



BSI Standards Publication

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

National foreword

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

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ELECTROTECHNICAL
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CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
0.1 Objective	8
0.2 EVs, utilities, and charging.....	8
0.3 EV standardisation efforts in the IEC	9
0.4 EV use cases	11
0.5 Purpose of this document	12
1 Scope	13
2 Normative references	13
3 Terms, definitions and abbreviated terms	13
3.1 Terms and definitions.....	13
3.2 Abbreviated terms.....	16
4 Overview of the DER environment and functions	17
4.1 DER Stakeholders	17
4.2 DERs within a facility or microgrid.....	18
4.3 Utility and aggregator interactions with DER facility	19
4.4 EV interactions within the DER environment	20
4.5 List of DER functions potentially applicable to EVs	22
5 Historical overview of different EV architectures applicable to a DER environment	31
5.1 SGAM interoperability layers as applicable to EVs	31
5.2 E-mobility systems architectures.....	34
5.2.1 Overview	34
5.2.2 E-mobility in IEC TR 61850-90-8:2016	34
5.2.3 EV Integration in IEC SRD 63268:2020.....	35
5.2.4 EV architectures in the IEC 63110 series.....	38
5.2.5 EV architecture (IEC 63382 series).....	40
5.2.6 EV architecture from the IEC 63380 series	41
5.2.7 EVs in buildings architectures from IEC SC 23K	41
5.2.8 EV architectures in SAE	42
5.2.9 OCPP updates.....	43
5.2.10 ISO 15118-20 updates.....	44
5.3 E-mobility roles	44
5.3.1 E-mobility role definitions from the IEC 63110 series	44
5.3.2 EV roles for DER use cases.....	47
5.4 EV-related standards	49
5.4.1 EV-related standards organizations	49
5.4.2 Standards and documents including EV-related information exchange requirements	49
5.5 EV as DER architecture using the IEC 61850-7-420 information model	50
5.6 EV-DC and EV-AC charging and discharging	51
5.6.1 V2G EV-charging station configurations.....	51
5.6.2 Grid code functions in DC charging/discharging.....	54
5.6.3 Grid code functions in AC charging/discharging	54
5.6.4 SAE J3072 for V2G AC discharging	54
5.6.5 Information exchange requirements for EV-as-DER functions	54
5.6.6 Issues related to different configurations of charging stations	54

6	EV-as-DER business cases	55
6.1	Business cases versus use cases	55
6.2	Transmission EV-as-DER business cases for balancing authorities and transmission utilities	56
6.2.1	General	56
6.2.2	Business case: fault-induced delayed voltage recovery (FIDVR)	56
6.2.3	Business case: steady-state consumption control	56
6.2.4	Business case: power factor management	56
6.2.5	Business case: frequency response (active power-frequency control)	57
6.2.6	Business case: underfrequency load shedding	57
6.2.7	Business case: ride-through performance: remaining connected during grid disturbances	57
6.3	Distribution EV-as-DER business cases for MV and LV grid support	58
6.3.1	General	58
6.3.2	Business case: manage potential overload situations via EV peak power limiting	58
6.3.3	Business case: provide benefits to EV owners via vehicle-to-home (V2H)	58
6.3.4	Business case: provide benefits to the grid via vehicle-to-grid (V2G)	59
6.3.5	Business case: improve grid efficiency through coordinated charge/discharge of EVs	59
6.3.6	Business case: provide voltage support via volt-watt response by EVs	59
6.3.7	Business case: provide reactive power support via watt-var function	59
6.3.8	Business case: help meet export and/or import limits via the limit active power export/import function	59
7	EV-as-DER use cases	59
7.1	General	59
7.1.1	Overview	59
7.1.2	Use case E1: EV peak power limiting on demand	60
7.1.3	Use case E4: volt-watt response by EVs	60
7.1.4	Use case E8: coordinated charge/discharge of EVs	60
7.1.5	Use case E9: V2G EV as DER	60
7.1.6	Use case E12: watt-var function	61
7.1.7	Use case E15: limit active power export function	61
7.2	Use case: limit active power import operational function	61
7.2.1	Name of use case	61
7.2.2	Version management	61
7.2.3	Scope and objectives of use case	61
7.2.4	Narrative of the use case	61
7.2.5	Scenario steps	62
7.2.6	Use case diagrams – Sequence diagram	62
7.3	Use cases: frequency-active power (frequency-watt) operational functions	63
7.3.1	Overview of frequency-active power (frequency-watt) operational functions	63
7.3.2	Use case: frequency-active power as FSM operational function	66
7.3.3	Use case: frequency droop or "primary frequency response" operational function	68
7.3.4	Use case: secondary frequency response (AGC) operational function	69
7.3.5	Use case: tertiary or spinning reserve frequency response operational function	70
7.3.6	Use case: synthetic Inertia operational function	70

7.4	Use cases: ride-through operational functions for charging stations	72
7.4.1	Use case: frequency ride-through operational functions for charging stations.....	72
7.4.2	Use case: voltage ride-through operational functions for charging stations.....	73
8	Gaps of EV-as-DER in IEC e-mobility standards	73
8.1	Overview of EV-as-DER gaps	73
8.2	EV-as-DER-related standards, inclusion of V2G and/or V1G as controllable load	75
8.2.1	EV-as-DER in standards defining DER functional requirements	75
8.2.2	EV-as-DER in communication standards.....	75
8.2.3	EV-as-DER OEM telematics	75
8.3	Balancing authority and/or transmission utility business and use cases	75
8.4	Distribution system operator business and use cases	76
8.5	IEC 61850 and/or CIM information model requirements for each use case	77
8.6	EV-as-DER protocols	77
8.7	Testing of EV-as-DER stationary equipment	77
8.8	Testing/Attestation of EVs to meet EV-as-DER requirements	77
9	Next steps	77
	Bibliography.....	78
	Figure 1 – EV as DER architecture within the larger grid environment.....	10
	Figure 2 – IEC Standards for EV grid support and charging management	11
	Figure 3 – Illustrations of ECP, PoC, PCC, RPA, local EPS, and area EPS.....	14
	Figure 4 – Key DER stakeholders	18
	Figure 5 – DER within a facility: residence, campus, or plant, potentially as a microgrid, with flexibility market	19
	Figure 6 – Utility and aggregator interactions with DER facilities or directly with DERs	20
	Figure 7 – DER architecture with a focus on charging stations	21
	Figure 8 – Smart grid architecture model (SGAM).....	31
	Figure 9 – GWAC Stack and SGAM	33
	Figure 10 – Core communication protocols and information models for EV-as-DER	33
	Figure 11 – E-mobility SGAM view (out of date).....	34
	Figure 12 – EV-related IEC 61850-90-8 data objects	35
	Figure 13 – Addition interfaces to support EV mapped to the SGAM communication layer (in case of H&B).....	36
	Figure 14 – Marketplace interfaces mapped to the SGAM information layer	37
	Figure 15 – IEC entities involved in supporting marketplace interfaces	38
	Figure 16 – E-mobility standards landscape within the IEC	39
	Figure 17 – Message flow between IEC TC 69 standards (not including TC 57 standards)	39
	Figure 18 – Information flow between actors based on the IEC 61850-7-420 information model	40
	Figure 19 – IEC 63382 diagram of actors and IEC standards responsible for the communications.....	40
	Figure 20 – EV architecture in the IEC 63380 series	41
	Figure 21 – EVs in buildings architecture from IEC SC 23K	42

Figure 22 – SAE PEV standards for communication, interoperability, and security	43
Figure 23 – OCPP topology for DER control via the charging point operator (CPO)	43
Figure 24 – EV roles (actors) identified in the IEC 63110 series	44
Figure 25 – Example of scope of key roles	45
Figure 26 – Roles for charging stations applicable to a DER environment	48
Figure 27 – Communication protocols associated with EV roles in a DER environment	49
Figure 28 – EV as DER architecture	51
Figure 29 – Overview of charging configuration with DC bus, with DC/DC charging	52
Figure 30 – Extract of charging configuration with AC bus, EVSE inverter conversion AC to DC, and DC charging	52
Figure 31 – Extract of charging configuration with AC bus, EVSE pass-through of AC, and AC charging with EV inverter	53
Figure 32 – Extract of charging configuration with no bus, EVSE pass-through of AC, and AC charging with EV inverter	53
Figure 33 – Extract of charging configuration with no bus, EVSE inverter conversion AC to DC, and DC charging of EV	54
Figure 34 – Active power limiting sequence diagram	63
Figure 35 – For zone 1 frequency sensitivity, potential use of WMax or WRef to determine the gradient	64
Figure 36 – Frequency-active power constrained by static boundary: DER to remain within the boundaries of frequency-active power curves	65
Figure 37 – Sequence diagram: frequency-watt sensitivity operational function for EV- DC	67
Figure 38 – Sequence diagram: frequency-watt sensitivity operational function for EV- AC	68
Figure 39 – Frequency droop typical curve	69
Figure 40 – Sequence diagram: frequency ride-through grid code function for charging stations	73
Figure 41 – Diagram of EV-as-DER gaps	74
Table 1 – DER functions for EV environment: roles and information exchanges	22
Table 2 – Roles applicable to EVs in a DER environment	45
Table 3 – EV charging station configurations	51

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

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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 1547TM-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 series¹ 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.

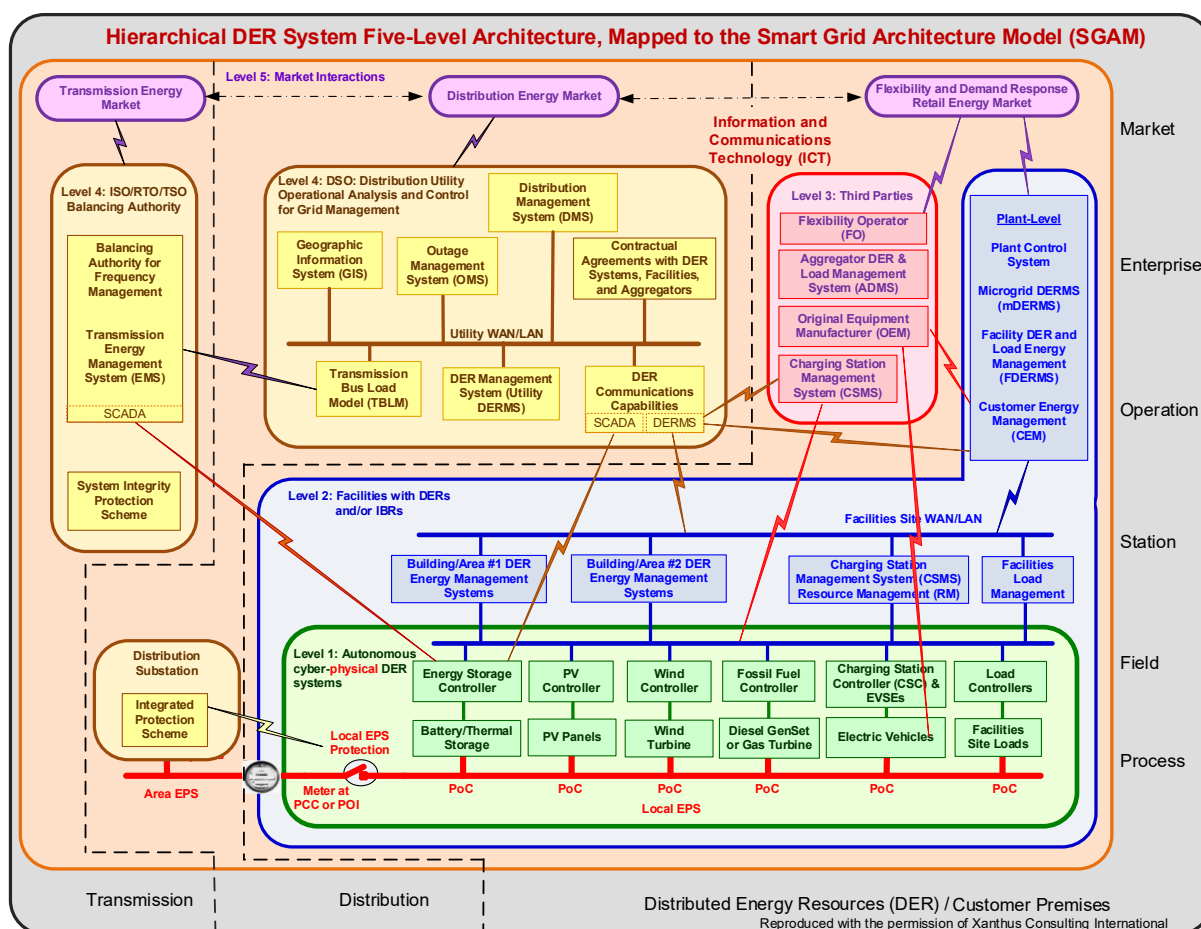


Figure 1 – EV as DER architecture within the larger grid environment

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.

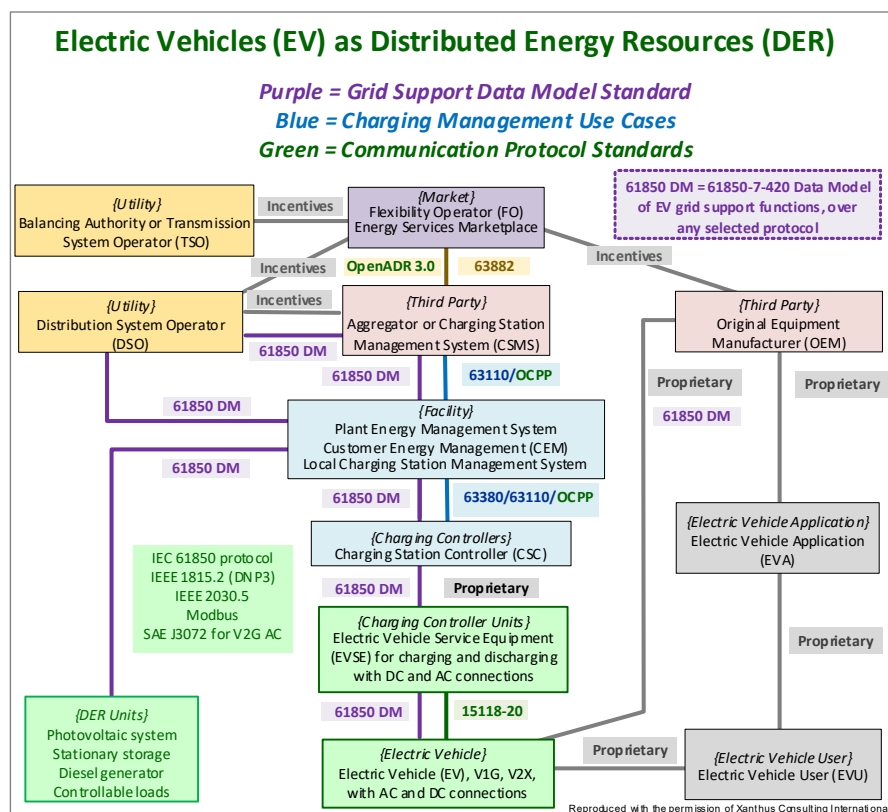


Figure 2 – IEC Standards for EV grid support and charging management

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 taken 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.

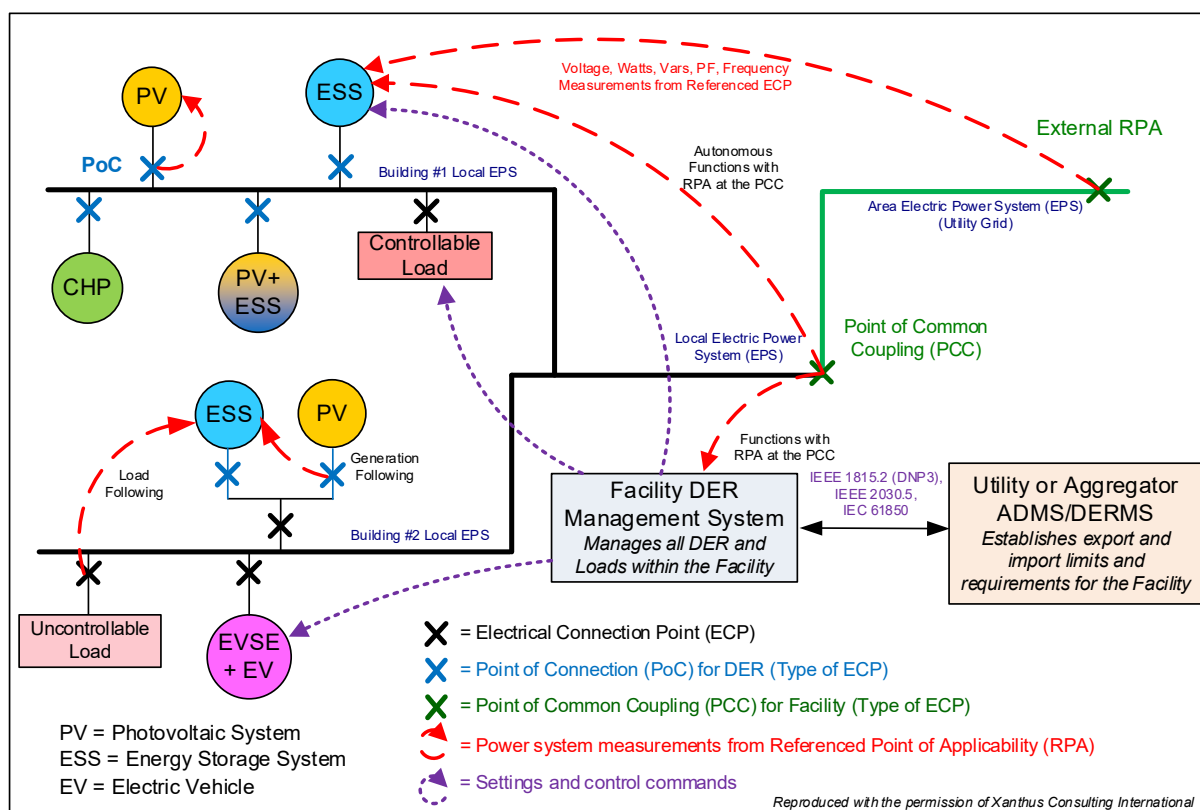


Figure 3 – Illustrations of ECP, PoC, PCC, RPA, local EPS, and area EPS

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.

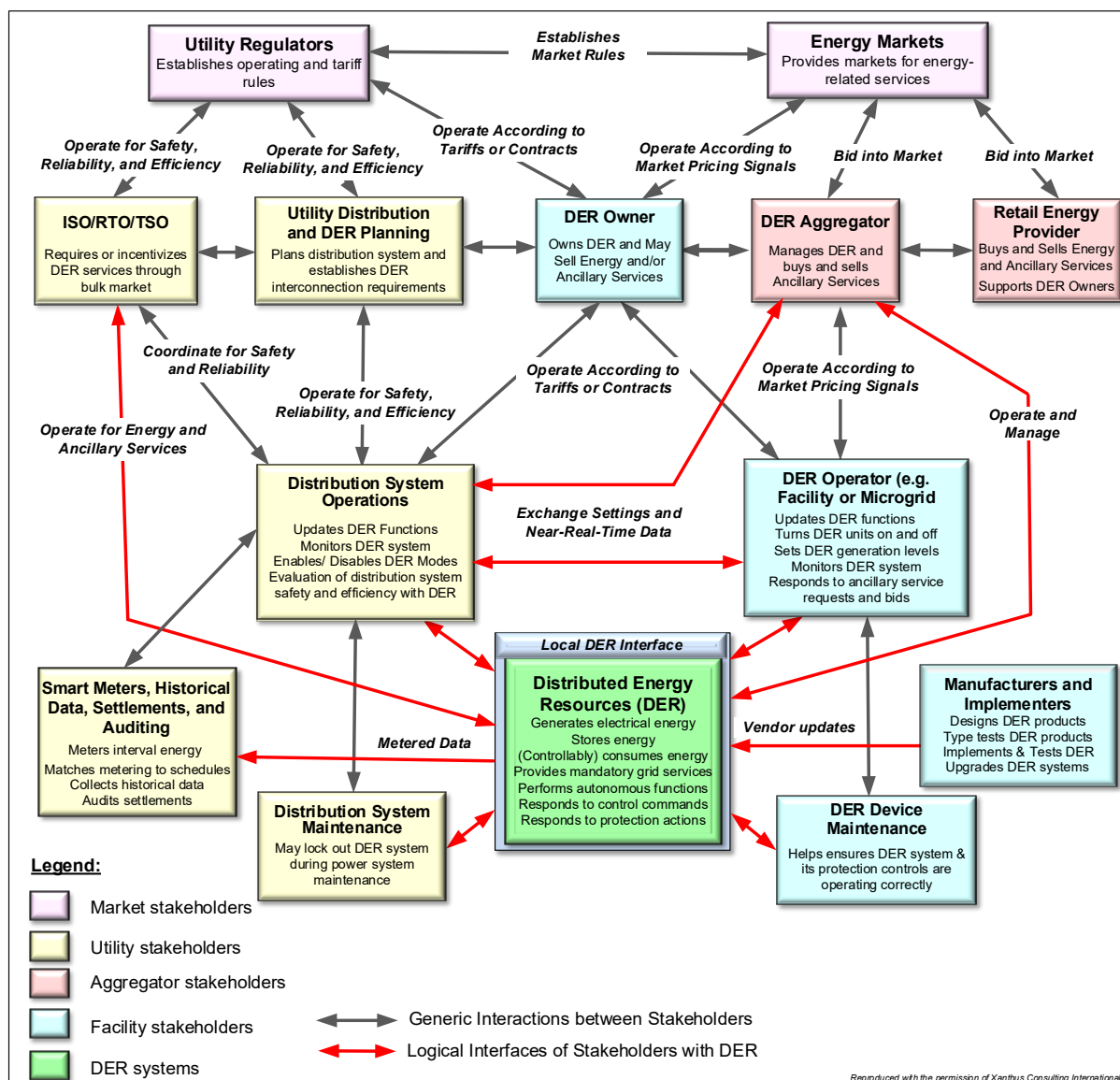


Figure 4 – Key DER stakeholders

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.

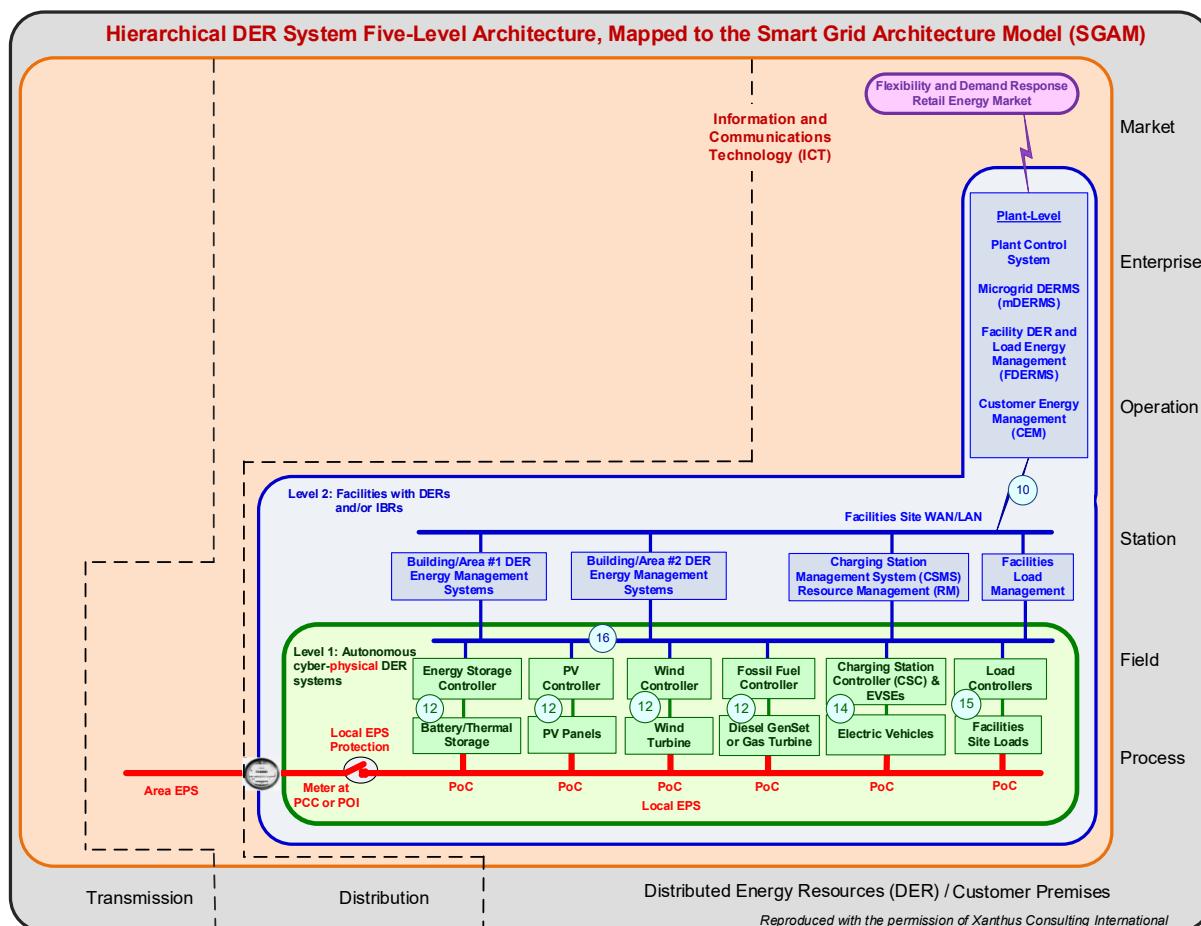


Figure 5 – DER within a facility: residence, campus, or plant, potentially as a microgrid, with flexibility market

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.

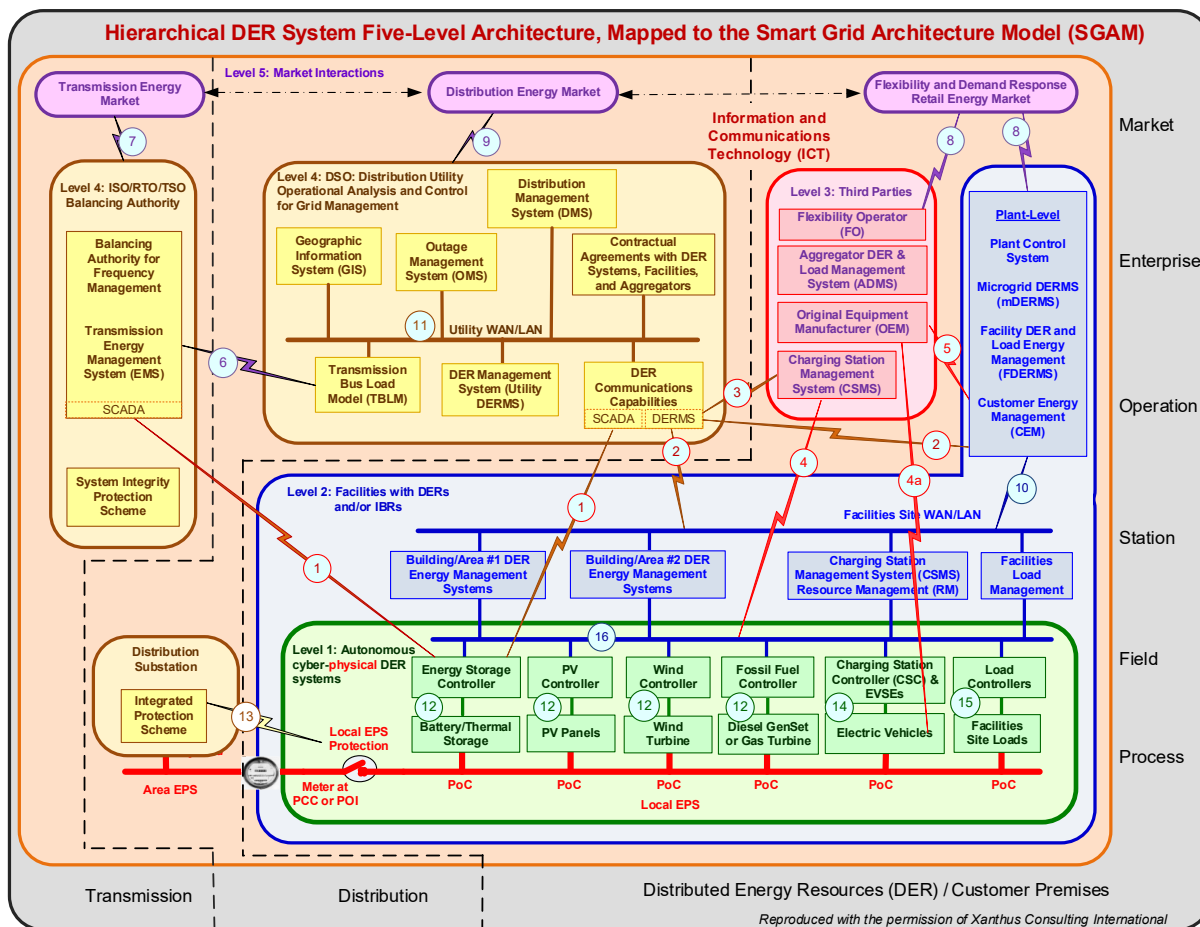


Figure 6 – Utility and aggregator interactions with DER facilities or directly with DERs

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.

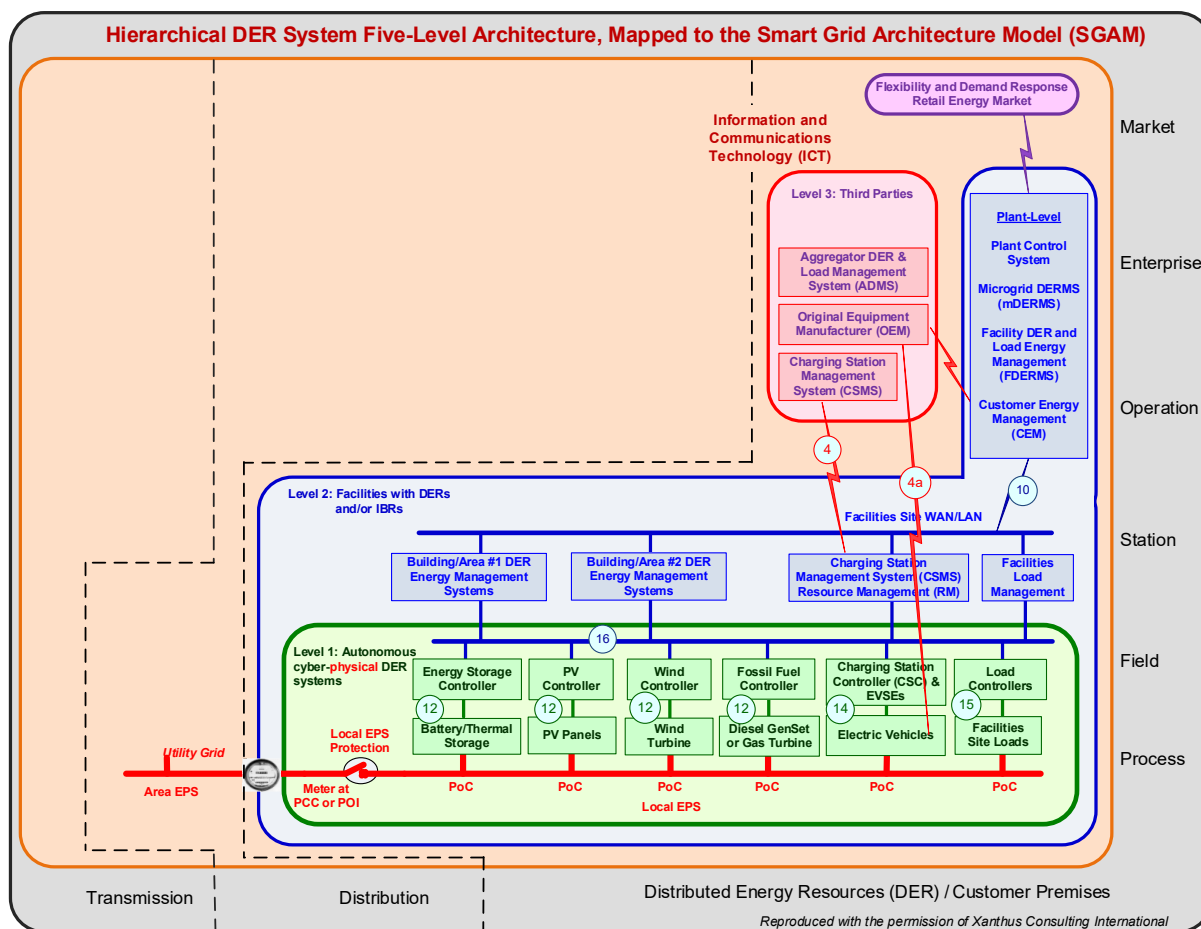


Figure 7 – DER architecture with a focus on charging stations

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 function? (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