/LFRT is mandatory for all DER	Req
5.	**Dynamic reactive current support operational function** The DER reacts against rapid voltage changes (spikes and sags) to provide dynamic system stabilization dV/dt	The DER provides dynamic reactive current support in response to voltage spikes and sags, similar to acting as inertia against rapid changes. This operational function might be focused on emergency situations or might be used during normal operations. When the dynamic reactive current support operational function is enabled, the DER monitors the voltage at the referenced point of applicability (RPA) and responds based on the parameters.	No direct mention Synthetic inertia is requested, starting for class C. Reactive power injection in case of grid fault is requested starting class B, upon balancing authority request. Also requested for transmission connected facilities	Is included as optional but might become mandatory	Lo
6.	**Droop/frequency-active power primary control operational function** The active power output of a generator reduces as the line frequency increases above nominal frequency, and vice versa.	Droop is a control mode used for AC electrical power generators to maintain the frequency within the normal operating zone, focused on returning the frequency to its nominal value (e.g. 50 Hz or 60 Hz). Specifically, the active power output of a generator reduces as the line frequency increases above nominal frequency, and vice versa. It is commonly used as the speed control mode of the governor of a prime mover driving a synchronous generator connected to an electrical grid.		Not explicitly mentioned but expected of larger DERs	Med

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
7.	**Frequency-active power sensitivity operational function** The DER responds to large frequency excursions during abnormal events at an RPA by changing its production or consumption rate Can include fast frequency response (FFR)	The DER is provided with frequency-active power curves that define the changes in its watt output based on frequencies around the nominal frequency during abnormal events. When the frequency-active power sensitivity operational function is enabled, the DER monitors the frequency and adjusts its production or consumption rate to follow the specified emergency frequency-active power curve parameters.	Over frequency "frequency sensitive operational function (FSM)" is mandatory for all DER types. Underfrequency is requested starting class C Maximum power decrease in case of frequency decrease is specified and should be respected by all DER	Frequency droop although not quite the same	Hi
8.	**Volt-watt operational function** The DER responds to changes in the voltage at the referenced ECP by changing its production or consumption rate	The DER is provided with voltage-watt curves that define the changes in its watt output based on voltage deviations from nominal, as a means for countering those voltage deviations. When the volt-watt operational function is enabled, the DER receives the voltage measurement from a meter (or another source) at the RPA. The DER adjusts its production or consumption rate to follow the specified volt-watt curve parameters.		Included	Med
9.	**Fixed (constant) power factor operational function** The DER power factor is set to a fixed value.	The DER power factor is set to the specified power factor. A leading power factor is positive, and a lagging power factor is negative, as defined by the IEEE or IEC sign conventions.	For types C and D DER, the ability to adjust reactive power, automatically by either voltage control operational function, reactive power control operational function or power factor	Mandatory for all DER	Req
10.	**Fixed (constant) reactive power operational function** The DER is requested to provide a fixed amount of reactive power	The DER is requested to provide a fixed amount of reactive power		Mandatory for all DER	Req

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
11.	**Volt-var control operational function** The DER responds to changes in voltage at the RPA by supplying or absorbing reactive power in order to maintain the desired voltage level	The DER is provided with voltage-var curves that define the reactive power for voltage levels. When the volt-var operational function is enabled, the DER receives the voltage measurements from a meter (or another source) at the RPA. The DER responds by supplying or absorbing reactive power according to the specified volt-var curve in order to maintain the desired voltage level.	For types C and D DER, the ability to adjust reactive power, automatically by either voltage control operational function, reactive power control operational function or power factor	Mandatory for all DER	Req
12.	**Watt-var operational function** The DER responds to changes in power at the RPA by changing its reactive power	The DER is provided with watt-var curves that define the changes in its reactive power-based changes of power. When the watt-var operational function is enabled, the DER modifies its reactive power setting in response to the power level at the RPA.	German LV grid codes VDE-AR-N4105	Included	Med
13.	**Watt-PF operational function** The DER responds to changes in power at the RPA by changing its power factor	The DER is provided with watt-PF curves that define the changes in its power factor-based changes of power. When the watt-PF operational function is enabled, the DER modifies its PF setting in response to the power level at the RPA.			Med
14.	**Set active power operational function** Set the DER to generate or consume energy as a percentage of maximum capability	The DER is set to a percentage of maximum generation or consumption rate. In the generation frame of reference, a positive value indicates generation, negative means consumption [b].			Med
15.	**Limit active power production or consumption operational function** Limits the production and/or consumption level of the DER based on the RPA	The production and/or consumption of the DER is limited at the RPA, indicated as absolute watts values. Separate parameters are provided for production or consumption limits to permit these to be different.		Included	Med

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
16.	**Low frequency-active power operational function** for demand side management (fast load shedding)	Enable automatic "low frequency" disconnection of a specified proportion of their demand (in stages) in a given time frame.	For all transmission-connected facilities	Not mentioned explicitly in IEEE Std 1547 which does not cover loads, but expected to be available	Med
17.	**Low voltage-watt operational function** for demand side management	Provide capabilities to enable automatic or manual load tap changer blocking and automatic "low voltage" disconnection.	Optionally for all transmission connected facility	Not mentioned explicitly in IEEE Std 1547 which does not cover loads, but expected to be available	Med
18.	**Monitoring function** The DER provides nameplate, configuration, status, measurements, and other requested data	The DER provides status, measurements, alarms, logs, and other data as authorized and requested by users. Examples include connect status, updated capacities, real and reactive power output/consumption, state of charge, voltage, and other measurements. Also of interest are forecast status and expected measurements.	Real-time monitoring of key power system values for types C and D DERs for FSM Compliance monitoring for types B, C, and D and optionally for type A (balancing authority decision). Also requested for any units which provide demand service response (DSR) within a demand facility	Communications capability mandated for all DER (not necessarily implemented in all DER) Monitoring where needed is mandatory	Hi (within charging station)
19.	**Scheduling of power settings and operational functions**	The DER follows the schedule which consists of a time offset (specified as a few seconds) from the start of the schedule and is associated with - a power system setting, - the enabling/disabling of a function, and - a price signal.		Expected for larger DER but not mandatory	Med

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
	Non-grid code functions (market functions)				
20.	**Peak power limiting operational function** The DER limits the load at the RPA after it exceeds a threshold target power level	The active power output of the DER limits the load at the RPA if it starts to exceed a target power level, thus limiting import power. The production output is a percentage of the excess load over the target power level. The target power level is specified in absolute watts.			Hi
21.	**Load following operational function** The DER counteracts the load by a percentage at the RPA, after it starts to exceed a threshold target power level	The active power output of the DER follows and counteracts the load at the RPA if it starts to exceed a target power level, thus resulting in a flat power profile. The production output is a percentage of the excess load over the target power level. The target power level is specified in absolute watts.			Lo
22.	**Generation following operational function** The consumption and/or production of the DER counteracts generation power at the RPA.	The consumption and/or production of the DER follows and counteracts the generation measured at the RPA if it starts to exceed a target power level. The consumption and/or production output is a percentage of the excess generation watts over the target power level. The target power level is specified in absolute watts.			Lo
23.	**Dynamic active power smoothing operational function** The DER produces or absorbs active power in order to smooth the changes in the power level at the RPA. Rate of change of power – dW/dt	The DER follows the specified smoothing gradient which is a signed quantity that establishes the ratio of smoothing active power to the real-time delta-watts of the load or generation at the RPA. When the power smoothing operational function is enabled, the DER receives the watt measurements from a meter (or another source) at the RPA. New data points are provided multiple times per second.			Med
24.	**Automatic generation control (AGC) operational function** The DER responds to raise and lower power level requests from a balancing authority to provide frequency regulation support	When AGC operational function is enabled, the DER responds to signals to increase or decrease the rate of consumption or production every 4 s to 10 s, with the purpose of managing frequency.			Med or Lo

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
25.	**Operating reserve (spinning reserve) operational function** The DER provides operating reserve	The DER can provide reserve power available within about 10 min.			Med (for fleets?)
26.	**Synthetic or artificial inertia frequency-active power operational function** The DER responds to the rate of change of frequency (ROCOF) by changing its watt output or input to minimize spikes and sags	The DER responds to the rate of change of frequency (ROCOF) by changing its watt output or input to minimize spikes and sags			Hi
27.	**Coordinated charge/discharge management operational function** The DER determines when and how fast to charge or discharge so long as it meets its target state of charge level obligation by the specified time (focus is on electric vehicle consumption)	The DER is provided with a target state of charge and a time by which that SOC is to be reached. This allows the DER to determine when to charge or discharge based on price. The DER takes into account not only the duration at maximum consumption/production rate, but also other factors, such as that at high SOC the maximum consumption rate might not be able to be sustained, and vice versa, at low SOC, the maximum discharge rate might not be able to be sustained			Hi
28.	**Frequency-active power Smoothing operational function** The DER responds to changes in frequency at the RPA by changing its consumption or production rate based on frequency deviations from nominal, as a means for countering those frequency deviations $\mathrm{d}f/\mathrm{d}t$	The DER is provided with frequency-active power curves that define the changes in its watt output based on frequency deviations from nominal, as a means for countering those frequency deviations and smoothing the frequency. When the frequency-active power operational function is enabled, the DER monitors the frequency and adjusts its production or consumption rate to follow the specified frequency-active power curve parameters. New data points are provided multiple times per second.		Shall remain operational during ROCOF events within limits, but no explicit mention of smoothing	Med

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
29.	**Power factor limiting (correcting) operational function** The DER supplies or absorbs reactive power to hold the power factor at the RPA within the PF limit	When the PF limiting (correcting) operational function is enabled, the DER is provided with the target PF. The DER supplies or absorbs reactive power in order to maintain the PF at the RPA within the limits of the target PF.		Being discussed	Lo
30.	**Delta power control function** Decrease active power output to ensure there remains spinning reserve amount that was bid into the market	Decrease active power output to ensure there remains spinning reserve amount that was bid into the market			Lo
31.	**Power ramp rate control** The power increase and decrease are limited by specified maximum ramp rates	Manage active power ramp time, when the active power should be at the required power level by the end of the ramp time. It might reach the required power level earlier, but not later.			Lo
32.	**Dynamic volt-watt function** Dynamically absorb or produce additional watts in proportion to the instantaneous difference from a moving average of the measured voltage	Dynamically absorb or produce additional watts in proportion to the instantaneous difference from a moving average of the measured voltage. This function utilizes the same basic concepts and settings as the dynamic reactive current function but uses active power as an output rather than reactive current.			Lo
	Non-functional capabilities				
33.	**Collect and provide historical information**	Collect and provide detailed measurement and performance data which might be valuable to record in an operational historian			Hi
34.	**Establish different ramp rates for different purposes**	In addition to the default ramp rate, the DER might support multiple ramp rates that reflect different conditions.		Relevant ramp rates or ramp times are included in each operational function	Lo
35.	**Soft-start return to service**	Use ramp rate and/or random time within window when reconnecting	"Ensuring appropriate reconnection", including random reconnect time windows	Using open loop response times rather than ramp rates	Med

No.	DER functions	Description and key parameters	European network codes EN 50549[a]	IEEE Std 1547:2018 (including V2G EVs)	Could EVs/charging stations be capable of function? How important (Req, Hi, Med, Lo)
	Microgrid capabilities being defined in IEC TR 61850-90-23[2]				
36.	**Microgrid separation control (intentional islanding)**	Process for normal separation, emergency separation, and reconnection of microgrids. These microgrids could be individual facilities or could be multiple facilities using area EPS grid equipment between these facilities.	Types C and D shall be capable of taking part in island operation if required by the relevant system operator	Separation requirements are identified but not fully described for intentional (microgrid) and unintentional islanding	Lo
37.	**Provide black start capability**	Ability to start without grid power, and the ability to add significant load in segmented groups	Not mandatory, but requirements are expected to be discussed		Lo
38.	**Provide backup power**	Ability to provide power to local loads when not connected to the grid			Hi

[a] Type A: DER connection point below 110 kV and maximum capacity of 0,8 kW or more. Type B: DER connection point below 110 kV and maximum capacity at or above a threshold and below the limit established by the relevant regulatory authority (Ranging between Baltic countries at 0,5 MW, Continental Europe at 1 MW, and Nordic countries at 1,5 MW).

[b] In mobility standards (ISO 15118 and IEC 63110 series), positive is for consumption (charging) and negative for generation (discharging).

2 Under preparation. Stage at the time of publication: IEC TR ACD 61850-90-23:2022.

5 Historical overview of different EV architectures applicable to a DER environment

5.1 SGAM interoperability layers as applicable to EVs

Interoperability (ability to exchange information that is understandable by all users) involves more than the traditional concept of communication protocols which are just bits and bytes going over a wire or other channel. The exchange of information involves multiple layers of interactions, involving business purposes down to the various media that could transport the information (including carrier pigeons). As an example, the SGAM model and the GWAC stack model are different: the IEC's smart grid architecture model (SGAM)[3] identifies 5 communication layers (see Figure 8).

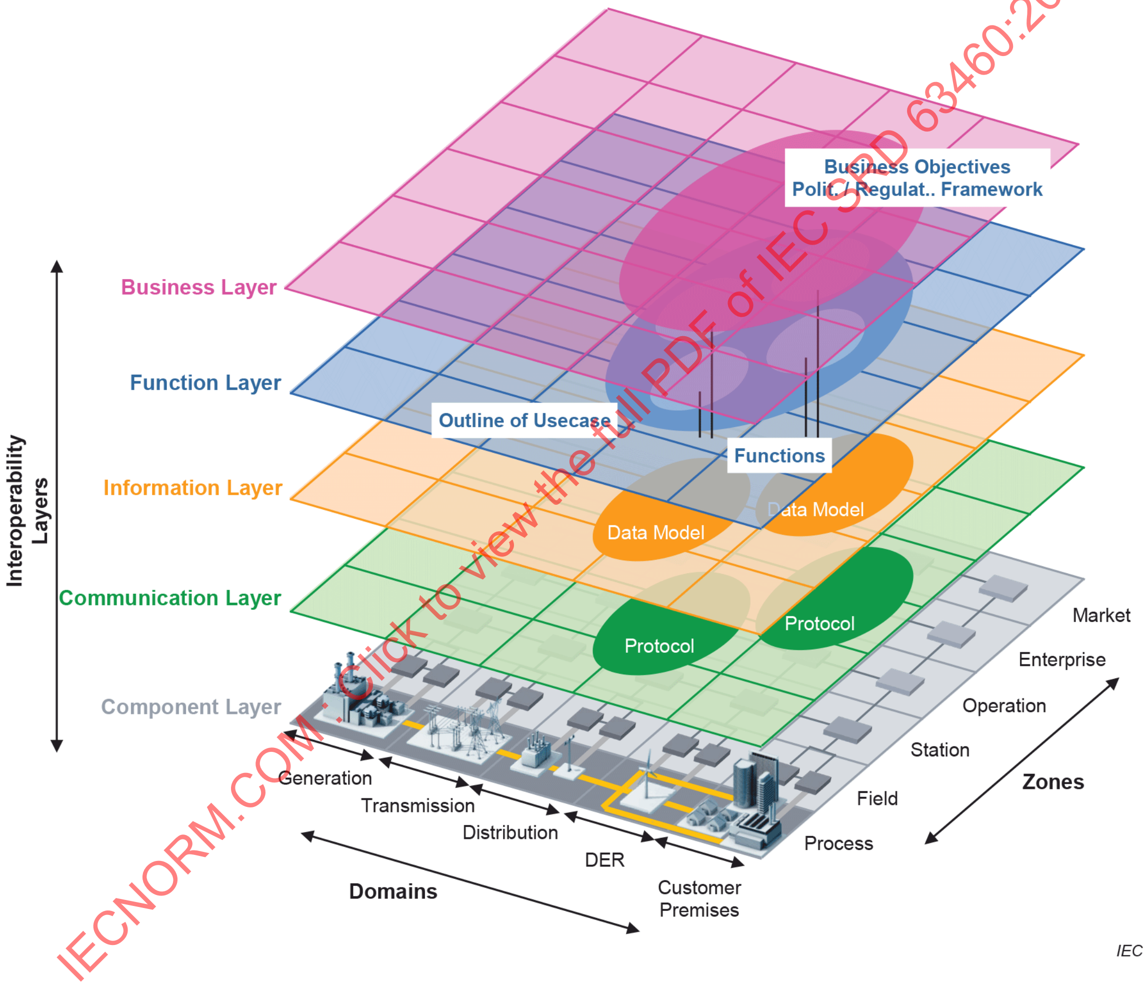


Figure 8 – Smart grid architecture model (SGAM)

3 https://assets.ctfassets.net/ucu418cgcnau/6B0cTQfQ2nDOGgxHoLZ3xm/d50a857bb44f74ce70f710c4de91ba8f/D1-12A_Scholer_-_Summary_of_updates_to_SAE_for_AC_DER.pdf. Summary of updates to SAE for AC DER Hank McGlynn Leader of V2G Working Group Rich Scholer Chair of SAE Hybrid Communication and Interoperability Task Force

As can be seen, the 3-dimensional SGAM diagram provides a very complete and complex model, but can be difficult to use without splitting it into 2-dimensions, such as the functional layer, the information layer, and the communication layer. Another architecture model, the GridWise Architecture Council's "GWAC stack" has 8 layers, but these two models are easily "mapped" to each other. The following descriptions illustrate the primary SGAM layers compared to the GWAC stack (see Figure 9):

- Business objectives, economic/regulatory policy, business layer: This layer covers the business purposes for communications, including providing information for business decisions, meeting regulatory requirements, and requiring interoperability.
- Business context and procedures, function layer: This layer addresses the functionality and use of the data within business contexts, such as "this collection of settings, monitored information, commands, defaults, timing, etc. provide the information exchange requirements for the voltage-reactive power function" or "this is the sequence of steps with specific data exchanged in each step for a DER to perform the frequency ride-through function".
- Semantic understanding, information layer: This layer provides the meaning of the data and acts as "nouns" in the sense of "this is the three-phase RMS voltage measurement on Feeder A in Substation Z", "this is the maximum active power rating of DER B right now", or "this is the updated setting for reactive power for power plant Y".
- Syntactic interoperability, communications (application) layer: This layer provides the communication services and acts as "verbs" in the sense of "getting data", "monitoring data", "controlling data", "setting data values". It does not cover the meaning of the data, only the services.
- Network interoperability, communications (transport) layer: This layer transports the information, usually in message packets, from one end to the other end. This might involve going through multiple nodes, gateways, routers, etc.
- Basic connectivity; component (physical) layer: This layer encompasses the physical media, such as wires, wireless, fibre optics, coaxial cable, LANs, WANs.

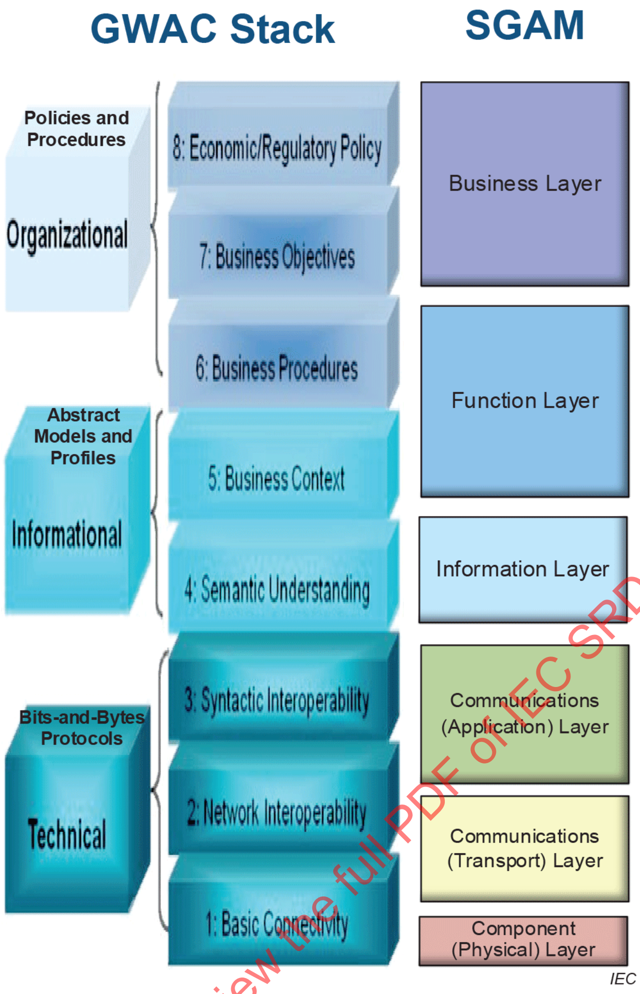


Figure 9 – GWAC Stack and SGAM

There are many different communication protocols, information models, and cybersecurity standards for EVs as DER. Each has specific capabilities based on their origins and purposes, although some have expanded over time. The core communication protocols and information models are illustrated in Figure 10.

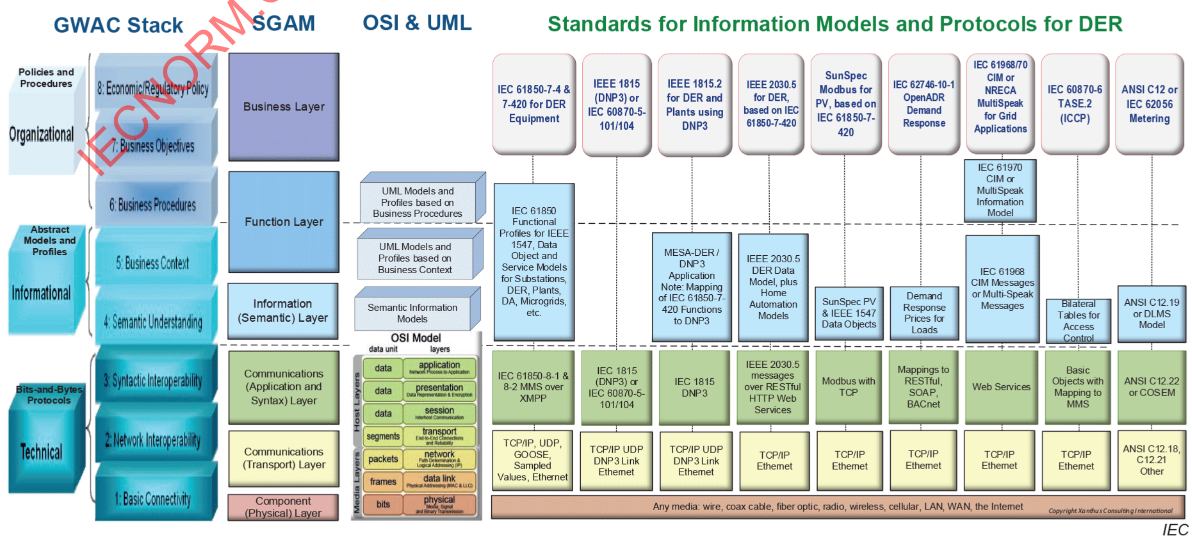


Figure 10 – Core communication protocols and information models for EV-as-DER

5.2 E-mobility systems architectures

5.2.1 Overview

The EV world is changing so rapidly that standards efforts have not been able to keep up. Initially, many architectures and technologies have simply been developed by the EV and charging equipment manufacturers, such as plug shapes, AC charging levels, and DC charging levels. However, it became clear that communications between EVs and the charging equipment (EVSEs) was required to handle the charging. Interoperability requirements quickly led to some information exchange and protocol standards to be developed (e.g., ISO 15118-20 for information exchanges between the EVSE and the EV).

Once the basic charging standards were developed, other standards related primarily to payment methods for charging were required. Again, the equipment manufacturers had quickly adopted the OCPP communications standard for payment at charging stations for charging EVs, but soon recognized that just charging EVs as fast as possible (analogous to gasoline cars filling up as rapidly as possible) was not the only use case, since the prices for charging could vary significantly based on location, time of day, and other factors. In addition, EV batteries could also discharge (V2G) and could even provide grid services. Additional standards needed to be developed for managing charging based on new use cases.

Subclauses 5.2.2 to 5.2.10 address some of the key EV standards efforts on use cases for EV charging and, more recently, EV discharging (V2X).

5.2.2 E-mobility in IEC TR 61850-90-8:2016

One of the earliest standardization efforts was to develop the EV charging requirements using IEC 61850. IEC TR 61850-90-8:2016 was developed. This approach was not accepted at that time, due to other standards being viewed as more appropriate. The SGAM view of e-mobility systems as described in IEC TR 61850-90-8 is shown in Figure 11, where the primary actors are shown with the logical connections that could involve information flows between these actors. However, this view is currently out-of-date due to more recent work.

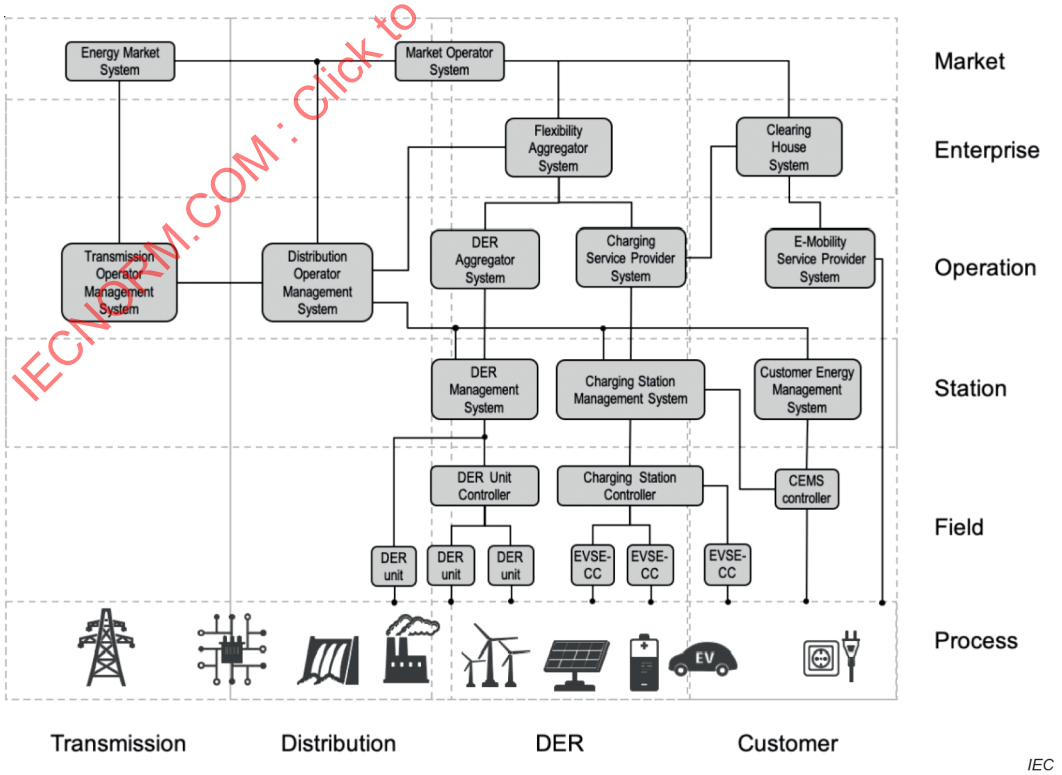


Figure 11 – E-mobility SGAM view (out of date)

Some new logical nodes were identified as needed for electric vehicle management (see Figure 12), including the following:

- DEEV: model of the electric vehicle characteristics;
- DEOL: model of the plug characteristics;
- DESE: model of the EVSE.

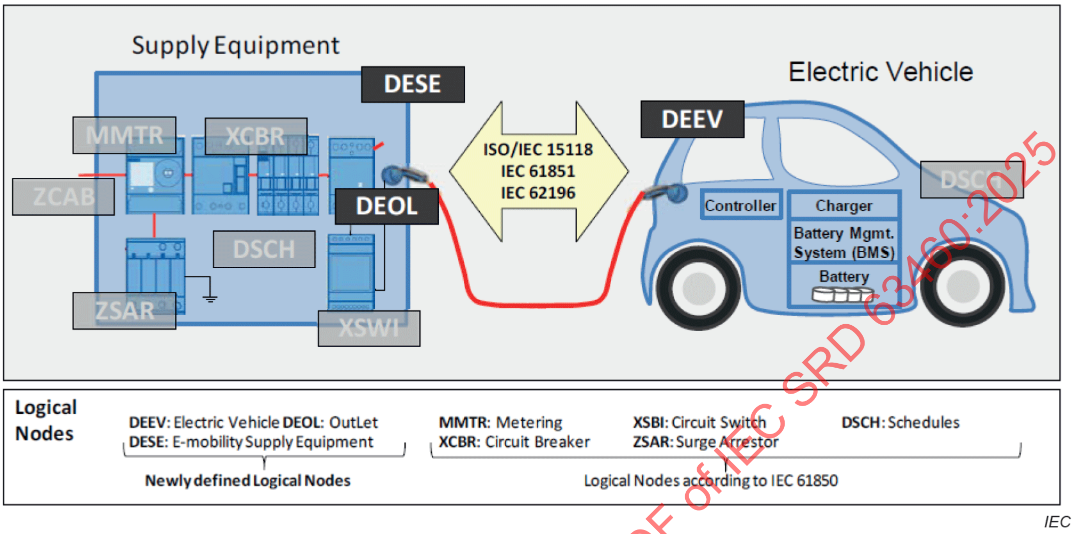


Figure 12 – EV-related IEC 61850-90-8 data objects

These logical nodes are out of date, due to the fact they were developed before IEC 61850-7-420:2021. Also, this approach was not accepted at that time, due to other standards being viewed as more appropriate and already used for basic charging. However, the concept of using IEC 61850 data model for EVs is still important and is currently being seen as critical for "EV as DER", where the data models for many grid services are already defined.

5.2.3 EV Integration in IEC SRD 63268:2020

5.2.3.1 Communications layer

IEC 63268:2020 was developed to identify the various communication and information standards being applied for the interfaces between different types of equipment. Figure 13 shows a mapping of the EV interfaces into the SGAM communication layer.

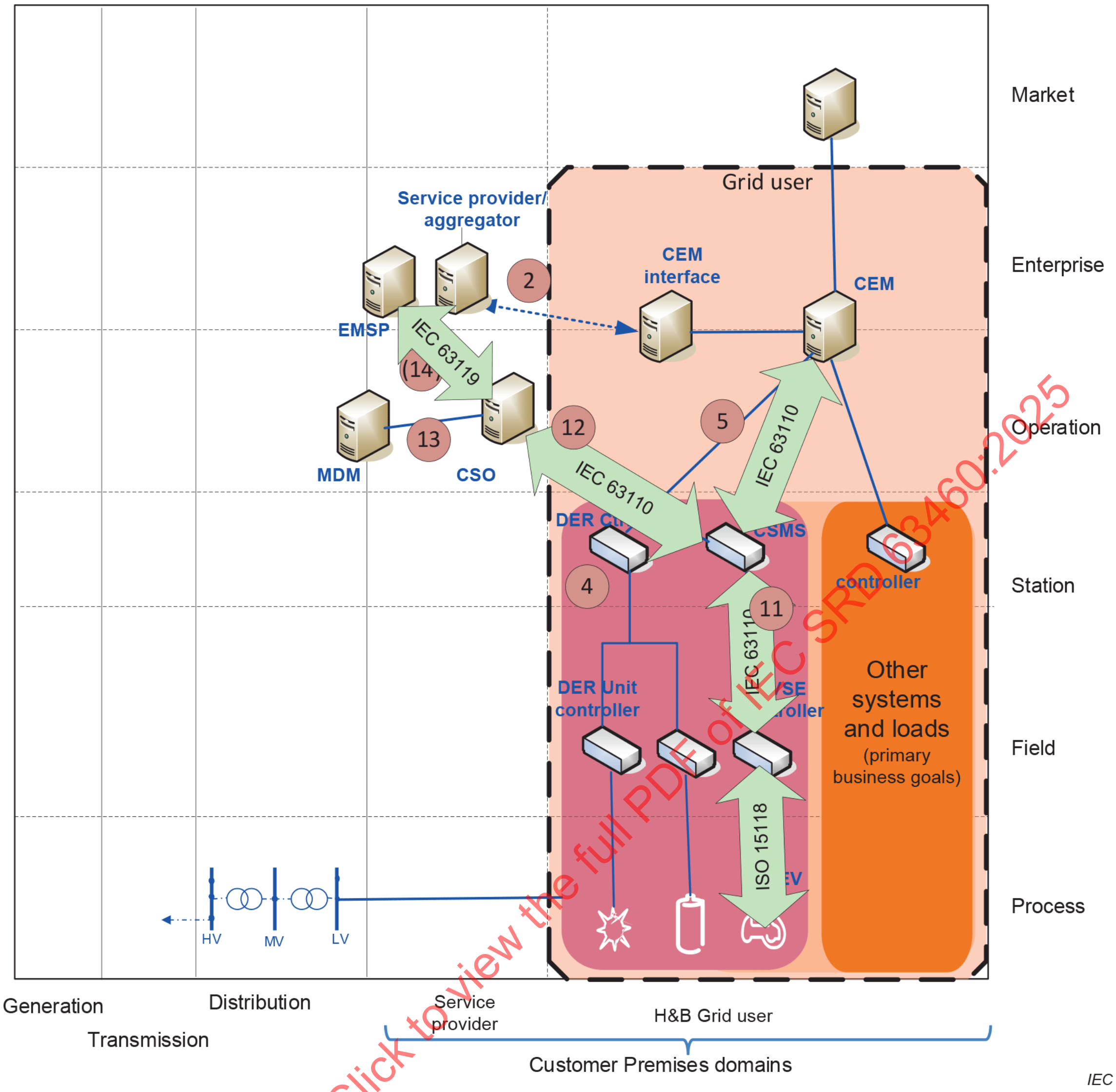


Figure 13 – Addition interfaces to support EV mapped to the SGAM communication layer (in case of H&B)

5.2.3.2 Information (data) layer

The marketplaces communication interfaces are identified in Figure 14 which shows such a mapping onto the SGAM information layer.

NOTE Since the IEC 63380 series is not yet published, it is not included.

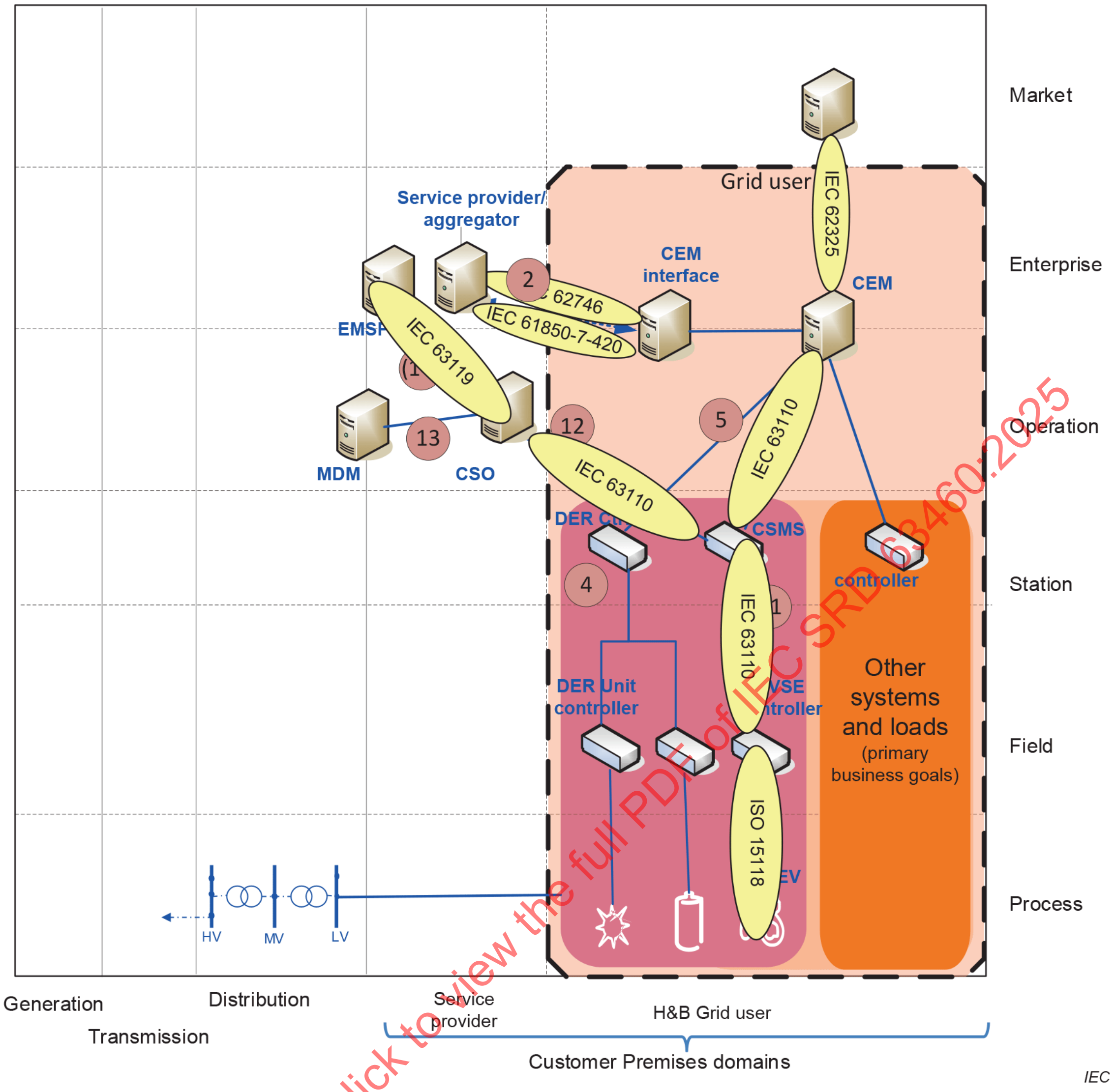


Figure 14 – Marketplace interfaces mapped to the SGAM information layer

5.2.3.3 Mapping involved IEC entities to the SGAM architecture

IEC entities involved in supporting marketplace interfaces are shown in Figure 15. As can be seen, there are silos between the different working groups working in this space. In addition, EV configurations are evolving over time as V2X is becoming realistic. This means that the silos are actually hindering the standardization of EV-as-DER.

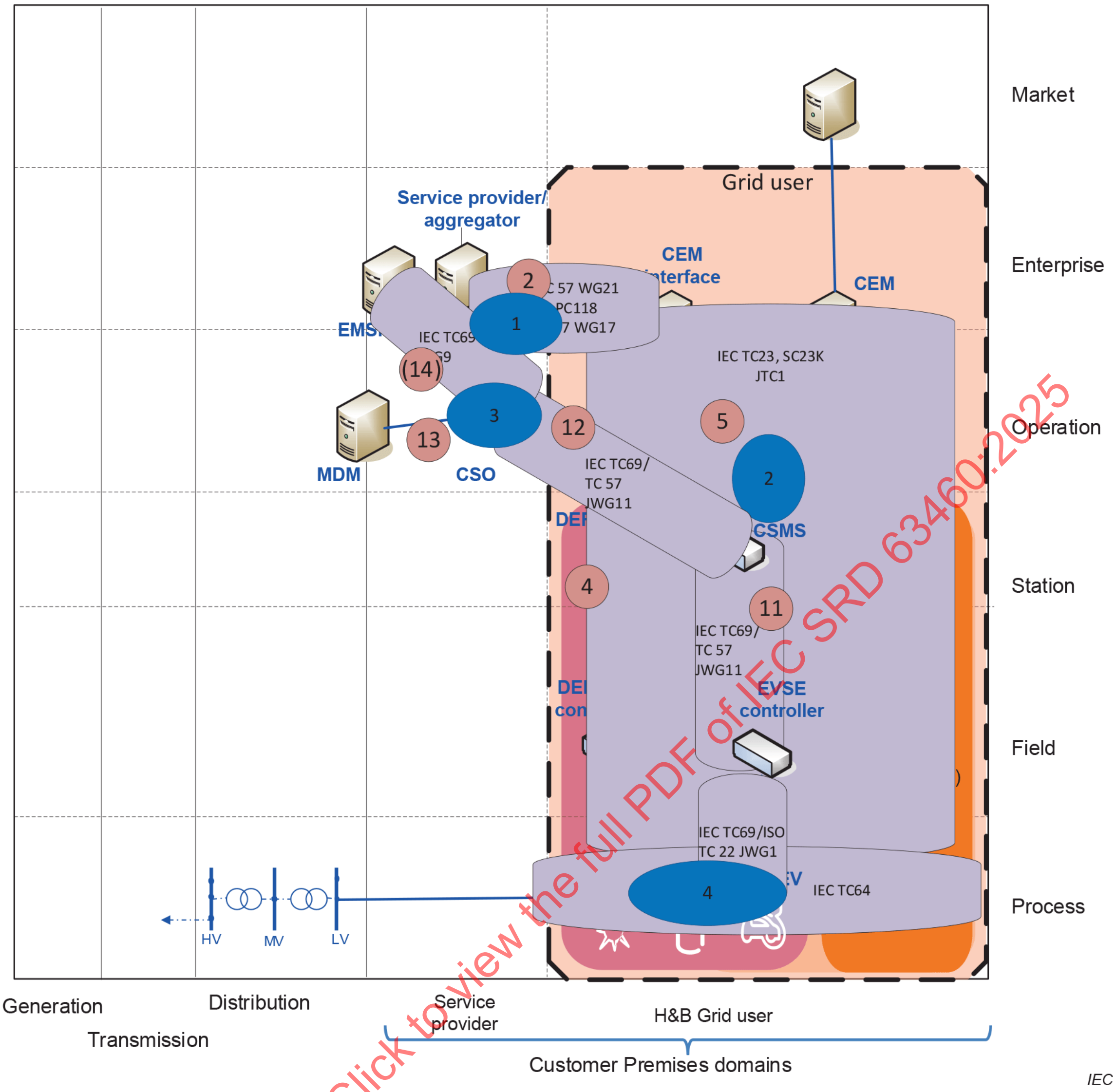


Figure 15 – IEC entities involved in supporting marketplace interfaces

5.2.4 EV architectures in the IEC 63110 series

The IEC has developed many standards in different groups related to e-mobility, including the IEC 63110 series, the IEC 63119 series, and the ISO 15118 series. Figure 16, Figure 17, and Figure 18 are examples of how these standards expect to interrelate with each other. These figures are also changing as new understandings of EV capabilities and uses are evolving. In particular, Figure 18 shows how IEC 61850-7-420 could be used for "EV as DER" interactions.

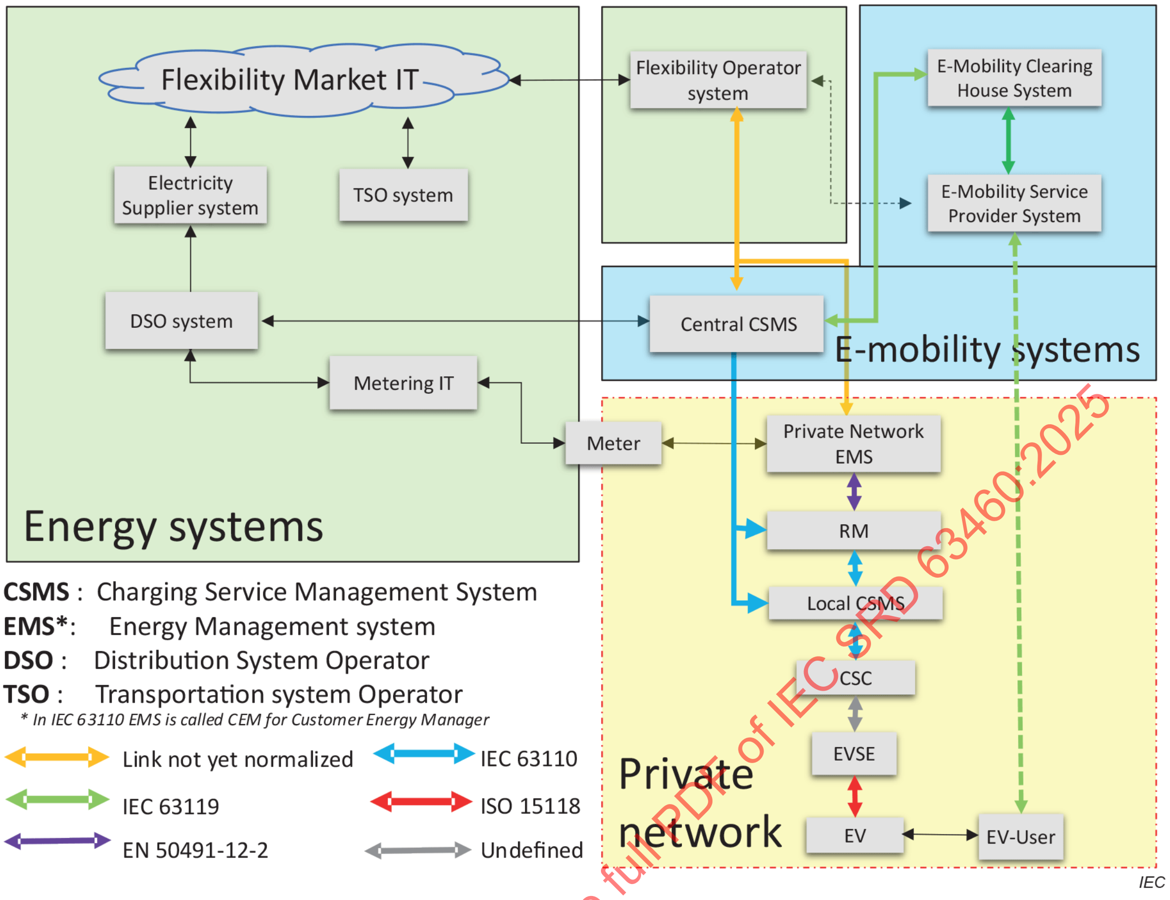


Figure 16 – E-mobility standards landscape within the IEC

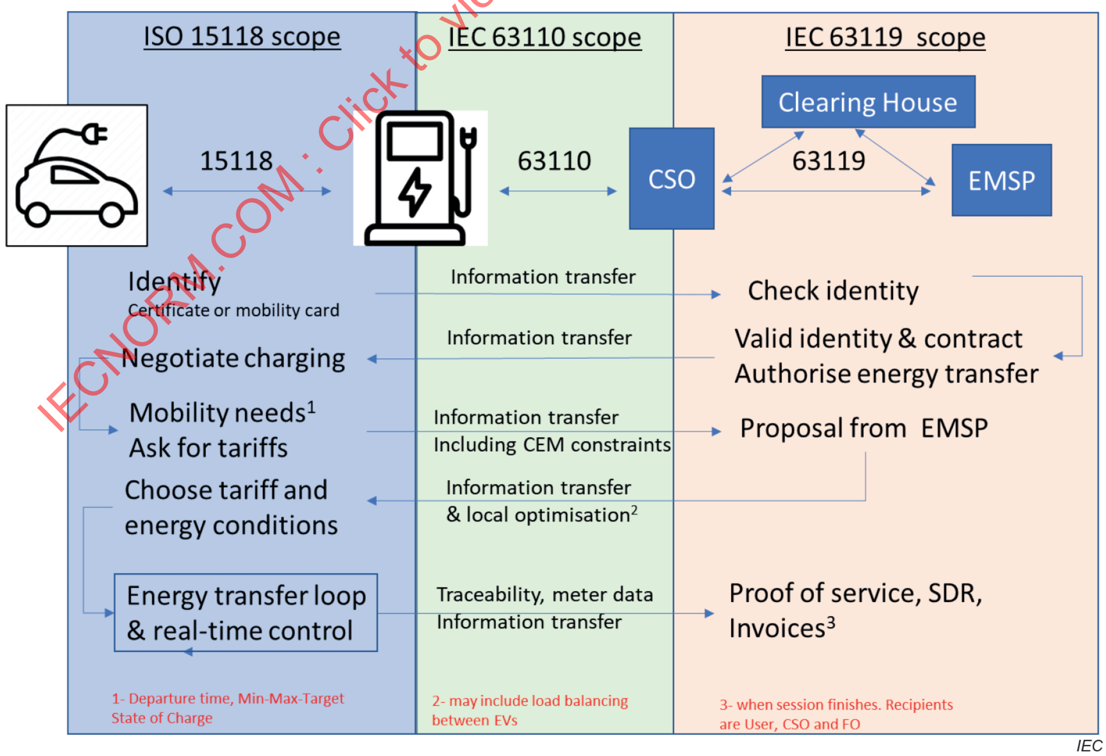


Figure 17 – Message flow between IEC TC 69 standards (not including TC 57 standards)

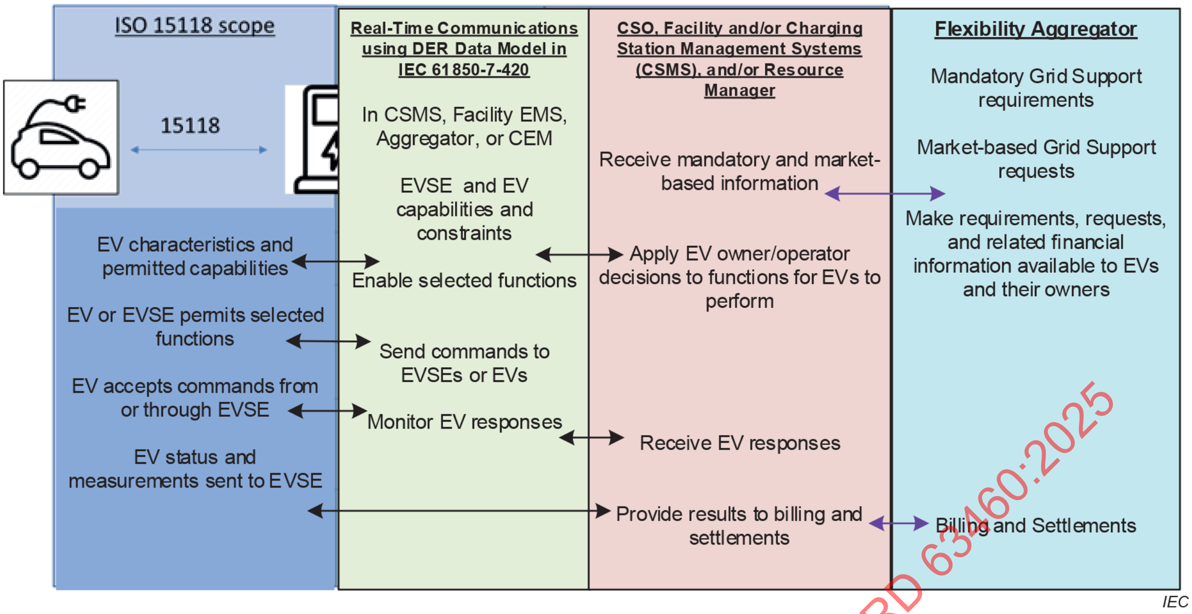


Figure 18 – Information flow between actors based on the IEC 61850-7-420 information model

5.2.5 EV architecture (IEC 63382 series)

The IEC 63382 series identified the broader scope of EV architectures, including identifying interfaces which do not yet belong to any specific IEC standard (black lines) (see Figure 19). However, this diagram does not distinguish between the three most relevant SGAM communication layers, namely the functional layer, the information layer, and the protocol layer. Specifically, it is the information layer (semantics and to some degree the syntax) that provides the core of interoperability. The bits and bytes of communication protocols can be easily translated if the semantics are the same or very similar across the protocols.

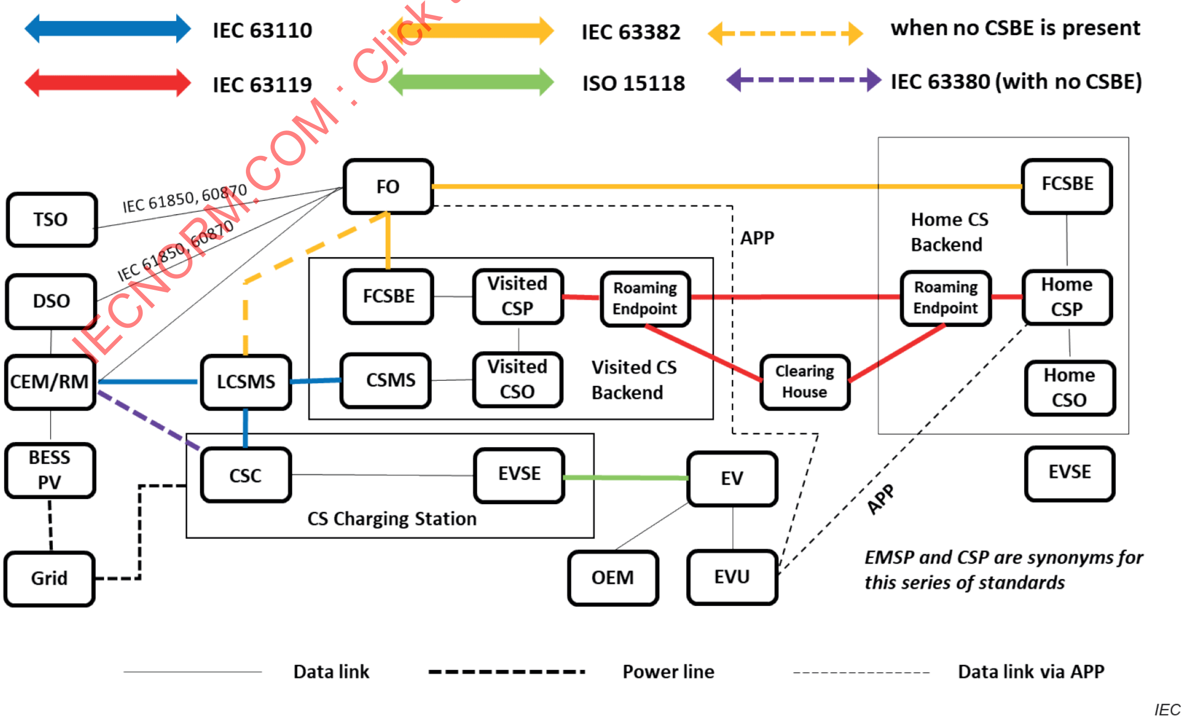


Figure 19 – IEC 63382 diagram of actors and IEC standards responsible for the communications

5.2.6 EV architecture from the IEC 63380 series

The IEC 63380 series defines the secure information exchange between local energy management systems and electric vehicle charging stations. The local energy management systems communicate to the charging station controllers via the resource manager.

The IEC 63380 series specifies use cases, the sequences of information exchange, the data models as well as the communication protocols to be used and covers all aspects of local energy management of charging stations. The IEC 63380 series covers scenarios where the charging infrastructure is managed by the operator of the private electrical network, and local energy management systems are used for local load management. The IEC 63380 series does not cover the secure information exchange between the charging station and the IT backend system(s), such as the management of energy transfer of the charge session, contractual and billing data, provided by the IT backend.

The EV architecture according to the IEC 63380 series is shown in Figure 20.

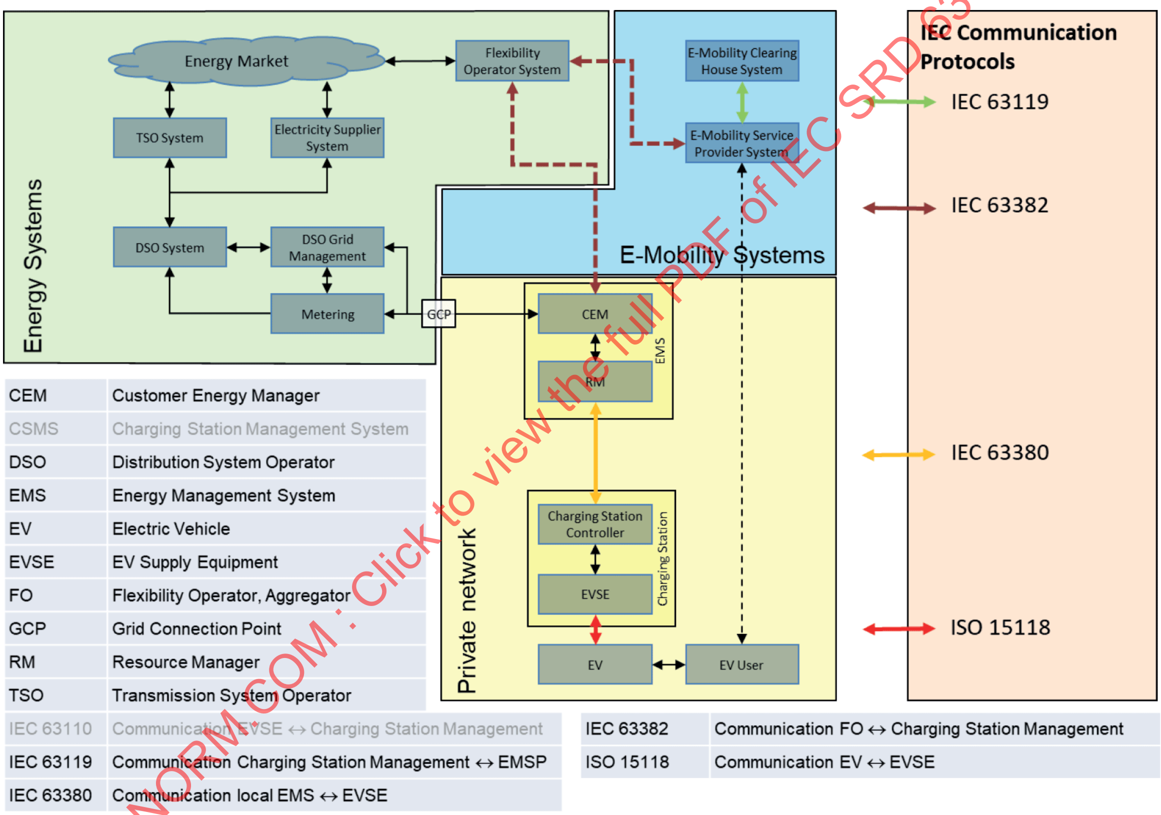


Figure 20 – EV architecture in the IEC 63380 series

5.2.7 EVs in buildings architectures from IEC SC 23K

Figure 21 illustrates the architecture of buildings with DERs, building equipment, and EVs (see light orange box) from IEC SC 23K.

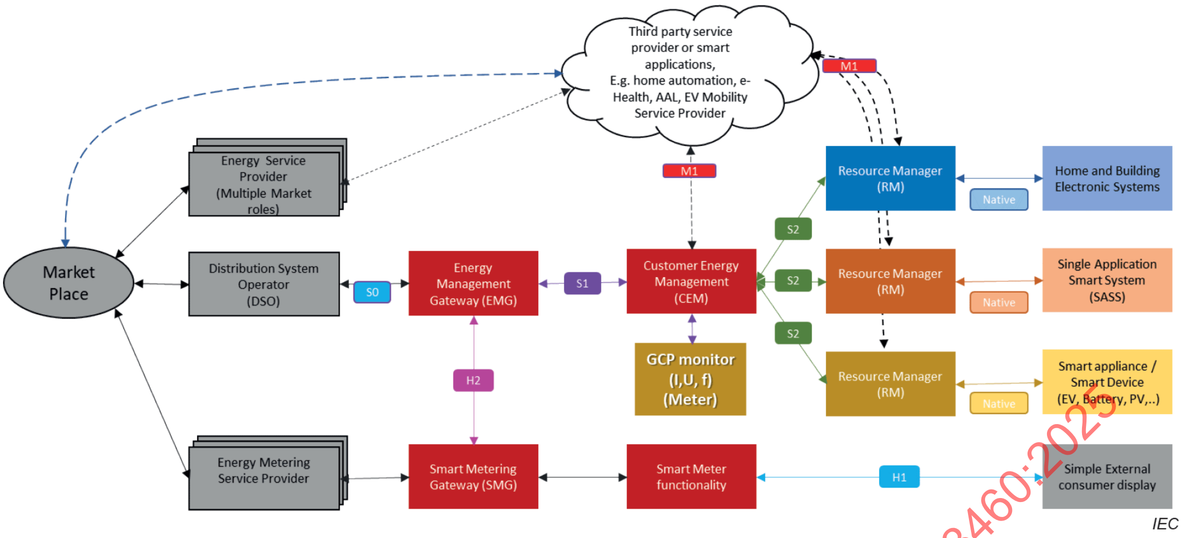


Figure 21 – EVs in buildings architecture from IEC SC 23K

5.2.8 EV architectures in SAE

SAE International (SAE) is a global association of engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries. One of its core competencies is consensus standards development. SAE defines the interface (mechanical, electrical, and communication) standards on vehicles and between EVs and the electric power system (EPS). SAE relies on standard bodies such as the IEEE Standards Association and International Electrotechnical Commission (IEC) to verify that vehicle equipment that interfaces to the EPS complies with internationally recognized standards. For example, in North America, inverters that interface to the EPS and can export active power should comply with IEEE Std 1547 grid codes standards.

SAE has a suite of standards that apply to plug-in electric vehicles (PEV) that interact with electric power systems. The overall informative SAE document is SAE J2836/1, that establishes the instructions for the documents required for the variety of potential functions for PEV communications, energy transfer options, interoperability, and security. The purpose of SAE J2836/1 is to document the general information that is supported by the SAE J2836 series, SAE J2847 series, SAE J2931 series and SAE J2953 series and SAE J3072 for plug-in electric vehicles.

Figure 22 shows the various SAE PEV standards and how they relate to one another[4]. As is noted, the standards incorporate various uses cases for EVs interacting with electric power systems. Of particular interest for this document is PEV as distributed energy resource SAE J2836/3 that applies to both AC and DC. For PEV DC interaction with the EPS, the inverter is in the EVSE where the grid codes will be incorporated. For PEV AC interaction with the EPS, the grid codes will be incorporated in the onboard inverter. When the inverter is on the PEV, SAE J3072 defines the communication between the PEV and the EVSE required for the PEV onboard inverter function to be configured and authorized by the EVSE for discharging at a particular site. The SAE J3072 requirements are intended to be used with the IEEE Std 1547 grid codes. Initially the communication between the EVSE and EV is based on IEEE Std 2030.5^{TM}, but the intention is to implement ISO 15118-20 once it is developed.

4 https://assets.ctfassets.net/ucu418cgcnau/6B0cTQfQ2nDOGgxHoLZ3xm/d50a857bb44f74ce70f710c4de91ba8f/D1-12A_Scholer_-_Summary_of_updates_to_SAE_for_AC_DER.pdf. Summary of updates to SAE for AC DER Hank McGlynn Leader of V2G Working Group Rich Scholer Chair of SAE Hybrid Communication and Interoperability Task Force

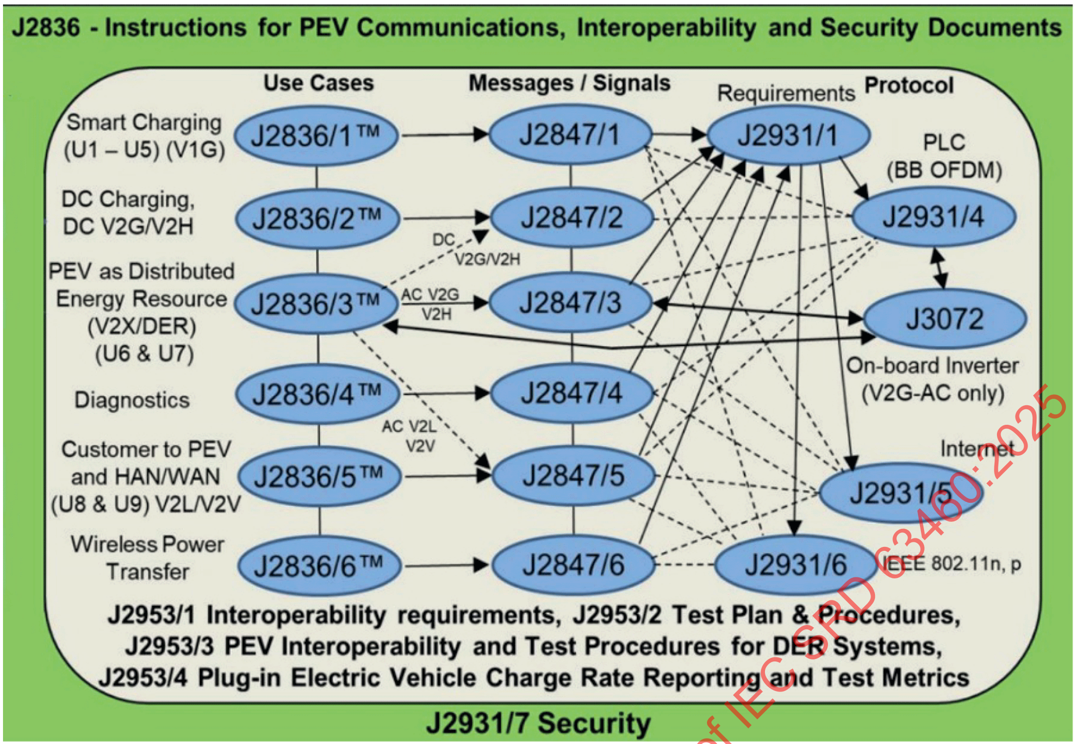


Figure 22 – SAE PEV standards for communication, interoperability, and security

5.2.9 OCPP updates

Although still a work in progress, a white paper was developed by the Open Charge Alliance (OCA) on the Open charge point protocol (OCPP) using IEC 61850-7-420 data objects for EV-as-DER purposes[5]. Figure 23 shows their vision of an OCPP topology.

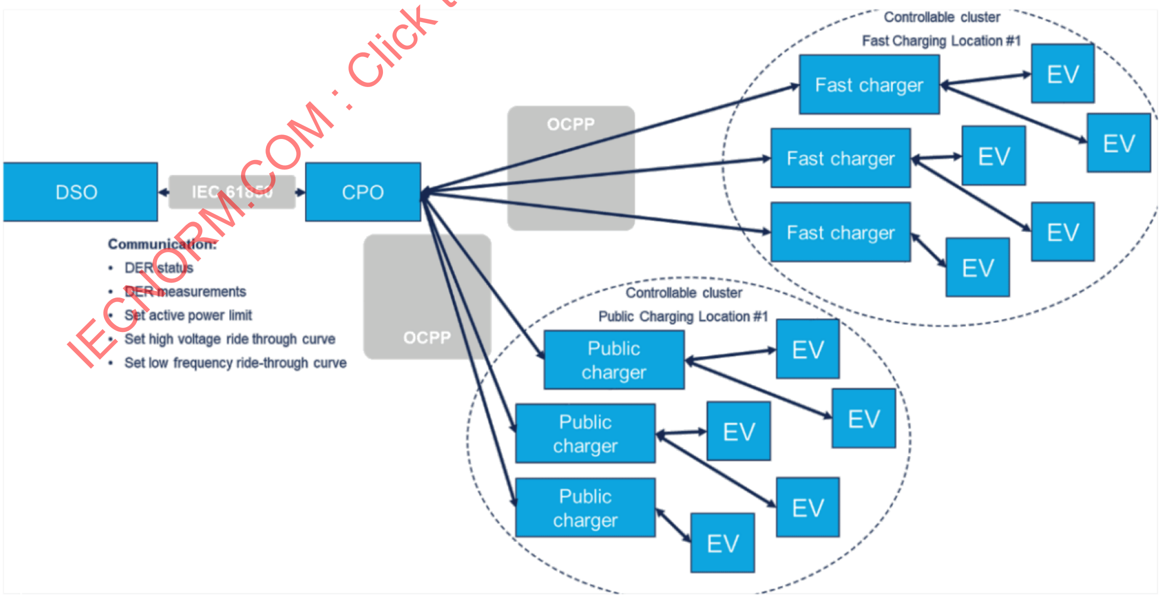


Figure 23 – OCPP topology for DER control via the charging point operator (CPO)

5 https://openchargealliance.org/whitepapers/

Although this is an excellent direction to head, there are still some issues and gaps with this approach. Only the top-level IEC 61850-7-420 logical nodes are identified, and then OCPP creates its own data objects under those headings, rather than using the existing IEC 61850-7-420 data objects. If new data objects are needed, then those could be added, but by ignoring the existing data objects, it will be far more difficult to achieve interoperability, including with IEEE Std 2030.5 (which is also based on IEC 61850-7-420) and, in the near future, IEEE P1815.2 which maps the IEC 61850-7-420 data objects to DNP3 (and could be easily used for mapping to IEC 60870-5-101) which maps over 1000 data objects, including the IEEE Std 1547 functions, storage-related functions, scheduling, curves, health of the equipment, etc. Although not all of these DER-specific data objects will be needed for EVs, it would be better to use what exists rather than invent new names and definitions.

5.2.10 ISO 15118-20 updates

In mid-2023, it was determined that ISO 15118-20 should be updated to include V2G AC discharging, so the communication requirements defined in SAE J3072 are being incorporated in ISO 15118-20. This effort is still evolving.

5.3 E-mobility roles

5.3.1 E-mobility role definitions from the IEC 63110 series

As illustrated in Figure 24, the IEC 63110 series has identified the following EV roles (actors), with only the primary actors actively initiating actions.

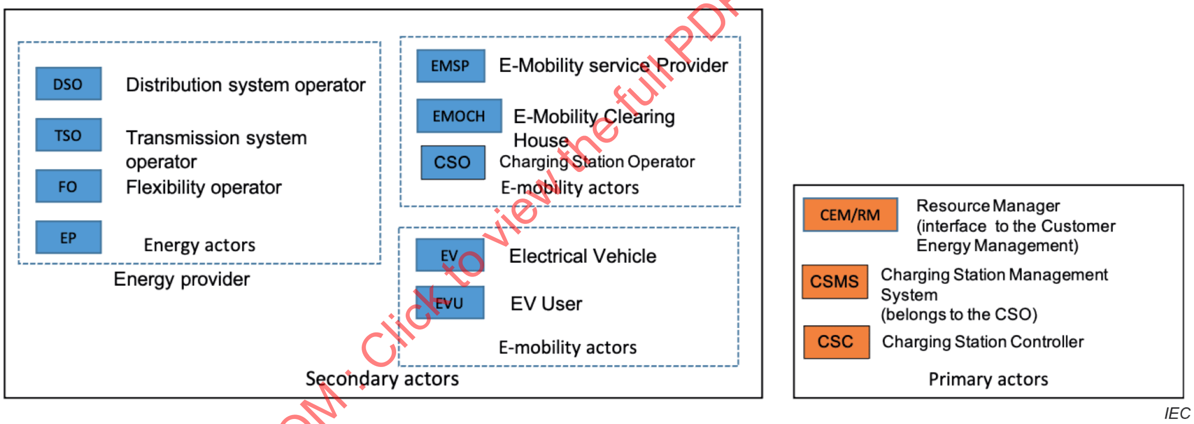


Figure 24 – EV roles (actors) identified in the IEC 63110 series

However, if EVs, EVSEs, charging stations, facilities, microgrids, third parties, and different types of Utilities are to participate as DERs to support the grid and to provide market-based DER functions, the scope of roles has to be somewhat expanded, and the information exchanges definitely need to be more broadly identified. Therefore, the list of roles extends beyond those covered by the IEC 63110 series. Another diagram for illustrating the scopes of the key roles for EVs participating in grid code functions is shown in Figure 25.

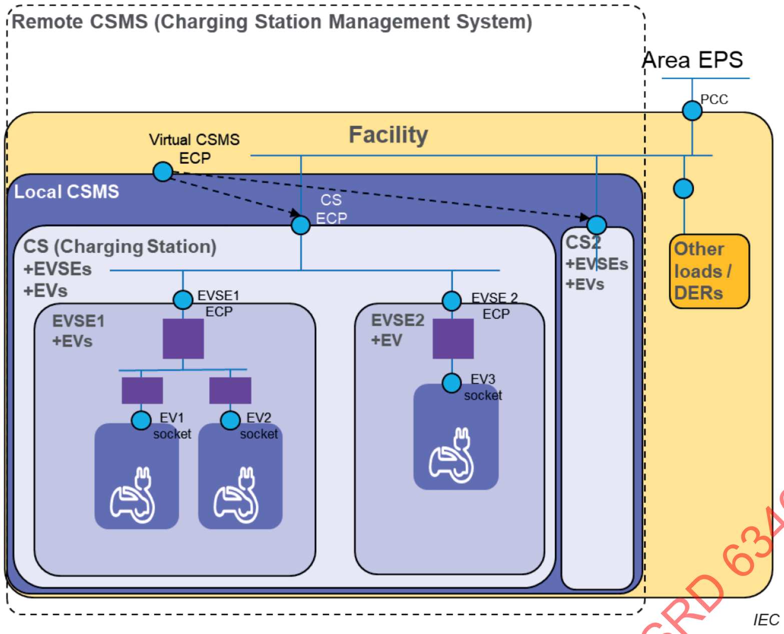


Figure 25 – Example of scope of key roles

Definitions of roles applicable to EVs in a DER environment, as initially identified in the IEC 63110 series, are shown in Table 2.

Table 2 – Roles applicable to EVs in a DER environment

EV roles in a DER environment	IEC 63110 definitions	Proposed modified definitions
Charging station (CS)	Physical equipment consisting of one or more EVSEs managing the energy transfer to and from EVs	Term used to encompass one or more CSCs and their EVSEs within a facility
Charging station controller (CSC)	System responsible to manage one or more EVSEs	System responsible for communication transfer/translation as well as physical safety management of one or more EVSEs
Charging station management system (CSMS)	System responsible for managing charging infrastructures	System responsible for managing one or more CS, including determining and managing the energy transfers to and from each EV: • based on grid codes and market-based functions; • constrained by EV capabilities and contracts; • constrained by area EPS capabilities and contracts.
Charging station operator (CSO)	Party responsible for the provisioning and operation of a charging infrastructure (including charging sites), and managing electricity to provide requested energy transfer services	Party responsible for the provisioning and operation of a charging infrastructure (including charging sites), and managing access to the area EPS for providing requested energy transfer services
Customer energy management system (CEMS)	CEM system which allows to manage the energy consumption and or production within the premises, consists of a CEM and attached resource manager which connects the home and building electronic system and/or smart appliances to the CEM	System which consists of customer energy management functions (including grid code functions) and connects to the CSMS, to the facility DER energy management system (FDEMS) and directly to some smart appliances.

EV roles in a DER environment	IEC 63110 definitions	Proposed modified definitions
Customer energy manager (CEM)	Internal automation function for optimizing the energy consumption and/or production within the premises according to the preferences of the customer using internal flexibilities and typically based on external information received through the smart grid connection point and possibly other data sources	Customer focused automation functions for optimizing the active and reactive power and the energy consumption and/or production within the premises according to the preferences of the customer, utility-based contractual arrangements, market-based information, market-based contracts, and regulatory grid codes.
Distribution system operator (DSO)	Entity responsible for the planning, operation, maintenance, and the development in given areas of the electricity distribution network (low voltage, medium voltage, and potentially high voltage), the quality of electricity supply (power delivery, voltage etc.) and for customer access to electricity provider market through his system under regulated conditions.	Entity responsible for the planning, operation, maintenance, and the development in given areas of the electricity distribution network (low voltage, medium voltage, and potentially high voltage), the quality of electricity supply (power delivery, voltage etc.) and for customer access to electricity provider market through his system under regulated conditions.
Electric vehicle (EV)	Vehicle which uses one or more electric motors or traction motors for propulsion. [a]	Vehicle which uses one or more electric motors or traction motors for propulsion. [a]
Electric vehicle communication controller (EVCC)	Embedded system, within the vehicle, that implements the communication between the vehicle and the SECC in order to support specific functions	Embedded system, within the vehicle, that implements the communication between the vehicle and the SECC in order to support specific functions
Electric vehicle supply equipment (EVSE)	Equipment or a combination of equipment, providing dedicated functions to supply electric energy from a fixed electrical installation or supply network to an EV for the purpose of charging and discharging	Equipment or a combination of equipment, providing dedicated functions to supply electric energy from a fixed electrical installation or supply network to an EV for the purpose of charging and discharging
Electric vehicle supply equipment (EVSE-AC)	Equipment for transferring energy to and from an EV	Equipment without (necessarily) an inverter for transferring active and reactive power to and from an EV-AC
Electric vehicle supply equipment (EVSE-DC)	Equipment for transferring energy to and from an EV	Equipment with an inverter for transferring direct current to and from an EV-DC
Electric vehicle with inverter (EV-AC)	Electric vehicle which includes the inverter and therefore exchanges AC active and reactive power	Electric vehicle which includes the inverter and therefore can exchange AC active and reactive power
Electric vehicle with DC charging (EV-DC)	Electric vehicle which does not use the inverter and therefore exchanges DC power	Electric vehicle which does not use its inverter and therefore exchanges DC power
Point of common coupling (PCC)		The point of connection between the area EPS and the Local EPS
Resource manager (RM)	Logical component (typically implemented in software) that exclusively represents a group of devices or a single smart device, and is responsible for sending unambiguous instructions to a group of devices or to a single device, typically using a device-specific protocol	Not modified
Supply equipment communication controller (SECC)	Entity which implements the communication to one or multiple EVCCs and which might be able to interact with secondary actors	Entity which implements the communication to one or multiple EVCCs and which might be able to interact with secondary actors
Vendor (generic) of equipment in CS		Entity that manufactured, installed, and/or maintains equipment in a charging station

[a] For this document, EVs are limited to those vehicles which transfer active and (in some cases) reactive power to and from their batteries via an external EVSE.

5.3.2 EV roles for DER use cases

Figure 26 shows these roles as they will be used in Use Cases. The colours signify the following.

- Orange roles signify the energy resource, in this case, the EV batteries. A black outline signifies it is "dumb" from a DER functional perspective, while a red outline signifies it has "smart" capabilities from a DER functional perspective.
- Bright yellow roles signify the power management capabilities. These are "black box" capabilities with vendors defining exactly how they work, particularly how multiple requests from different roles are handled.
- Pink roles signify the operational functions. The grid code functions are reasonably well defined, while market functions might be less precisely defined since different jurisdictions might have different requirements.
- Light yellow roles with red outlines signify equipment that play the role of both operational functions and power management capabilities.
- Blue roles signify electrical connection points, mostly where measurements are monitored.
- Purple roles signify external actors that can provide settings, setpoints, and/or control commands.
- Green roles signify entities that exist as systems or concepts but might not play active roles in EV-as-DER management.

NOTE In IEC 61850-7-420, the roles of operational functions and power management capabilities are very distinct even though they can or cannot reside in the same system or controller. However, in charging stations, there is always a separation between the vehicle (EV) and the electrical supply (EVSE). Communications need to bridge this separation, but the information could be very different depending upon the design and capabilities of the electric vehicles. For instance, EV-ACs which have their own inverters can handle some operational functions autonomously with only updated setpoints being provided by the EVSE-AC, while EV-DCs cannot perform these operational functions themselves. For this reason, the EV and EVSE roles in Figure 26, which is a high-level diagram, show this dichotomy. Lower-level diagrams can split these roles.

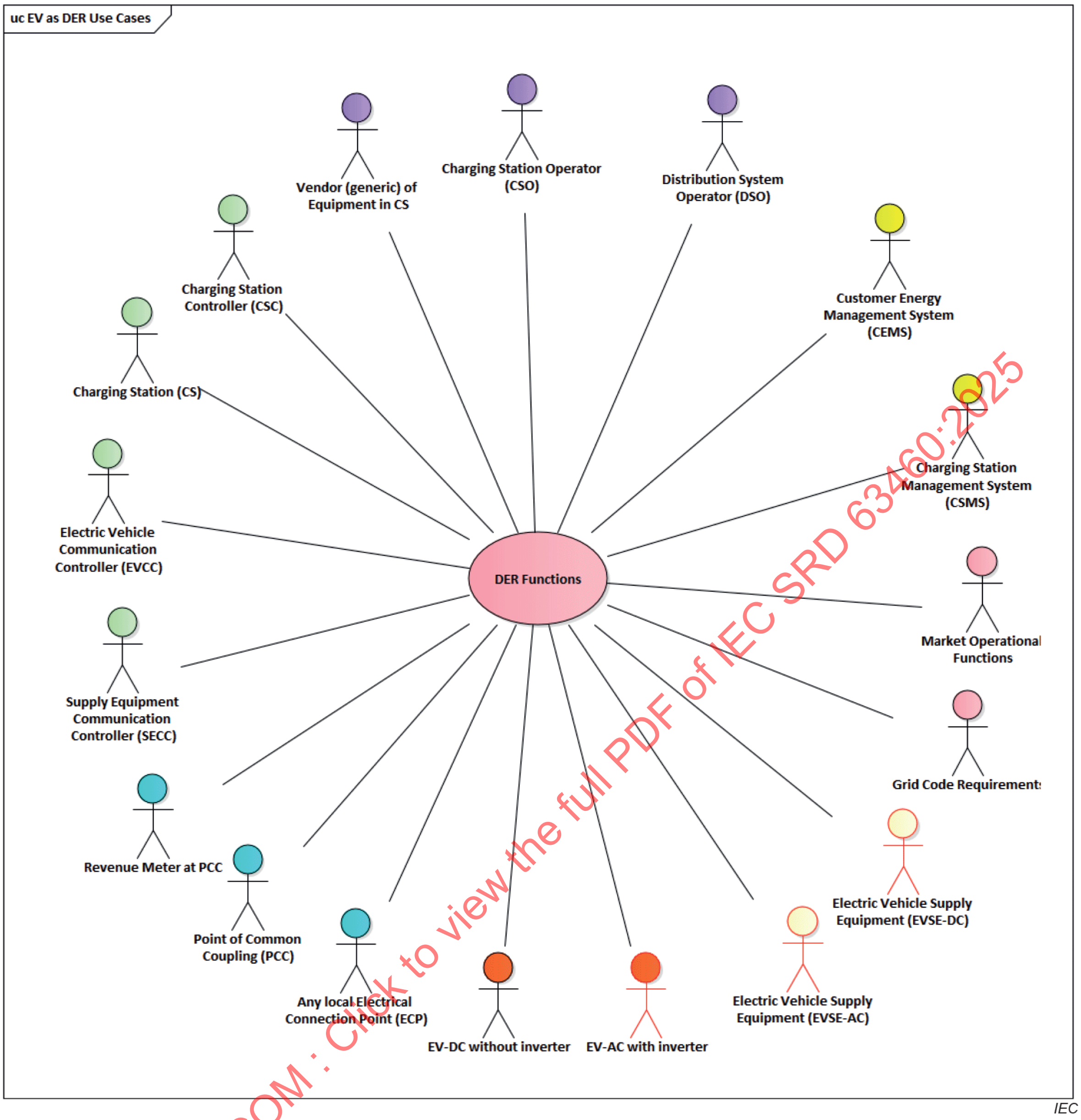


Figure 26 – Roles for charging stations applicable to a DER environment

No single communication protocol can be used for all interactions, but some standard communication protocols are more appropriate for different interactions, as illustrated in Figure 27.

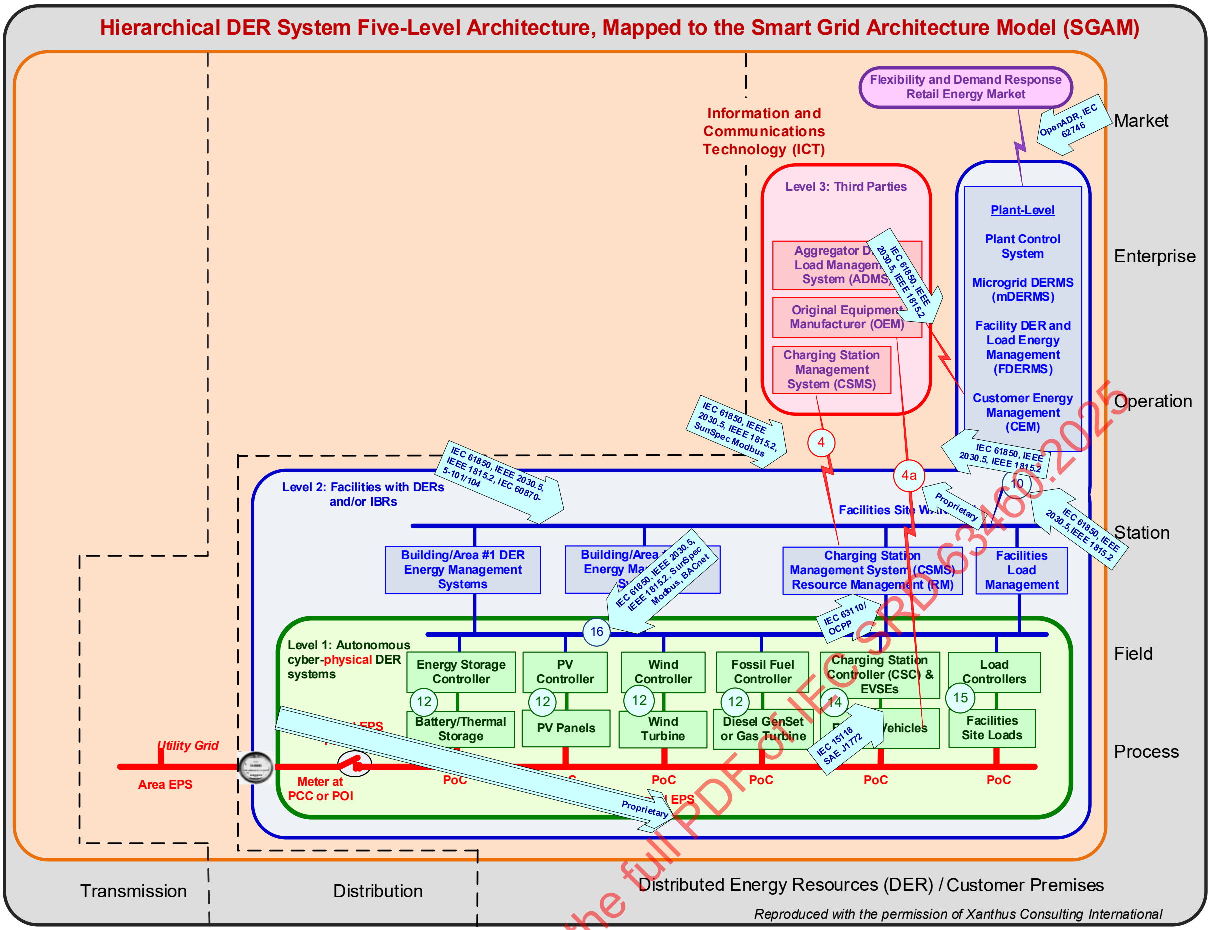


Figure 27 – Communication protocols associated with EV roles in a DER environment

5.4 EV-related standards

5.4.1 EV-related standards organizations

The following standard groups and industry groups have developed EV-related requirements:

a) IEC;
b) OCA;
c) SAE;
d) IEEE;
e) CAN;
f) UL.

5.4.2 Standards and documents including EV-related information exchange requirements

Some of the relevant EV-related standards that include information exchange requirements:

a) ISO 15118-20 (now being updated to use IEC 61850-7-420 data objects and names);
b) IEC 63110 series;
c) IEC 63382 series;
d) IEC 63380;
e) IEC 61850 data model;
f) IEC 63119 series;

g) SAE 3072;

h) IEEE Std 2030.5;

i) IEEE P1815.2;

j) OCPP 2.0.1;

k) SAE J1772;

l) IEC 62746-10-1 (OpenADR);

m) IEC 62351-9 for PKI;

n) IEC 62351-8 RBAC.

5.5 EV as DER architecture using the IEC 61850-7-420 information model

Using the diagrams in Figure 26 and Figure 27 as the source for the EV charging architecture, Figure 28 captures the parallel track for grid "EV as DER" services data. The roles and the associated standards are described as follows.

- Flexibility operator interacts with 3rd parties using IEC 63882: either aggregators or charging station management systems (CSMS).
- Aggregators and/or CSMS interact with facilities using the IEC 63110 series: either the customer energy management (CEM) or the local charging station management system (LCSMS).
- The CEM and/or LCSMS interact with local equipment using the IEC 63110 series: the resource manager (RM) and the charging station charger (CSC).
- The RM and CSC interact with the charger using IEC 61850 models over some protocol: the electric vehicle service element (EVSE).
- One or more resource management (RM) roles might be located in many different places – not just in one place.
- The EVSE interacts with the electric vehicle using the ISO 15118 series.
- The original equipment manufacturer (OEM) uses proprietary communications to link directly to their EVs and the EV users via EV applications that users can download on their phones or computers.

In parallel to these standards, a subset of IEC 61850-7-420 data model of grid support electrical functions and technical characteristics, over a any protocol, is used to pass the technical requirements for the EV as DER functions, as per SAE standards, such as SAE J3072. Other data models are available for other functions.

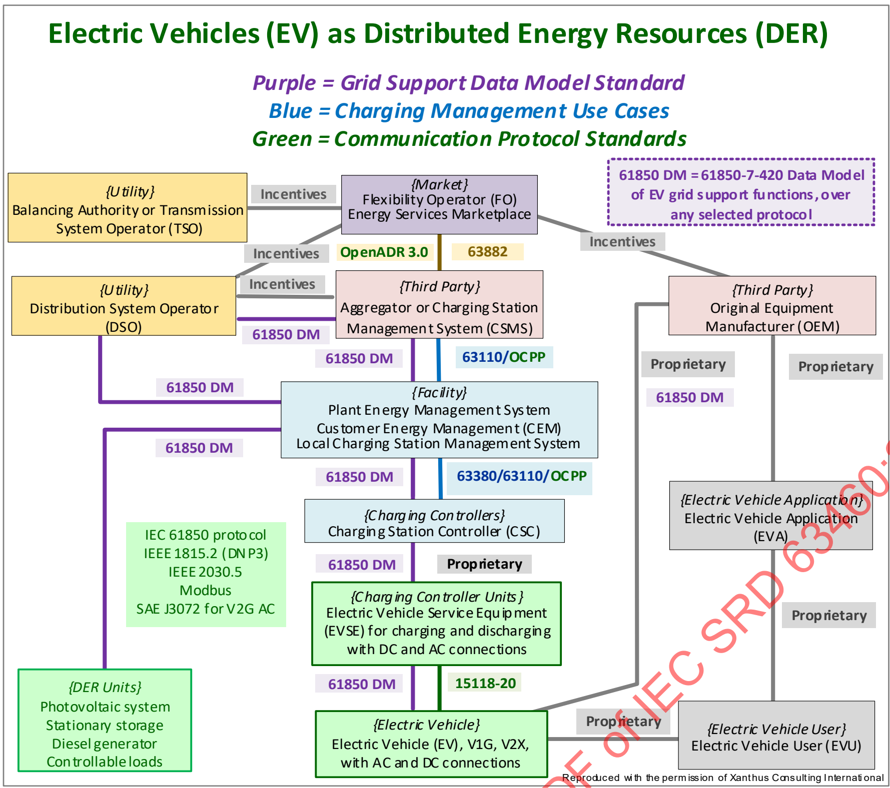


Figure 28 – EV as DER architecture

5.6 EV-DC and EV-AC charging and discharging

5.6.1 V2G EV-charging station configurations

Many different EV charging station configurations can exist and should be considered as standards are developed. IEC 63382-1:—[6], Table 2, includes the different configurations, while the diagrams shown in Figure 29, Figure 30, Figure 31, Figure 32, and Figure 33 illustrate the configurations.

Table 3 – EV charging station configurations

EVCS configuration diagram	Multi/ single EVSE	AC charge	DC charge	Bus	V2G	On board charger AC–DC	Off board charger	Connection to grid
1	multi	no	yes	DC bus	no	unidirectional	unidirectional	rectifier
1	multi	no	yes	DC bus	yes	unidirectional	bidirectional	inverter
2	multi	no	yes	AC bus	no	unidirectional	unidirectional	rectifier
2	multi	no	yes	AC bus	yes	unidirectional	bidirectional	inverter
3	multi	yes	no	AC bus	no	unidirectional	no	rectifier
3	multi	yes	no	AC bus	yes	bidirectional	no	inverter
4	single	yes	no	no bus	no	unidirectional	no	rectifier
4	single	yes	no	no bus	yes	bidirectional	no	inverter
5	single	no	yes	no bus	no	unidirectional	unidirectional	rectifier
5	single	no	yes	no bus	yes	unidirectional	bidirectional	inverter
Source: IEC 63382-1:—, Table 2.								

6 Under preparation. Stage at the time of publication: IEC/PRVC 63382-1:2024.

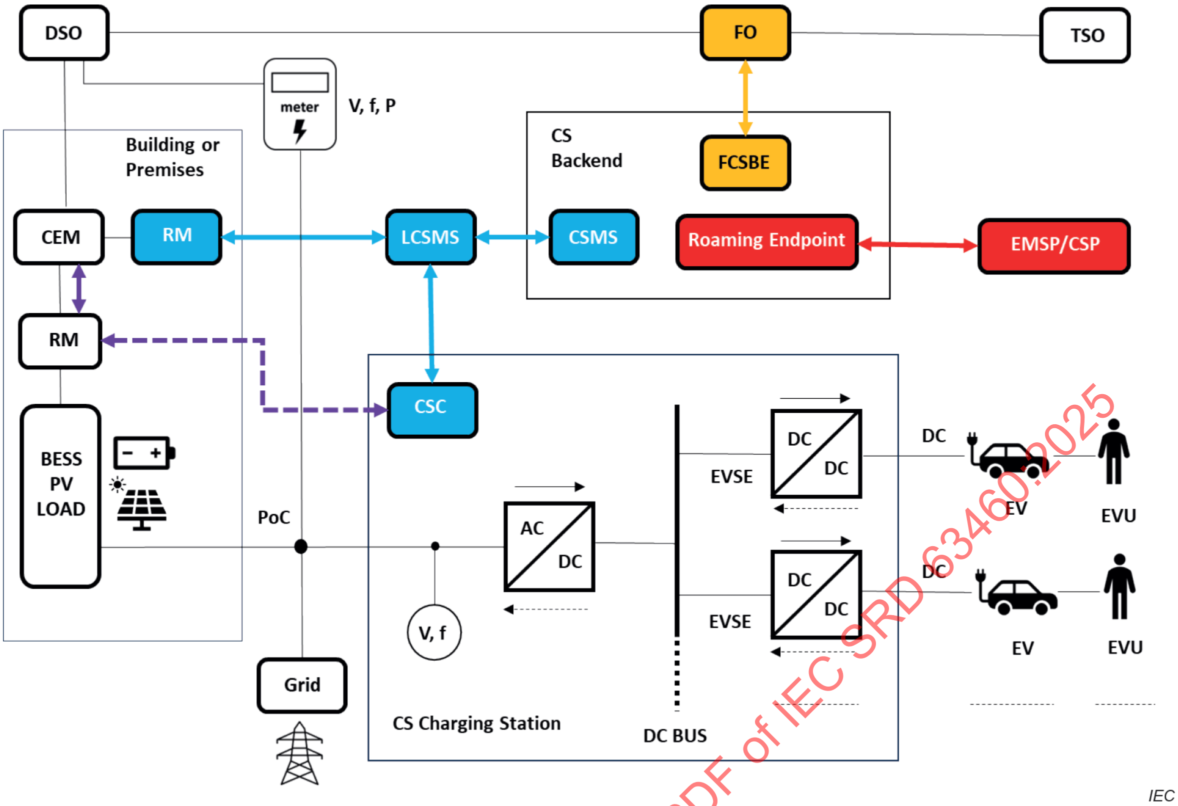


Figure 29 – Overview of charging configuration with DC bus, with DC/DC charging

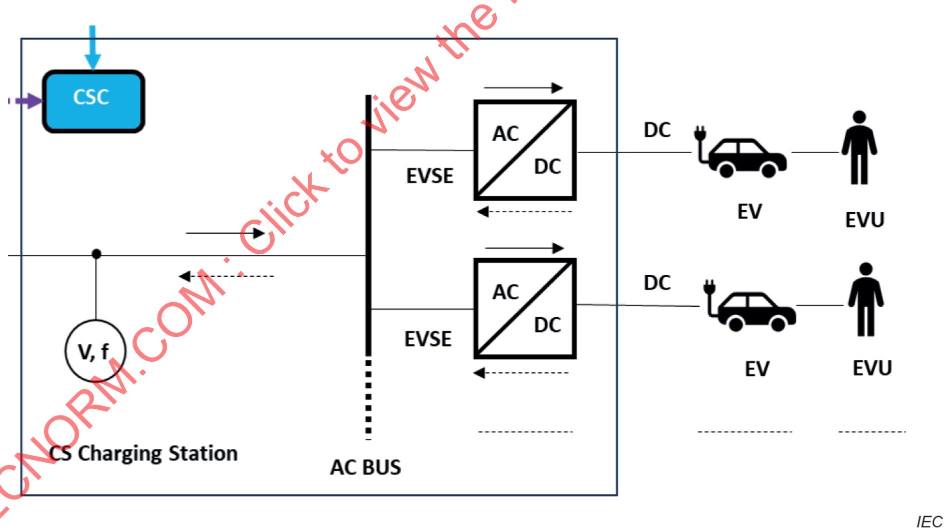


Figure 30 – Extract of charging configuration with AC bus, EVSE inverter conversion AC to DC, and DC charging

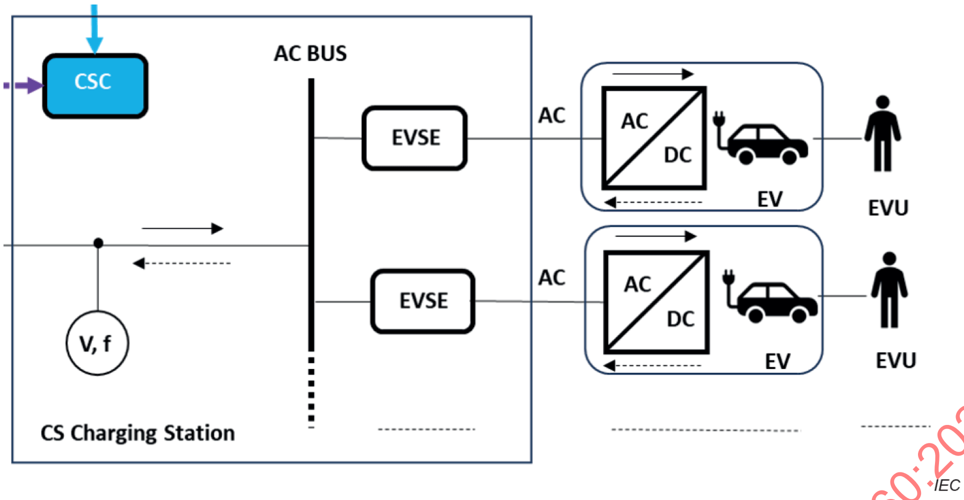


Figure 31 – Extract of charging configuration with AC bus, EVSE pass-through of AC, and AC charging with EV inverter

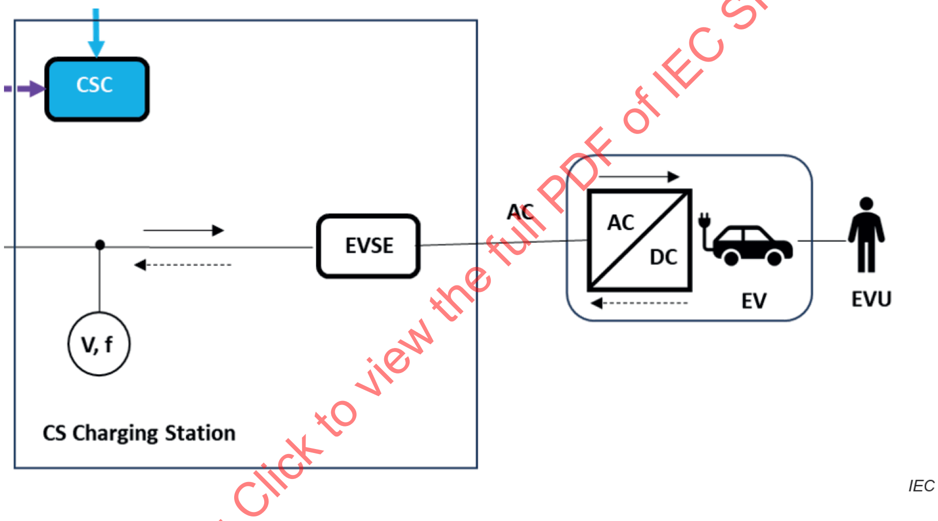


Figure 32 – Extract of charging configuration with no bus, EVSE pass-through of AC, and AC charging with EV inverter

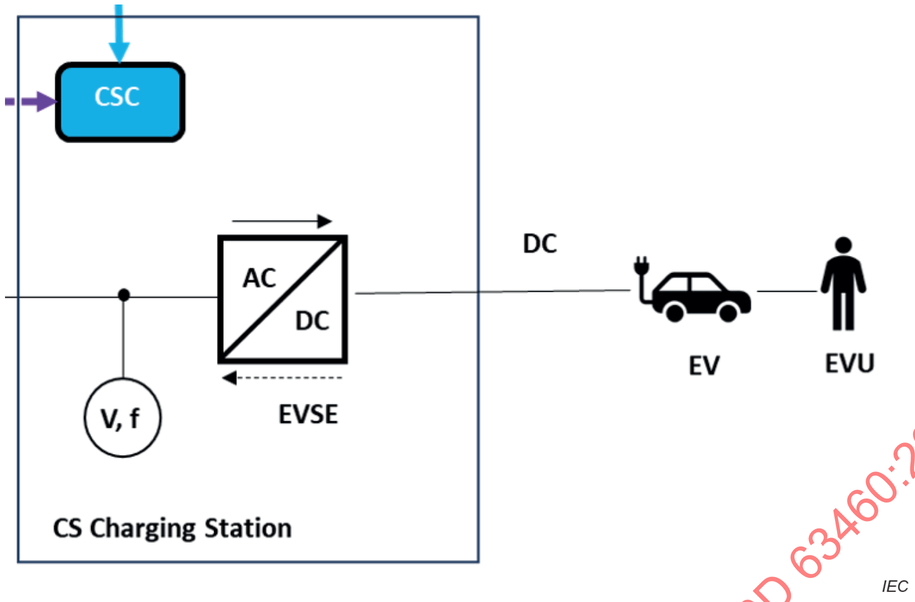


Figure 33 – Extract of charging configuration with no bus, EVSE inverter conversion AC to DC, and DC charging of EV

5.6.2 Grid code functions in DC charging/discharging

Most fast-charging EVSEs use DC changing (EV-DC), in which the inverter is in the EVSE. In this case, for grid code functions involving the management of reactive power, the charging station's inverter are used, and the EV-DC is a passive recipient of amps and voltage outputs.

5.6.3 Grid code functions in AC charging/discharging

Electric vehicles which use their inverters to receive AC power (EV-AC) might or might not be capable of executing some of the DER grid code functions autonomously, depending upon OEM decisions and potentially jurisdictional requirements. If the EV-AC is not capable or if the charging station cannot (decides not to) support autonomous management of the grid code functions by the EV-AC, then the EV-AC will also be treated as a passive recipient of AC power.

However, if an EV-AC is capable of autonomously executing some of the DER grid code functions and all relevant stakeholders support this capability, then additional settings, setpoints, and other parameters are provided to the EV-AC when it connects at a charging station. This implies that the information flows for these EV-ACs are different from the information flows for EV-DCs.

5.6.4 SAE J3072 for V2G AC discharging

V2G implies additional types of information that are exchanged between the EVSE and EV, because exporting power from the EV can pose different requirements. SAE has developed SAE J3072 to define those EVSE-EV information exchanges for AC discharging, and ISO 15118-20 is being updated to also include those (and possibly additional) data exchange capabilities. UL is developing UL 1741 Supplement C to provide the testing requirements for SAE J3072.

5.6.5 Information exchange requirements for EV-as-DER functions

The primary types of information exchanges include the following.

- Request for a specific DER function via the EVSE to the EV.
- Permission to use DER function (site permission, EV permission).

- Local parameters for the DER function (settings, curves, schedules, validation of data exchanges, error handling, etc.).
- Local constraints for the EV-as-DER (export limits, import limits, voltage limits, frequency limits, ROCOF limits, ride-through limits, etc.).
- Enable/disable DER function (EVSE and/or EV).
- Activation trigger of DER function (one or more grid values being monitored by the EVSE and/or EV).
- Monitoring and event logs of results of activated DER function, including both EVSE and EV logs.

5.6.6 Issues related to different configurations of charging stations

Some functions have to be able to operate autonomously since they have to respond in milliseconds to frequency and/or voltage measurements. Their settings would be set up ahead of time, then when they are enabled, they would become autonomously active based on local measurements. On the other hand, some functions might rely on communications for settings, such as an external entity changing active power consumption.

The access of EVSEs and/or EVs to power system measurements can be challenging, since different charging station configurations can make such access more difficult.

- Frequency measurements have to be directly accessible by EVSEs and/or EVs for all functions that respond to frequency
- Voltage might be set as a static offset from the PCC voltage measurement or might be calculated as a dynamic offset from the PCC voltage measurement.

6 EV-as-DER business cases

6.1 Business cases versus use cases

Business cases describe business objectives or purposes that could be provided through regulations, procedures, and/or technology. Typically, business cases stay at a high level to focus on what or why a process is needed, but not how that process might be implemented.

The goal of a business case is to include a clear and detailed explanation of the problem or opportunity that the stakeholders are facing, the goals and objectives of the potential solutions, and the identification of use cases that could be taken to achieve those goals. Business cases stay at a high level to focus on what and why this process is needed. The audience for the business base includes policymakers and other stakeholders.

Business cases are often used as a starting point for the development of one or more potential technology solutions through use cases, and are used to guide the design, development, testing, and deployment of those solutions.

Use cases describe the different ways the goals of business cases might be achieved and are used to determine how to achieve the business case goals. They include descriptions of the procedures and/or technologies involved and can include a list of actions or event steps typically defining the interactions between a role (actor) and a system to achieve the business case goals.

Often there is more than one possible technology or method for meeting those goals, and sometimes the same use case can meet or partially meet the goals of multiple business cases. In addition to technical challenges, regulatory issues can also impact which use cases might be more practical or timely to achieve.

6.2 Transmission EV-as-DER business cases for balancing authorities and transmission utilities

6.2.1 General

Some reliability business cases have been identified by the North American Electric Reliability Corporation (NERC), the California Mobility Centre (CMC), and the Western Electric Coordination Council (WECC) on how EVs and EVSEs could affect the reliability of the bulk power grid. Some excerpts[7] are showed in 6.2.2 to 6.2.7.

6.2.2 Business case: fault-induced delayed voltage recovery (FIDVR)

One study involved the use of simulation tools to model the impacts of EV charging on the problem of fault-induced delayed voltage recovery (FIDVR). The study found that some EV charger models responded in a manner that is grid friendly, meaning that their behaviour supported rapid restoration to a stable operating condition. At the same time, the study also found instances when other EV charger models responded in a manner that is grid unfriendly, meaning that their behaviour was detrimental to the restoration of stable operating conditions.

Recommendation: the study recommended testing and validation of the actual performance of newer generations of EV chargers and EVSE to improve the basis for future planning studies.

6.2.3 Business case: steady-state consumption control

"Grid-friendly" EV charging performance characteristics (either on-board or through EVSE) as they relate to BPS reliability are based on foundational power system stability concepts: transient stability, frequency stability, voltage stability, asymptotic stability, ride-through performance, and the essential BPS reliability services required to manage them. Historical electric end-use loads, such as resistive heating, lighting, and cooking were considered grid friendly because their electrical characteristic is constant impedance. As voltage dropped slightly, the device power draw would also reduce and hence support stable steady-state operation of the grid. Many, if not most, of today's electronically coupled loads do not exhibit this constant impedance characteristic; rather, their power electronic controls seek to maintain either a constant current level or a constant power level regardless of system voltage or frequency (within a normal operating band). When they seek to maintain a constant power level, these loads are not grid friendly from a grid dynamics and stability perspective. A constant power load exacerbates system instability because, during events on the system when voltage reduces, the load draws more current in order to maintain constant power. In contrast, constant current loads maintain a fixed level of current consumption, independent of voltage, which is "grid friendly." This behaviour allows power consumption to drop slightly when system voltages decline.

Recommendation: EV chargers and EVSEs should employ a steady-state control strategy that uses constant current control rather than constant power level control during normal operations.

6.2.4 Business case: power factor management

Many equipment standards often focus on power quality issues, and power factor typically will fall into this category (in addition to the harmonic distortion requirements). Specific equipment standards, such as the Society of Automotive Engineers (SAE) requirements, might dictate certain power factor (and harmonics) requirements for EVs and EVSEs. A reasonably tight control of power factor ensures that distribution system voltages can be managed appropriately and also ensures that the distribution system will not experience significant draws of reactive power unexpectedly, which could affect BPS voltage stability across the transmission-distribution interface where load tap changes automatically attempt to regulate voltage.

[7] NERC, CMC, WECC, "Electric Vehicle Dynamic Charging Performance Characteristics during Bulk Power System Disturbances", April 10, 2023, https://www.nerc.com/comm/RSTC/Documents/Grid_Friendly_EV_Charging_Recommendations.pdf

Recommendation: EV chargers and EVSEs should operate with a power factor (at fundamental frequency) of 0,985 or higher (leading or lagging). Power factor should be maintained for AC supply voltages from 80 % to 110 % of nominal voltage.

6.2.5 Business case: frequency response (active power-frequency control)

EVs and EVSEs can support grid reliability by actively contributing to system frequency response. System frequency response involves autonomous minute changes in active power (active current) to control system frequency. The ability of end-use loads (and generators) to support grid frequency is a core tenet of overall grid reliability. All newly interconnecting generating units on the BPS are required to have active power-frequency controls. Active power consumption should be proportional and in opposition to changes in frequency measured at the EV charger or EVSE. This type of response is conducive to overall frequency stability and frequency response of an interconnected synchronous power system. Proportional reduction in EV charging loads and EVSE power draw supports control of grid frequency by reducing power consumption during low frequency conditions.

Recommendation: EV chargers and EVSEs should have a programmable current consumption droop characteristic with a programmable range and a default value of 5 %.

6.2.6 Business case: underfrequency load shedding

It is also critical to have load response coordinated with underfrequency load shedding (UFLS) actions. This would enable these loads to support grid frequency response and return to service seamlessly with very minimal impact to end-user experience. Response times to changes in measured frequency should occur within 100 ms to 200 ms. Frequency should be measured over a time window (e.g., multiple electrical cycles); frequency should not be measured instantaneously for these types of applications. The first step of UFLS is typically set around 59,3 Hz (for North America with 0,7 Hz change from nominal).

Recommendation: EV chargers and EVSEs should be programmed with the capability to rapidly reduce current consumption for severe frequency excursions before UFLS levels are reached.

6.2.7 Business case: ride-through performance: remaining connected during grid disturbances

Disconnection and connection settings are key to ensuring stable grid frequency and voltage support during loss of generation events and grid faults. The behaviour of large loads (or large aggregate levels of loads) need to be coordinated with distribution and transmission level protections and safety net schemes put in place. Some degree of randomization (or ranges of adjustability) can help with load performance diversity; however, reasonable bounds ought to be established based on grid needs. Ride-through performance can be categorized loosely into the following modes of operation.

- Continuous operation: steady-state operations or minor grid disturbances (e.g., distant faults and generator trips, line switching) where EV chargers and EVSEs should remain connected to the grid and consuming constant current.
- Ride-through operation during large grid disturbances: response to larger grid disturbances (e.g., close-in or three-phase faults, delayed clearing protection system operations, large frequency excursions, other natural disasters) where EV chargers and EVSEs should use their power electronics to dynamically control current consumption based on measured terminal conditions in a way that supports grid reliability.
- Severe and unexpected grid conditions: response to extreme grid events (e.g., system separation, cascading outages, blackouts) where EV chargers and EVSEs should disconnect from the grid and return using "cold load pickup" protocols.

Recommendation: each EV charger and EVSE should be programmed to respond autonomously to their measured terminal conditions and support grid reliability. Grid-friendly performance characteristics in this time frame should not require any advanced communications between devices or with the grid operator(s); rather, converter protection and controls should respond automatically to modify EV charging behaviour and operation. Details regarding the exact manner in which EV chargers and EVSEs should respond is an important area to address in future modelling and validation efforts.

6.3 Distribution EV-as-DER business cases for MV and LV grid support

6.3.1 General

Although EVs have batteries and inverters like stationary energy storage systems (ESS), their fundamental purpose is to provide transportation, not grid services. However, they typically spend large percentages of their time parked and connected to the grid through chargers termed electric vehicle service elements (EVSEs) and could provide grid services at those times, so long as they were ready (adequately charged) when needed by their drivers.

The purposes of the grid services could fall into the following categories:

- Minimize the impact on the grid of many EVs charging simultaneously, such as potential thermal overloads or voltage sags.
- Provide benefits to the grid by improving grid safety, reliability, and efficiency, such as participating in frequency and voltage ride-through events, providing voltage support, and in aggregate, providing frequency support to the transmission system.
- Provide benefits to EV owners, such as acting on incentives for providing certain grid services that could improve grid reliability and efficiency.
- Provide societal benefits, such as providing alternatives to grid services that would otherwise need to be provided by fossil fuel generators.

Although DER can provide many grid support functions, some of the key functions that could be provided by charging station management system (CSMS) and individual EVs for providing these business case benefits include the business cases of 6.3.2 to 6.3.8.

6.3.2 Business case: manage potential overload situations via EV peak power limiting

For the peak power limiting of electric vehicles (planned or emergency load reduction), the DSO determines that thermal overload constraint of specific circuits is required for the near future. Since these circuits contain charging stations for EVs, the DSO issues a load import limit schedule or command, containing the limit of active power import permitted during the constrained times. The charging station management system (CSMS) then determines if the EVs charging during that time would exceed the import limit. If so, it can request any non-EV DER to increase generation to cover the EV loads. If such a DER does not exist or cannot make up the difference, the CSMS reviews any contractual obligations for the EVs (e.g., emergency vehicles could continue rapid charging) or financial constraints (e.g., an EV owner requests rapid charging), and then determines which other EVs would have their rate of charging slowed down.

6.3.3 Business case: provide benefits to EV owners via vehicle-to-home (V2H)

The EV provides backup power during power outages and/or power to the home during on-peak, high tariff times. The regulations for V2H could be very similar to those currently provided for stationary storage systems in the home. For instance, unless the vehicle is charged from "green" sources, the power cannot be exported to grid except under special circumstances or provisions.

6.3.4 Business case: provide benefits to the grid via vehicle-to-grid (V2G)

The EV exports power to the grid when additional generation is needed for emergency or efficiency reasons. The power can be used either in the local electric power system (EPS) to support local loads, or, if authorized, exported to the area EPS, with similar regulations to stationary storage. SAE has developed J3072 for AC discharging, for which testing requirements are being developed in UL 1741 Supplement C.

6.3.5 Business case: improve grid efficiency through coordinated charge/ discharge of EVs

Coordinated charge/discharge of EVs is designed to ensure desired state of charge is reached at the requested time. The CSMS receives information from the EV's owner that informs the CSMS the time by when the EV is required to reach a specified state of charge. The CSMS then takes this information into account as it determines when and how fast to charge the EV. Considerations include not only the current, on-peak/off-peak, and forecast price of energy, but also any demand charges, load import limits, use of the EV to provide other ancillary services, etc.

6.3.6 Business case: provide voltage support via volt-watt response by EVs

The CSMS would monitor the voltage at the PCC. If the voltage at the PCC exceeds the voltage limits, the CSMS would allocate the proportion of the Volt-Watt response to each EV (and its EVSE) currently charging, and the EVSEs would decrease the charging rate of the connected EVs according to this Volt-Watt proportion. Although this use case only is for decreasing active power of those EVs charging, the same criteria could be used for any V2G EVs that are able to increase active power by discharging.

6.3.7 Business case: provide reactive power support via watt-var function

While IEEE Std 1547-2018 and California's Rule 21 describe the function, SAE J3072 describes the interoperability requirements for EVs and EVSEs to establish the curves and other parameters for the watt-var function. The requirements require the interactions between the EV, the EVSE, and an energy management system (EMS) to be automated and for that automation to be tested separately for the individual types (EVSEs and EVs), since it would be impossible to require every EV to be tested with every EVSE. How to automate this interaction between different types of equipment, but yet separately test the automation has not been defined, but is addressed by UL 1741 SC.

6.3.8 Business case: help meet export and/or import limits via the limit active power export/import function

While IEEE Std 1547-2018 and California's Rule 21 describe the function, SAE J3072 describes the interoperability requirements for EVs and EVSEs to establish the parameters for the limit active power function. The requirements require the interactions between the EV, the EVSE, and an energy management system (EMS) to be automated and for that automation to be tested separately for the individual types (EVSEs and EVs), since it would be impossible to require every EV to be tested with every EVSE. How to automate this interaction between different types of equipment, but yet separately test the automation has not been defined, but is addressed by UL 1741 SC.

7 EV-as-DER use cases

7.1 General

7.1.1 Overview

Business cases are how to justify why EVs might be used as DERs. Use cases identify possibly multiple ways how EVs might be used to meet the business case requirements.

The use cases in this document address the information exchanges required between the different roles (actors) for implementing the different grid support functions. These use cases do not identify why a particular grid function is being implemented – that is left to specific business cases.

The use cases of 7.1.2 to 7.1.7 were identified as highly important during a study with the California Public Utilities Commission (CPUC).

7.1.2 Use case E1: EV peak power limiting on demand

For the peak power limiting of electric vehicles (planned or emergency load reduction), the DSO determines that thermal overload constraint of specific circuits is required for the near future. Since these circuits contain charging stations for EVs, the DSO issues a load import limit schedule or command, containing the limit of active power import permitted during the constrained times. The charging station management system (CSMS) then determines if the EVs charging during that time would exceed the import limit. If so, it can request any non-EV DER to increase generation to cover the EV loads. If such a DER does not exist or cannot make up the difference, the CSMS reviews any contractual obligations for the EVs (e.g., emergency vehicles could continue rapid charging) or financial constraints (e.g., an EV owner requests rapid charging), and then determines which other EVs would have their rate of charging slowed down.

If the request for limiting load is more general, for instance due to the lack of bulk power generation, a demand-response program could be initiated to request EVs to stop or to slow down charging based on some type of incentive, such as a financial incentive (e.g., more favourable tariff, direct compensation, etc.)

7.1.3 Use case E4: volt-watt response by EVs

The CSMS would monitor the voltage at the PCC. If the voltage at the PCC exceeds the voltage limits, the CSMS would allocate the proportion of the volt-watt response to each EV (and its EVSE) currently charging, and the EVSEs would decrease the charging rate of the connected EVs according to this volt-watt proportion.

Although this use case only is for decreasing active power of those EVs charging, the same criteria could be used for any V2G EVs that are able to increase active power by discharging.

7.1.4 Use case E8: coordinated charge/discharge of EVs

The CSMS receives information from the EV's owner that informs the CSMS the time by when the EV is required to reach a specified state of charge. The CSMS then takes this information into account as it determines when and how fast to charge the EV. Considerations include not only the current, on-peak/off-peak, and forecast price of energy, but also any demand charges, load import limits, use of the EV to provide other ancillary services, etc.

7.1.5 Use case E9: V2G EV as DER

While IEEE Std 1547-2018 and California's Rule 21 describe the function (enter service), SAE J3072 describes the interoperability requirements for EVs and EVSEs for permission to discharge (and ISO 15118-20 is being updated to include those interoperability V2G requirements). The functions required include the IEEE Std 1547 permission to enter service function and the set active power function. The requirements require the interactions between the EV, the EVSE, and an energy management system (EMS) to be automated and for that automation to be tested separately for the individual types (EVSEs and EVs), since it would be impossible to require every EV to be tested with every EVSE. How to automate this interaction between different types of equipment, but yet separately test the automation has not been defined, but is being addressed by UL 1741 SC.

7.1.6 Use case E12: watt-var function

While IEEE Std 1547-2018 and California's Rule 21 describe the function, SAE J3072 describes the interoperability requirements for EVs and EVSEs to establish the curves and other parameters for the watt-var function. The requirements require the interactions between the EV, the EVSE, and an energy management system (EMS) to be automated and for that automation to be tested separately for the individual types (EVSEs and EVs), since it would be impossible to require every EV to be tested with every EVSE. How to automate this interaction between different types of equipment, but yet separately test the automation has not been defined, but is being addressed by UL 1741 SC.

7.1.7 Use case E15: limit active power export function

IEEE Std 1547-2018 and California's Rule 21 describe the function, SAE J3072 describes the interoperability requirements for EVs and EVSEs to establish the parameters for the limit active power function. The requirements require the interactions between the EV, the EVSE, and an energy management system (EMS) to be automated and for that automation to be tested separately for the individual types (EVSEs and EVs), since it would be impossible to require every EV to be tested with every EVSE. How to automate this interaction between different types of equipment, but yet separately test the automation has not been defined, but is being addressed by UL 1741 SC.

7.2 Use case: limit active power import operational function

7.2.1 Name of use case

As an example of a use case, the limit active power import use case is described.

Use case identification		
ID	**Area(s)/Domain(s)/Zone(s)**	**Name of use case**
	Active power operational functions	Limit active power import operational function

7.2.2 Version management

Version No.	Date	Name of author(s)	Changes	Approval status
0.1	2020-04-08	fmc	Creation of the use case	WD working document

7.2.3 Scope and objectives of use case

Scope and objectives of use case	
Scope	Active power import (load) is limited to a preset value at a specific point of connection such as the PCC by using active power output of generation and/or storage DER to offset the EV charging loads if possible. If not, derate the EV charging rates.
Objective(s)	Minimize import of active power into the grid into an EV facility if the excessive load could cause grid problems.
Related business case(s)	Minimize potential excess active power on the distribution system and potential brownouts or blackouts.

7.2.4 Narrative of the use case

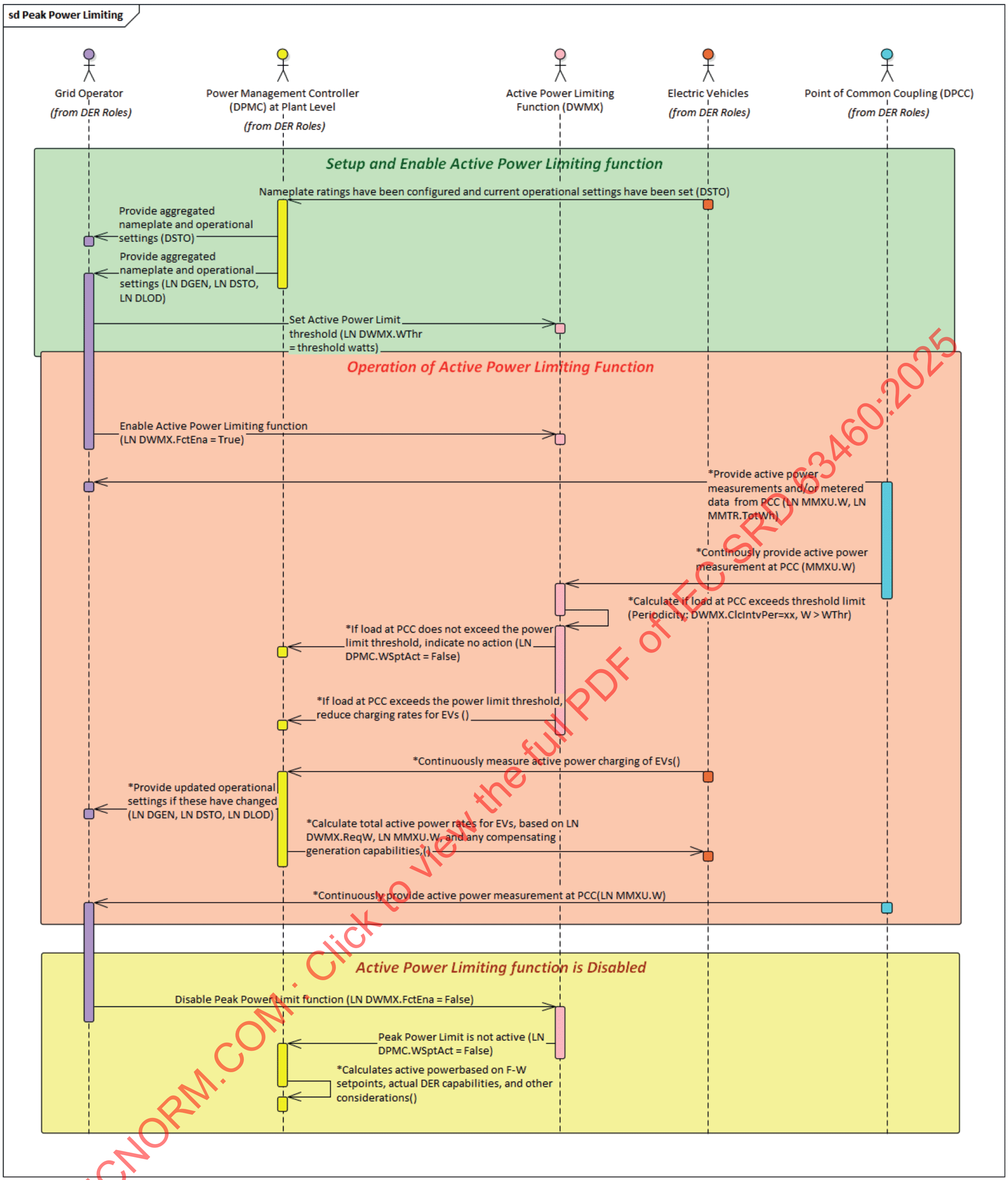
Narrative of use case
Short description
The net active power imported from the grid are not permitted to exceed the active power limit.
Complete description

7.2.5 Scenario steps

Step No	Name of process/activity	Description of process/activity	Information producer	Information receiver	Information exchanged (IDs)
0	Retrieve nameplate and current operational data	It is assumed that the nameplate ratings have been configured and are available, and that current operational settings have been set before this function is enabled	DER	Power management controller or CEM	See preconditions
1	Set active power import limit	Set active power import limit at the PCC	Grid operator	Active power limiting function	DWMX.WLimSpt = limit of import watts
2	Enable active power limiting function	Enable peak power limiting function	Grid operator	Active power limiting function	DWMX.FctEna = True
3	Measure imported active power at PCC	Continuously measure load at PCC	Point of common coupling (PCC)	Active power limiting function	MMXU.W = watts at PCC (negative = load)
4	Measure generation increase and load reduction capabilities	Continuously measure active power charging of EVs, and the generation capabilities of generation with the facility	DER	Power management controller	MMXU.W = watts of DLOD plus DGEN
5	Determine most effective and least costly method for maintaining the active power within the requested limit	Calculate if the active power output at the PCC exceeds the import limit (W > DWMX.WLimSpt). If not, indicate no action. If so, request most efficient and least costly method for remaining within the import limit.	Active power limiting function	Power management controller	DWMX.ReqW.q = false or DWMX.ReqW = (W – WLimSpt), q = True
6	Set active power for each DER: DGEN, DSTO, DLOD	Calculate the actual active power output for each type of DER	Power management controller	DER	DPMC.OutWSet = actual active power for storage

7.2.6 Use case diagrams – Sequence diagram

Figure 34 illustrates the active power limiting functions for electric vehicles, including the EV plugging into the EVSE (green area), the function being enabled and determining if the power should be limited (orange area), and the function being disabled (yellow area).



IEC

Figure 34 – Active power limiting sequence diagram

7.3 Use cases: frequency-active power (frequency-watt) operational functions

7.3.1 Overview of frequency-active power (frequency-watt) operational functions

There are multiple different purposes that the frequency-active power support functions can provide. The first two would necessarily use the frequency-active power function autonomously, the third requires direct commands from a balancing authority, while the others might be autonomous or might rely on external signals.

- Frequency sensitivity mode (FSM): the frequency rapidly decreases or increases beyond normal limits (e.g. due to a loss of a large generator and possibly within a frequency ride-through situation). The frequency-active power function is used to sharply and rapidly increase (or reduce) power, so that the DER goes to WMax (or ChaWMax) using the slope (WGra) established as a percent of WMax (or ChaWMax) to try to bring the frequency within normal limits. See Figure 35.

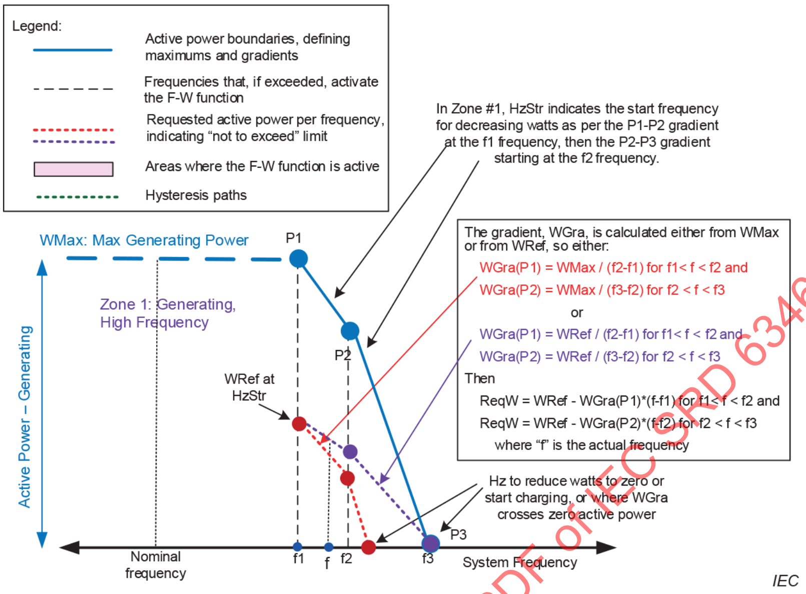


Figure 35 – For zone 1 frequency sensitivity, potential use of WMax or WRef to determine the gradient

- Frequency droop or "primary frequency response": droop is a control mode used for AC electrical power generators to maintain the frequency within the normal operating zone, focused on returning the frequency to its nominal value (e.g. 50 Hz or 60 Hz). Specifically, the power output of a generator reduces as the line frequency increases above nominal frequency, and vice versa. It is commonly used as the speed control mode of the governor of a prime mover driving a synchronous generator connected to an electrical grid. With droop speed control, when the grid is operating at the maximum normal operating frequency (e.g. 60,6 Hz), the prime mover's power is reduced to 0 % (cease-to-energize), and when the grid is at the minimum normal operating frequency (e.g. 58,5 Hz), the power is set to 100 % (WMax), and intermediate values at other operating frequencies. Although usually associated with synchronous generators connected at the bulk power level which provide droop by changing the speed (RPM) of their rotors, inverter-based systems connected at any level might also be able to provide equivalent droop capabilities, in which the active power output of the inverter is reduced (increased) as the frequency increases (decreases) from nominal frequency, based on a frequency-active power curve. This curve might be linear or might be more complex (but still monotonic).
- Secondary frequency response: the frequency is managed by the balancing authority which sends active power signals every 4 s to 10 to all DER participating in the balancing or automatic generation control (AGC) ancillary service. This function cannot be performed autonomously.
- Tertiary or spinning reserve frequency response: the balancing authority requests additional active power to be available within a few seconds or minutes. The balancing authority might provide an actual watt value, or the DER might be expected to ramp as rapidly as possible to its maximum watt output upon receiving the signal. The reverse situation, namely requiring additional load immediately, might also be possible.

- Fast frequency response (FFR) or frequency sensitivity: during frequency emergency situations, the DER responds to frequency or ROCOF (rate of change of frequency) excursions beyond normal limits by rapidly changing active power to try to reverse the excursion and bring the frequency back within the normal range. Detailed performance requirements are defined in IEEE 2800-2022.

  FFR requires specific settings of the frequency-active power capability to respond to frequency changes very rapidly by increasing or decreasing active power. When the transmission and distribution system frequency is outside of a pre-defined frequency deadband range, DERs inject or absorb active power to help push system frequency back within the frequency deadband. FFR systems respond to changes in frequency autonomously in a timeframe of less than one second. This autonomous DER capability requires specific settings of the frequency-watt function (currently only having Rule 21 settings for the droop capability) to meet these more extreme responses.

- Synthetic or artificial inertia: synchronous generators naturally provide inertia to changes in frequency as their rotors are forced to slow down or speed up. Inverter-based systems do not have this natural inertia since they can respond almost instantaneously to frequency changes. However, inertia is useful to slow changes in frequency (df/dt) with the aim of preventing sharp or rapid changes in frequency. Therefore, the frequency-active power function can be used by inverter-based systems to counter frequency changes and thus provide artificial inertia. This synthetic inertia function is not specifically focused on returning the frequency toward its nominal value, but rather providing transient stability. This function might be autonomous or might require direct and rapid commands from a utility (e.g. fast reserve).

- Frequency static boundary response: The DER needs to remain within the frequency-active power boundaries, but it is not required to "go to" the boundary. This function could be of particular use within microgrids to avoid DERs from causing frequency problems. See Figure 36.

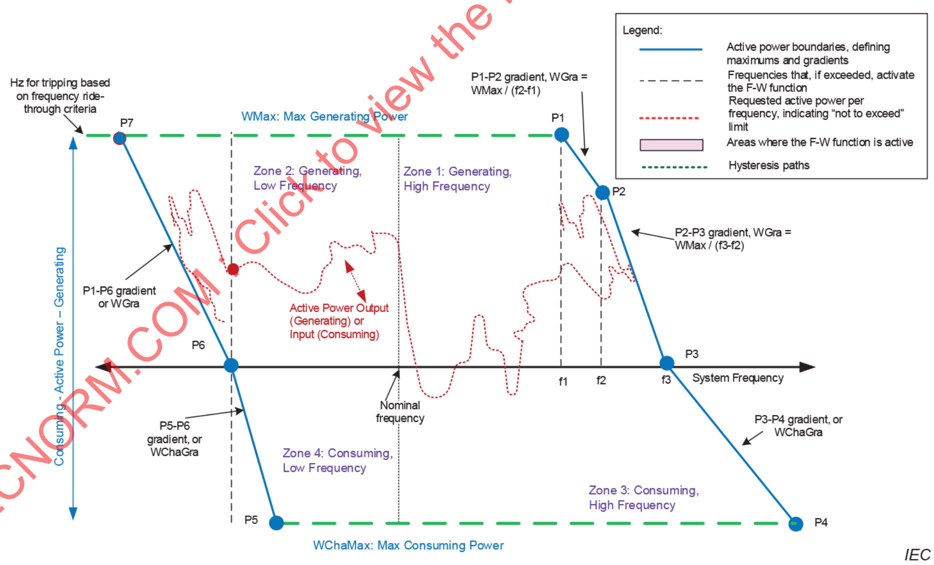


Figure 36 – Frequency-active power constrained by static boundary: DER to remain within the boundaries of frequency-active power curves

There can be multiple frequency-active power operational functions configured into an DER. For example, the desired frequency-active power settings might be different on-peak versus off-peak, or different when islanded versus when grid connected. Some might be enabled at the same time: for instance, the frequency-active power sensitivity mode might be permanently enabled, while other frequency-active functions might be enabled as needed.