Integrating the Energy System – IES

Technical Framework on **Electric Vehicle Charging**

TF-EVC

Vol. 1

Version 0.3

First trial ☕ release

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The TF-EVC was initiated in the **DiPS4EV@work** project [www.dips4ev.work] by:

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The work is since progressing, and partners from . . . have been invited to contribute. More to follow in the years to come.

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Contents

About the Document

This document comprises Vol. 1 of the Technical Framework on Electric Vehicle Charging, i.e., the collection of Electric Vehicle Charging related IES Integration Profiles released and here included at the date this document was last compiled, i.e., 31st May 2024.

The **Technical Framework on Electric Vehicle Charging (TF-EVC)** is a structured compilation of informative and normative specifications compiled according to the IES (Integrating the Energy System – www.iesaustria.at) recommendations and template, as shown in Figure 0.1.1. The TF-EVC shall enable the normalised use and application of existing standards and practices. Thereby, and in particular because this document is public, interoperability among cooperative but independently developed products and systems shall be enabled.

0.1 Document structure

This Vol.1 summarises and clarifies the Electric Vehicle Charging Business Case considered henceforth, including environmental constraints and envisioned opportunities to integrate energy consumers and distributed energy resources (DER) in the short term balancing of energy supply and demand. The Vol.1 closes with the informative specification of operational functionalities (*Business Functions*) and the naming of the independent IT systems that interact (*Meta-Actors*). The technical Vol.2 is a dynamic compilation of normative IES Integration Profiles (IIPs).

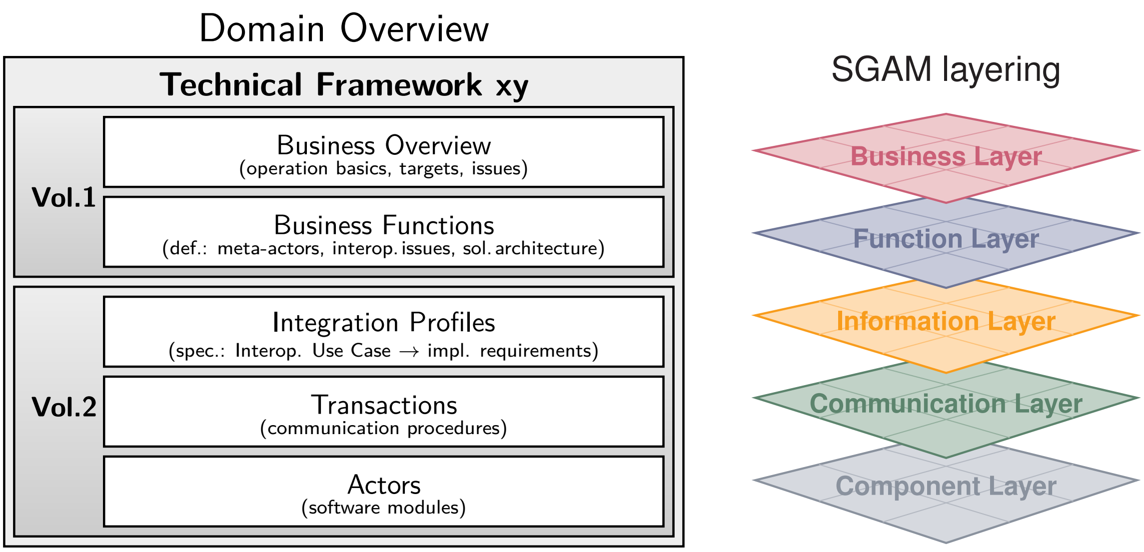

Figure 0.1.1: The IES Document Structure: roughly incorporating the five SGAM Layers [1].

IIPs state technical constraints and recommendations on how to apply standards and good practice wherever interoperability is at risk. IIPs specify a single feature each, Vol.2 adds a relational table that links the Business Functions from Vol.1 with the IIPs in Vol.2.

The entire Technical Framework shall be embedded in a business domain overview on modern energy systems and smart grid integration in general. The concept of Technical Frameworks and Integration Profiles is based on the established IHE (Integrating the Healthcare Enterprise – www.ihe.net) approach to *interoperability* in the medical IT sector. The base of the structuring reflects the common approach to complex problems, divide and conquer, also underlying the V-model. The Smart Grid Architecture Model (SGAM) [2] also uses the common layering approach to handle complexity by multi disciplinary separation.

◇ **Vol.1**

- Business Case Overview (informative)
  - Typical applications
  - Relevant meta-actors
  - Related standards
- Business Functions (informative)
  - Describe interoperability issues (use IEC 62559 Use Case Methodology)
  - Use Case diagrams
  - Actor Transaction diagrams

◇ **Vol.2**

- Business Functions to Integration Profile mapping (normative)
  - Table(s) binding Integration Profiles to Business Functions
- Integration Profiles (normative)
  - Definition of Interoperability issue addressed (Use Case)
  - Definition of needed transactions
  - Definition of involved actors
- Transactions (normative)
  - Specification of individual steps and list of actors involved
  - Specification of used IT standards, options, variants, etc.
  - Specification of communication security and resiliency
- Actors (normative)
  - Specification of actors' interfaces
  - Specification of used IT standards, options, variants, etc.
  - Specification of actor safety and data security measures

↪ The structure of Technical Frameworks follows the *top-down* approach and the informatics tradition to first name items, than define them, and finally specify them. For example: name an algorithm, define what it does, and specify how to implement it, before actually coding it. The terms *"definition"* and *"specification"* are hence used accordingly. Writing a Technical Framework can be done in any order. Commonly, previous parts need amendment whenever later parts become changed or added because the context runs back-to-front.

↪ *Vol.2* starts with assigning Integration Profiles to the Business Functions from Vol.1. In this table also Integration Profiles from other Technical Frameworks may be assigned (*bundled*). Transactions and Actors are specified profile by profile. They may as well be bundled from one Integration Profile into some other. Bundling shall prevent redundant specification. The bundling formalism is specified in [3] and further addressed in Vol.2 (introduced also in Vol. 1 Section **??**).

0.2 What is *interoperability*

According to dictionary: *"Ability of a system to work with or use the parts or equipment of another system"* [Merriam-Webster] the term *interoperability* refers to the ability of a system to work with parts and features provided by some other system. To do so, information is essential. First, to know how to use which parts, and second, how to address and control the used features of the other system.

To cooperate seamlessly the following five *interoperability levels* need to be considered:[1]

- **Legal:** common compliance with regulatory obligations and standards
- **Semantic:** uniform understanding and interpretation of information and operation means
- **Syntactical:** equal data formats, coding schemes, and encryption methods
- **Technical:** using the same communication means and protocols
- **Operational:** timely reliable provisioning of info/response

Orderly cooperation of systems is possible where requirements are fulfilled layer by layer, and where all internal components of a device operate correctly, i.e., flawless. Imagine what happens if the unit of a metric differs (semantic issue): cooperation fails. E.g., the mars-lander crashed even though each sub-system worked perfectly to its own specification. Malfunction of cooperation does not necessarily imply faulty sub-system implementation; per se these may work fine. Consequently, *interoperability* cannot be assessed stand-alone without involving independent systems as test peers. Accordingly, INTEROPERABILITY CANNOT BE IMPLEMENTED INDIVIDUALLY.

Ad testing *interoperability* [ITU-T Z.450] says: *"Testing to assess the ability of two or more systems to exchange information and to make mutual use of the information that has been exchanged."* Here *mutual use* is pronounced, i.e., all involved systems shall benefit. Thus, correct interpretation and trust in the correctness and beneficial use of exchanged information and provided features are likewise essential.

Other references, examples and notes

◇ **wikipedia.org:** *"Interoperability imply Open standards ab-initio, i.e., by definition. When a vendor is forced to adapt its system to a dominant system that is not based on Open standards, it is not interoperability but only compatibility."*

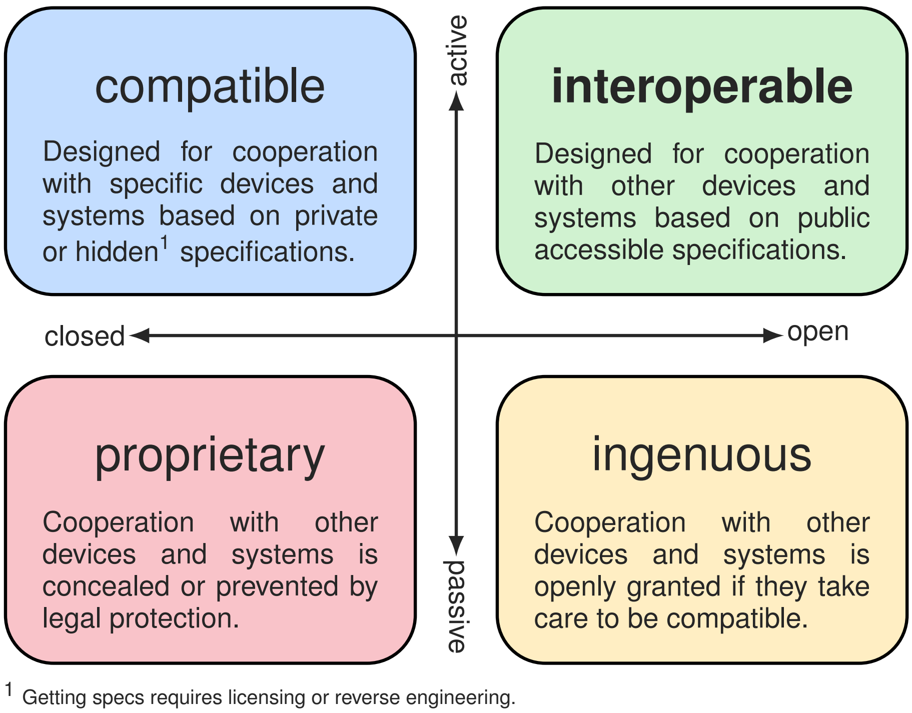

Figure 0.2.1: Matrix of cooperation options

◇ **interoperability-definition.info:** *"Interoperability is a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions."* Sadly this webpage proves itself semantic interoperability failure due to language

[1] Five layers similar to the SGAM and the Technical Framework structure.

complexity when definitions become translated. The German differs considerably: *"Interoperabilität ist die Fähigkeit eines Programms oder Systems (dessen Schnittstellen vollständig offengelegt sind) mit anderen gegenwärtigen oder zukünftigen Produkten oder Systemen ohne Einschränkungen hinsichtlich Zugriff oder Implementierung zusammen zu arbeiten bzw. zu interagieren."*

◇ **INTEROP NoE, 2014:** Systems are considered interoperable in the continuum between incompatible and fully integrated. Research on *Enterprise Interoperability* places emphasis on loosely coupled/integrated systems and discusses unified and federated interoperability (Zhiying Tu, Gregory Zacharewicz, David Chen, 2014). Notably, it is not implied that the integration end of the continuum provides higher quality. On the contrary, loosely coupled systems are more adaptive, which yields some resilience, and are much harder to engineer and predict, in general.

↪ *Only one definition in one language can be binding.* Not two or more, even though, all can be valid in their context. Not knowing how to interpret a particular definition, it remains an unspecific composition of words, like a sequence of letters can define a *name*-identifier. TERMS DESCRIBE CONTEXT ⇔ CONTEXT SPECIFIES TERMS.

0.3 Definitions

Active customer is a final electricity customer, or a group of jointly acting final customers, that may produce, use, sell and store electricity, commonly self-generated within their premises (within confined boundaries), for whom these activities do not constitute a primary commercial or professional aim.

Actor is here a functional component of an IT system that executes operational tasks commonly in cooperation and/or coordination with other actors.

Aggregation refers to a function performed by a natural or legal person (an *Aggregator*) that combines multiple customer loads or their generated electricity for sale, purchase or auction in some *electricity market*.

Ancillary service means a service necessary for the operation of a transmission or distribution system, including balancing, steady state voltage control, fast reactive current injection, inertia for local grid stability, short-circuit current, black start capability and island operation capability, but is not including any congestion management.

Business Case is the economic viable application of an idea or technology.

Business Function is a feature required to be realised for a Business Case to work.

Charging Service Provider is a company that hands out ID cards with which the EV driver can authenticate the charging. Billing of the EV driver and remuneration of the charging site owner is performed by the Charging Service Provider.

Charging Station is a technical entity that EVs can be connect to for recharging their battery. A charging station can be a single charging unit or an entire charging site with many charging points.

Charging Station Operator is the operational entity that manages charging stations. Primarily, it gets the authorisation ID and if payment is assured it enables the charging.

Conformance Testing is a standalone process to ensure that the implementation conforms to specified standards and profiles, i.e. an implementation's outputs and responses are checked against rules and patterns.

Demand response means the change of electricity load by a customer, in respect to the normal or current consumption pattern, in response to some signal, including time-variable electricity prices, incentive payments, or other reimbursement options for the potentially accepted comfort loss.

Demand side management means the change of electricity load by a remote entity in respect to this entities goals. Leasing customer owned assets for demand side management is commonly somehow reimbursed to compensate side-effects. If the controlled assets are owned by the controlling entity, the service the asset provides is sold to the customer, e.g., heating-as-a-service.

Distribution refers to the transport of electricity at different voltage levels towards the delivery to customers, but does not include supply.

Distribution System Operator is the legal entity that operates the electric wires that deliver electricity to customers, commonly responsible for energy grid safety and persistent power supply.

e-Mobility Service Provider is a CSP (charging service provider).

Electricity consumer is a technical asset that consumes electric power when operated. In a market centric view, the natural or legal person that operates electricity consuming assets is often referred to as energy consumer.

Electricity customer is a natural or legal person that purchases electricity service, i.e., the provisioning and on demand delivery of electric energy.

Electricity generation refers to the physical production of electricity, i.e., the conversion of some raw energy (e.g., wind or solar irradiation) into electricity.

Electricity markets are markets for electricity, including over-the-counter markets and electricity exchanges, markets for the trading of energy, of capacity, of balancing and ancillary services, in all time-frames, including forward, day-ahead and intra-day markets.

Electricity producer refers to a natural or legal person that operates assets to generate and sell electricity.

Electricity supply refers to the sale of electricity to customers; i.e., assuring and billing of the supply with the contracted amount of electric power.

Energy Management System is a control system that manages controlable loads and generation assets. It either controls the actual power flows or limits the power flows caused by the controlled assets to achieve best possible balance of power supply and demand.

Grid Codes are regulations, typically specifying technical requirements that need to be fulfilled to connect devices to the electricity grid or to participate in different electricity markets.

Integration Profile is the specification required to realise an atomic part of a Use Case (or several thereof) in an interoperable fashion (normalised).

Interoperability Level refers to the abstraction level of interoperability requirements. We consider five levels: Legal, Semantic, Syntactic, Technical, and Operational.

Interoperability Testing is a process to check whether the system interacts effectively with foreign systems, i.e., when different vendors meet to test their interfaces against each other.

Interoperability Use Case is a part of a Business Function that relies on data exchange between different actors according to an Integration Profile (i.e. where interoperability is required).

Meta-Actor joins functional components (actors) in order to fulfil all the functionalities required for a Business Function (IHE grouping). For the Use Case description, it could be a human operator, but typically it is a software component embedded in some device that provides an interface to some communication infrastructure.

Network Codes see *Grid Codes*.

Safety refers to maintaining a proper state of systems such that neither persons operating assets nor the electricity system itself, i.e., the seamless power supply to all customers, is undue endangered.

Security refers to both, security of supply and provision of electricity, and colloquially may also include technical safety. Primarily, security aims at the protection of the system's operation to assure system safety, including restricted physical and digital access to assets.

Smart Charging is a technology that enables dynamic limiting of the power provided for EV charging. It is typically used for peak shedding, but may also be used to adjust the charging power to the on-site power generation or excess power availability.

Smart Grid Architecture Model (SGAM) refers to the reference architecture model developed by the M/490 for the European Commission [4]. It provides a normative approach to position (locate) the different components, services, and sub-systems of a smart grid, among each other and to identify required interfaces.

Transaction is the execution of sending, receiving and reacting to a message or set of messages (1..n) exchanged between a pair or more actors. Transactions realise Use Case specific information exchanges (in one or both directions, in a strict or loose order) as specified by an Integration Profile.

Transmission refers to the (long distance) transport of electricity across the extra high-voltage and high-voltage grid with a view towards delivery to customers or distributors, but does not include supply.

Operational Use Case is a part of a Business Function that describes a task not involving any data exchange between actors. Such internal use cases are mentioned in the Technical Framework, but not considered as Integration Profiles because they do not cause interoperability issues.

Use Case is a well defined functionality in a well specified environment. Use Cases can be defined and specified on every SGAM Layer.

1 Introduction

The charging of the Electric Vehicle (EV) is an essential need of electric driving. EVs cannot be considered a feasible individual mobility alternative if convenient charging options are not available. The current battery technology cannot compete in terms of weight and volume to the energy capacity of liquid fuels, which limits the distance common Battery Electric Vehicles (BEV) can drive without re-fuelling (charging) to less then it is common for legacy fossil fuelled vehicles. However, a very high percentage of the daily travelled distances can be covered with the capacity of most BEV batteries without the need to re-charge, except for occasional long distance travels. Even daily re-charging is often not needed to maintain a state-of-charge (SoC) sufficient to commute to work or go shopping with comforting reserve.

The Technical Framework on Electric Vehicle Charging addresses the systems and use cases where interoperability is required to actually charge EVs. This shall cover all aspects; e.g., the physical transfer of energy, the communication to mange the charging process, and enabling the accounting and billing at public charging points.

1.1 EV charging

Electric vehicles store energy in batteries, which is than used to operate the vehicle. Physically, batteries support direct current (DC) dis-/charging only. An on-board battery controller manages the dis-/charging to protect the battery, i.e., to maintain its health (life-time) and to prevent harm (assure safe operation limits).

1.1.1 Charging control

The charging of an EV battery is controlled by the on-board charging electronics only. For AC charging, the on-board electronics also includes the AC-DC conversion, whereas for DC charging the power drawn from the charging station goes either directly or via a DC-DC converter into the high voltage EV battery.

The actual power-flow is controlled by the on-board charging electronics, considering the environmental conditions, e.g., battery temperature T_{bat} and current state-of-charge (SoC), and the limits communicated to it. It primarily aims at achieving the intended life-time, i.e., the number of charging-cycles and the remaining capacity at the batteries end-of-life, as promised by the EV vendor.

External entities can curtail the maximum power that the EV can use to charge its battery by adjusting the maximum power rating that the charging point communicates to the EV. The EV is than required to never draw more then the negotiated power. But never can external entities force the charging of the EV battery with a certain power different from what the on-board charging electronics chooses to use.[1]

The power $P_{\mathrm{ch}}^{\mathrm{EV}}$ with which an EV is charged is the *minimum* of the power made available by the charging point $P_{\mathrm{max}}^{\mathrm{CP}}$,[2] the power the on-board charging electronics can handle $P_{\mathrm{max}}^{\mathrm{EV}}$, and the battery state dependent $P_{\mathrm{max}}^{\mathrm{SoC,T,...}}$. Thus, the minimum of all limits determines the power

$$P_{\mathrm{ch}}^{\mathrm{EV}} = \min\left\{P_{\mathrm{max}}^{\mathrm{CP}}, P_{\mathrm{max}}^{\mathrm{EV}}, P_{\mathrm{max}}^{\mathrm{SoC,T,...}}\right\} \tag{1.1.1.1}$$

at which an EV is actually charged, and that is maintained by the on-board battery charging control unit.

Note: At high States-of-Charge (SoC) and at low battery temperatures T the power with which an EV battery can be charged drops drastically.

[1] If an EV draws too much power, the charging point can cut the supply (to zero), but cannot reduce the drawn power to a certain amount.

[2] $\sum P_{\mathrm{max}}^{\mathrm{CP}} \leq P_{\mathrm{max}}^{\mathrm{grid}}$ is commonly enforced, but actually $\sum P_{\mathrm{ch}}^{\mathrm{EV}} \leq P_{\mathrm{max}}^{\mathrm{grid}}$ is required.

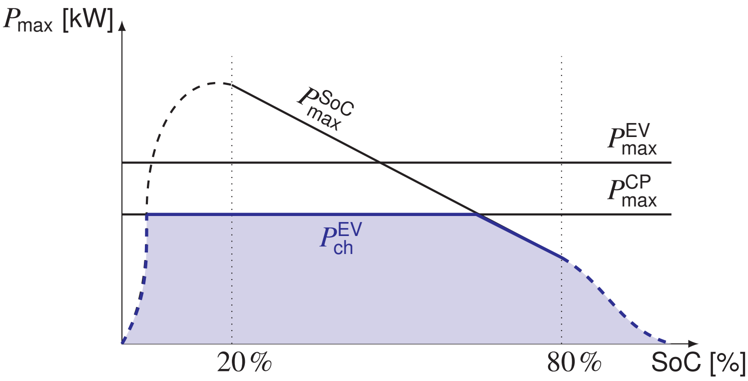

Figure 1.1.1: Simplified sketch illustrating the actual P^{EV}_{ch} determination according to equation 1.1.1.1, here for fast DC charging where the SoC drop starts at low SoC values. For AC charging up to 22 kW, only marginal drop is expected up to 80 % SoC.

1.1.2 Charging options

Connecting a battery to the electricity grid for charging requires inverter electronics because the public grid provides alternating current (AC) only. Established charging options include:

- **Recuperation** $\rightarrow$ from motion, using onboard AC-generator and AC-DC converter
- **AC charging** $\rightarrow$ from the AC grid using an embedded onboard AC-DC converter
- **DC charging** $\rightarrow$ from a DC source, e.g., external AC-DC converter or high voltage battery
- **Solar charging** $\rightarrow$ the EV is charged by the sun using PV cells mounted on the vehicle surface
- **Battery swapping** $\rightarrow$ the EV is re-powered by inserting a full battery, charging is externalised

Recuperation, i.e., the internal conversion of motion energy into electricity whenever an EV decelerates, contributes to the improved energy efficiency of EVs. Hybrid EVs (HEV) without external charging option solely rely on this source to charge the onboard battery required for driving. However, they also tap into the torque provided by the combustion engine to operate the AC-generator if the SoC drops below some threshold or when the combustion engine likes the added drag to be more efficient. Because this is a pure onboard, i.e., single vendor solution, interoperability is no issue and recuperation here no further considered. Thus, the acronym EV is henceforth used to refer to BEV and plug-in HEV, where not otherwise noted.

AC charging needs no external electronics, a household power outlet is sufficient. However, household outlets are limited in their maximum power by the fuse protecting the electric circuit; typically 2.7 kW (12 A) for Schuko[3] sockets and 3.7/7.3 kW (16/32 A) for one phase CEE sockets. Using 3-phase CEE sockets and cables, the power can reach 11/22 kW (3x 16/32 A).[4] Whether such a power level can be used depends on the rating of the onboard AC-DC converter and the connector used to connect the EV to some power outlet. In case this power outlet provides some "intelligence", i.e., supports digital communication with the EV to limit the charging to a power level below the maximum supported by the plug type, it is called a *Charging Station* (CS). How much power is actually drawn, is always determined by the EV embedded battery controller. A CS can only enforce an upper power limit, e.g., to protect the supply circuit from harm and avoid blowing the fuse.

DC charging outsources the AC-DC conversion into an external box – a *charging station* – and thereby overcomes the limitations of onboard conversion. However, high power charging requires according voltages and currents. For example, charging with 150 kW and 800 V requires a current close to 200 A ($P = UI$). The high voltage demands good cable shielding and the high current demands huge conductor cross sections, which make the cables bulky and heavy. Another problem is the access capacity to the public electricity grid. Common households are connected with a capacity of around ~5 kW, small business and farms with ~20 kW. Purchasing a higher grid access capacity is expensive and restricted by the grid capacity. A smart alternative is charging from a high voltage battery, which

[3] Schuko sockets are rated to handle 16 A but commonly limited to 12 A for increased safety.
[4] Common household wiring is limited to 16 A per phase; 32 A requires larger conducting cross sections than usually installed.

itself is charged rather slowly from the AC grid. If fast charging is sporadically used, this avoids the demand for a high grid access capacity, but batteries of sufficient size are expensive and may require regulatory approval.

Other, here no further considered EV charging options, include:

Solar-charged vehicles are covered in photovoltaic cells that convert sunlight into the electricity buffered in a battery and used for driving, i.e., use an onboard DC-DC converter to charge the battery. Solar cars have been developed for quite some years, but mostly toward prototype level only. That might change, several companies announced market ready products.[5] However, that is again an on-board single vendor solution, where interoperability is no issue.

Battery swapping replaces an emptied battery with a full battery to achieve fast re-powering of the vehicle. This option is in particular used where many electric vehicles can use the same battery and where fast re-powering is an operational need, e.g., for forklifts and autonomous transporters (movers) in the producing industry. The re-charging of the dismounted batteries does not need to be fast if sufficiently many spare batteries and charging points are available. Interoperability of batteries, sockets, and chargers could be an issue, if not sold and operated as a complete single vendor system.

1.1.3 Connector types

Electric Vehicles according to their charging types, mostly can be categorized into four main areas[6]:

- North America (CCS-1, Tesla US)
- Europe, Australia, South America, India, UK (CCS-2, Type 2, Tesla EU, Chademo)
- China (GBT, Chaoji)
- Japan (Chademo, Chaoji, J1772)

Also, it can be divided into three types based on acceptable current:

- AC (Type 1, Type 2)
- DC (CCS Combo 1-2, CHAdeMO, ChaoJi, GB/T)
- AC/DC (Tesla Supercharger)

Figure 1.1.2 depicts the common plug types according to the area and current types.

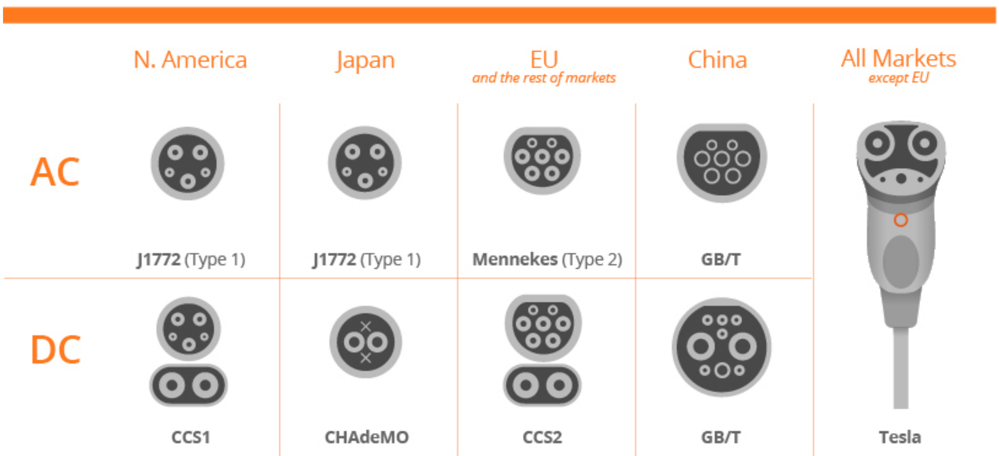

Figure 1.1.2: Charging Connector Types[7]

[5] https://en.wikipedia.org/wiki/Solar_car
[6] https://interchargers.com/plug/
[7] https://user-images.githubusercontent.com/31137215/74442833-7be40200-4e72-11ea-90fc-28ffa74c36ad.jpg

Type 1 J1772
Type 1 J1772 Standard Electric Vehicle Connector is produced for the USA and Japan. The plug has 5 contacts and can be recharged according to Mode 2 and Mode 3 standards of a single-phase 230 V network (maximum current of 32A). However, with a maximum charging power of only 7.4 kW, it is considered slow and outdated.

CCS Combo 1
CCS Combo 1 connector is a Type 1 receiver that allows the use of both slow and fast charging plugs. The proper functioning of the connector is made possible by an inverter installed inside the car, which converts alternating current into direct current. Vehicles with this type of connection can charge at maximum "rapid" speed, up to 200 A and power 100 kW, for voltages ranging from 200-500 V.

Type 2
It is commonly known as Mennekes, which is the name of the first brand that commercialised it. The Type 2 Mennekes plug is installed on nearly all European electric vehicles, as well as Chinese models intended for sale. Vehicles equipped with this type of connector can be charged from either a single or three-phase power grid, with the highest voltage being at most 400V and the current reaching up to 63A.

CCS Combo 2
CCS Combo 2 is an improved and backward compatible version of the Type 2 plug, which is very common across Europe. It allows for fast charging with power up to 100 kW.

CHAdeMO
The CHAdeMO plug is designed for use in powerful DC charging stations in Mode 4, which can charge up to 80 % of the battery in 30 minutes (at a power of 50 kW). It has a maximum voltage of 500 V and a current of 125 A with a power output of up to 62.5 kW. This connector is available for Japanese vehicles equipped with it and is very common in Japan and Western Europe.

CHAoJi
CHAoJi is the next generation of CHAdeMO plugs, which can be used with chargers up to 500 kW and a current of 600 A. The five-pin plug combines all the advantages of its parent and can also be used with GB/T charging stations (common in China) and CCS Combo via adaptor.

GBT
GBT Standard plug for electric vehicles produced for China. There are also two revisions: for alternating current and for direct current stations. The charging power through this connector is up to 190 kW at (250A, 750V).

Tesla Supercharger
The Tesla Supercharger connector differs between European and North American versions of electric cars. It supports fast charging (Mode 4) at stations up to 500 kW and can connect to CHAdeMO or CCS Combo 2 via a specific adaptor.

NACS
The North American Charging System (NACS), being standardized as SAE J3400, is an EV charging connector system developed by Tesla.

1.2 EV charging infrastructure

Either a regular power socket, e.g., CEE 7 (Schuko) or CEE 17 (IEC 60309), and a dedicated *charging cable* with electronics that manage the charging or a so called *charging station* (CS) with one or more *charging point* (CP), i.e., charging socket and/or fix mounted cable with a charging plug that connects to the EV, is required to charge an EV from an external power source. Small CS are often called *WallBox* because they are mounted onto a wall. Free standing CS often provide more than one CP, i.e., two or more charging sockets and/or fix mounted charging cables. Some also provide regular power sockets to connect a charging cable that the EV driver provides. Different socket and plug types are favoured by different car vendors and in different regions.

The electronics either integrated in the stand-alone charging cable or in the CS is responsible to communicate with the EV and determine the maximum power the EV may draw. Thereby, plug type ratings and limits of the power outlet, e.g., the fuse rating that protects the electric circuit powering the CS, are considered by the EV in the course of the charging process.

1.2.1 Power socket

Charging from a regular power socket is limited by the fuse protecting the circuit the socket is supplied from. The EV driver is responsible to configure the charging cable to a power limit that is safe. Actually, the power settings offered may not exceed the plug type limit, which is safe in general. As shown in Figure 1.2.1, the grid access is commonly shared with other loads and thus, monitoring the charged energy requires a sub-meter at the socket or is restricted to the onboard metering of the EV.

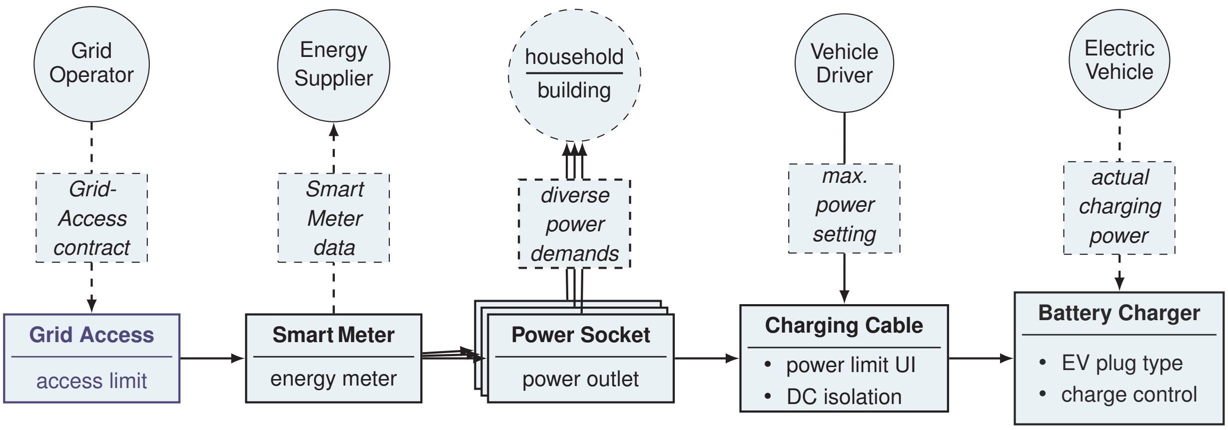

Figure 1.2.1: Power Socket EV Charging — Architecture

Automated charging power adjustment by an EMS is not possible because the timing and the maximum power are decided by the EV driver only. However, a locally visible signal, e.g., a "traffic light" near the power socket, might purge the EV driver to connect the EV when ample renewable and local energy is available. Disconnecting the socket at times power supply is insufficient to also charge an EV, is the other option.

1.2.2 Private charging station (WallBox)

Charging stations (wallboxes) are commonly supplied with electricity by a dedicated circuit and according fuses. They mandatorily integrate DC back-current protection and better models also include power metering and a digital user interface. Public accessible CS, in particular fast AC/DC charging stations, are typically supplied from a separate smart meter and thus a dedicated grid access, whereas in private environments with no public access, grid access is commonly shared with other loads.

Figure 1.2.2 shows the architecture for a private *WallBox* scenario. Similar to the power socket scenario above, share many loads the grid access and thus, sub-metering is required to monitor the charged energy. However, the monitoring amy occur at the root of the circuit connecting the wallbox, and better wallboxes have integrated metering and a digital interface to access it. Commonly, this interface also supports automated maximum power limitation, i.e., dynamic reduction, such that the EV charging via a wallbox can be managed by an EMS.

1.2.3 Public charging station (fast AC/DC-charging)

Figure 1.2.3 shows a typical set-up for one or more public accessible CS. The charging stations are supplied from a dedicated grid access point with dedicated smart meter and energy supply contract. Because energy trading

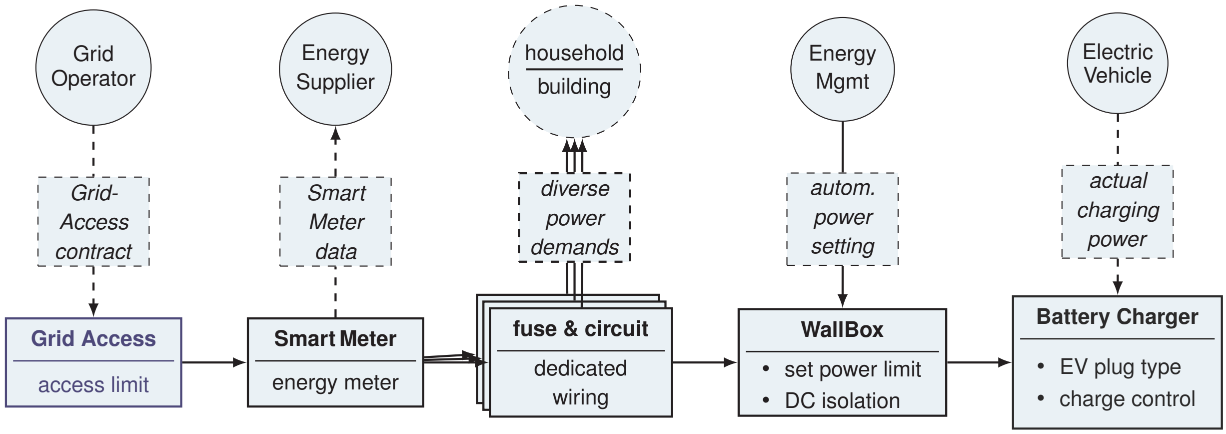

Figure 1.2.2: Private Charging Station (WallBox) — Architecture

requires an energy trading license with hard to achieve obligations, the operation of public accessible EV charging is commonly outsourced to a *Charging Point Operator* (CPO). This operator needs the charging data for the billing, and thus, the such managed CS needs to provide reliable charge metering per charge point (CP) and a digital interface to forward the data to the CPO. However, the data may be coarse, i.e., charged energy from start-time to end-time. To monitor the load on the grid, in particular where multiple CP use the same grid access, power metering at the root of the supply circuit is required. The Smart Meter has exactly that data, and if real-time access is possible for the *Energy Mgmt* unit, it can realise *Smart Charging* to assure that the grid access limit is not exceeded.

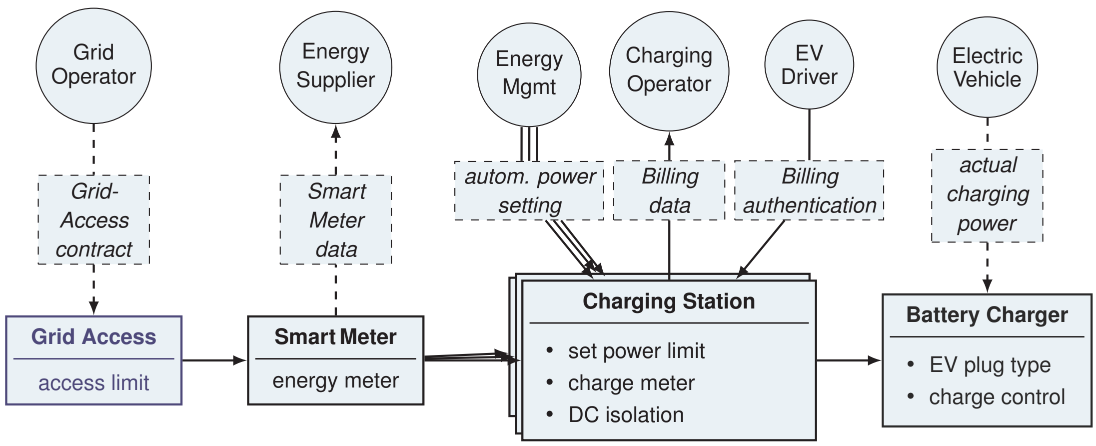

Figure 1.2.3: Public Charging Station (fast AC/DC charging) — Architecture

Here not shown is the optional Charging Service Provider (CSP), also known as e-Mobility Service Provider (EMSP), who issues so called *charging cards* to EV drivers based on some contract. To allow payment via *charging cards*, the CPO needs a contract with the CSP, which then handles the actual billing of the EV driver. The EV driver gets in return reduced energy prices compared to direct payment using a regular debit or credit card.

1.2.4 Battery buffered DC charging

Figure 1.2.4 sketches the buffered charging, where between the fast DC charging of EVs a buffer battery is installed. The power needed for the fast DC charging is provided by the buffer battery. The grid access needs to power the re-charging of the buffer battery only. If high power demands are rare, the re-charging can be performed rather slow and scheduled to times when ample renewable local power is commonly available.

This buffered scenario appears to be perfect, might even be integrated in private households, but is challenged by the cost and size of the required buffer battery. However, when used EV batteries, so called *second life* batteries,

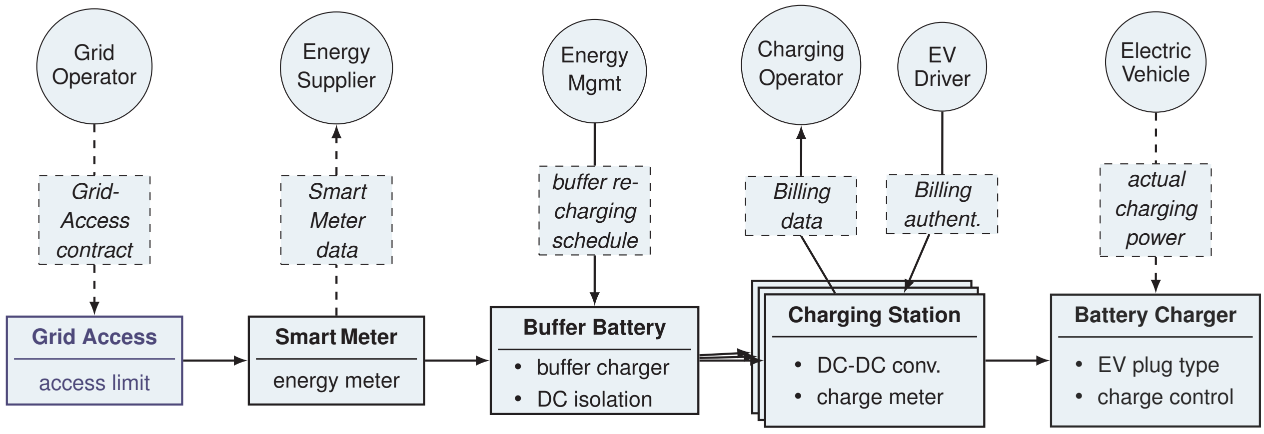

Figure 1.2.4: Battery buffered Fast Charging Station — Architecture

become affordable, this charging scenario may flourish. Still, at home and at work, where the EV is commonly parked for several hours, fast charging is rarely required. For charging sites along highways, with ten and more charging points, buffered charging will be more economic, eventually.

The different setups need to be considered when EV charging shall become integrated in some energy management solution, e.g., to realise smart charging as outline in section 1.2.5.

1.2.5 Smart Charging infrastructure – extended architecture

The charging scenarios discussed above already include an optional energy management system (EMS). If the charging of EVs is actively managed, it is called *Smart Charging*. Traditionally, EVs negotiate the maximum charging power with the CS and respect this limit throughout the charging process, but do not consider later limit adjustments. According to recent regulations, new EVs now need to reduce the charging power also in the course of the charging process whenever the limit of the CS is adjusted. However, they only need to reduce to a tighter limit, but do not need to increase the drawn power if the limit is relaxed. Henceforth, greedy charging is assumed, meaning that EVs increase the power drawn if the limit is relaxed and the charging can make use of it.

The ***Smart Charging*** technique is commonly implemented to assure that the grid access limit is not exceeded. Where charging is supplied from a dedicated access point and smart meter, the smart charging controller can maintain the total power below the grid limit $P_{\text{grid}}^{\text{max}}$ using the metered power demand of each CS $P_{\text{cs}}(i,t)$, to achieve $\sum_i P_{\text{cs}}(i,t) \leq P_{\text{grid}}^{\text{max}}$. In a household or building attached charging setting, where the EV charging is supplied from the same grid access as the household or the building, the loads caused by the household or building $P_{\text{hh}}(j,t)$ need to be considered as well, i.e., $\sum_i P_{\text{cs}}(i,t) + \sum_j P_{\text{hh}}(j,t) \leq P_{\text{grid}}^{\text{max}}$. However, the $P_{\text{hh}}(j,t)$ components are in general not known, at least not all. Therefore, the smart charging control needs live metering at (or just behind) the smart meter to know $P_{\text{tot}}(t)$, in order to realise smart charging according to

$$\sum_i P_{\text{cs}}(i,t) \leq P_{\text{grid}}^{\text{max}} - \sum_j P_{\text{hh}}(j,t) = P_{\text{grid}}^{\text{max}} - P_{\text{tot}}(t) + \sum_i P_{\text{cs}}(i,t) \tag{1.2.5.1}$$

by dynamically adjusting all $P_{\text{cs}}(i,t)$ in total by a $\Delta P_{\text{cs}}(t^+) \leq P_{\text{grid}}^{\text{max}} - P_{\text{tot}}(t^-)$, such that $P_{\text{tot}}(t) \leq P_{\text{grid}}^{\text{max}}\ \forall t$.

This on demand power adjustment mechanism can also be applied to implement other aims, e.g., energy price dependent charging and charging solely from self-supply, by accordingly setting the smart charging power limit $P_{\text{cs}}^{\text{max}}(\text{price}(t))$ and $P_{\text{cs}}^{\text{max}}(t) \leq P_{\text{self}}(t)$ or $P_{\text{cs}}^{\text{max}} \leq P_{\text{self}}(t) - \sum_j P_{\text{hh}}(j,t)$ if only excess self-supply shall be charged.

Figure 1.2.5 shows a generalised scenario, where at some site both, private and public accessible charging stations are installed and shall be operated smart and integrated in the site's energy management system (EMS).

This leads to the generalised system-of-systems architecture shown in figure 1.2.6. Based on general scenario and architecture, the inter-operation needs can be identified.

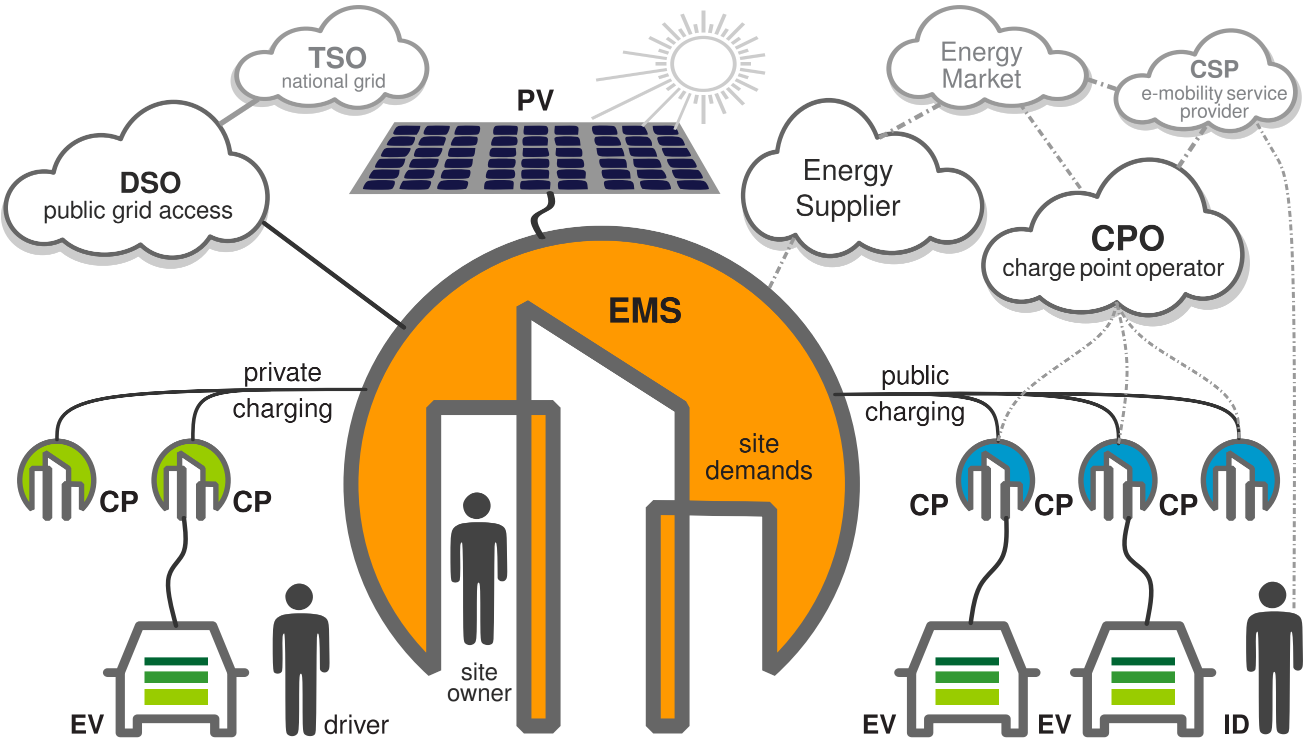

Figure 1.2.5: Generalised EV charging scenario

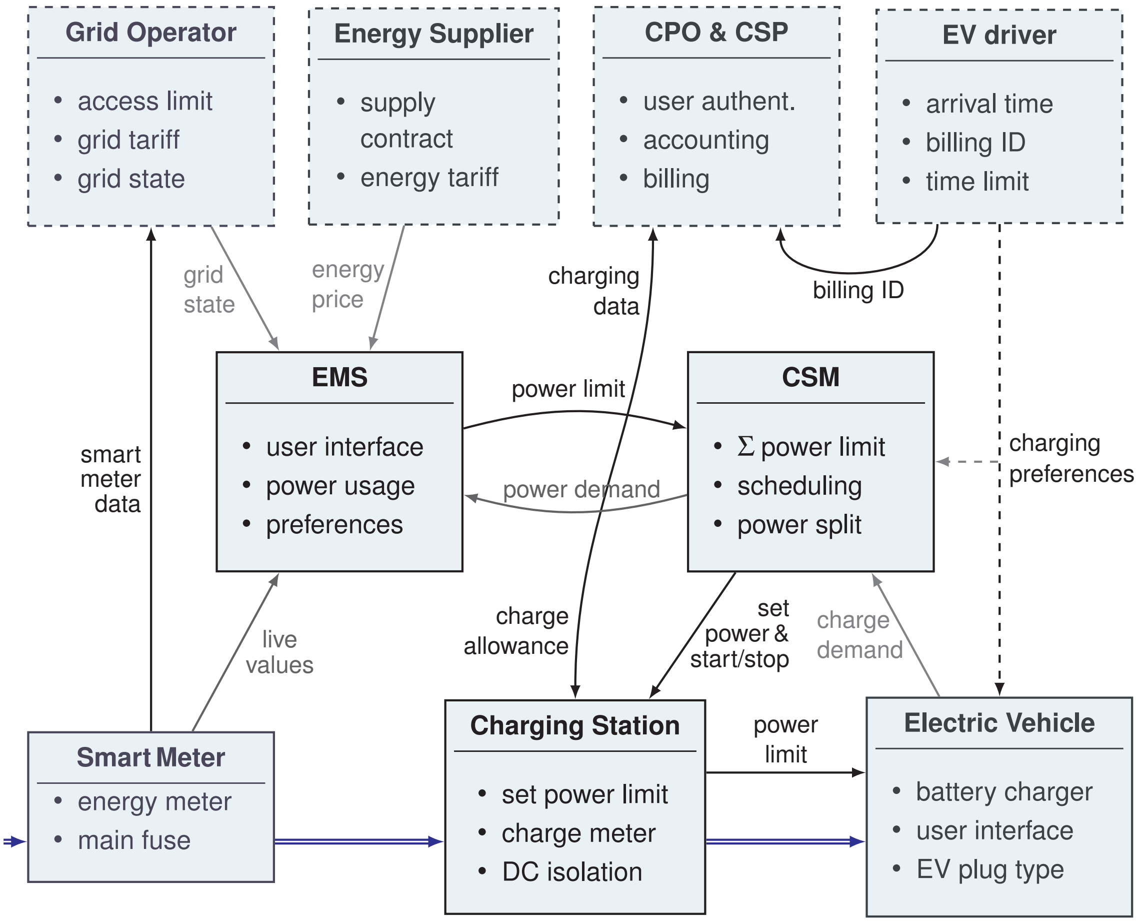

Figure 1.2.6: Generalised Smart-Charging IT-Architecture

The meta-actors shown in Figure 1.2.6 represent different entities on the top, different management systems in the middle, i.e., general building/company EMS and a CS-Manager (CSM), in the middle, and the unites that actually conduct electricity at the bottom. The blue double lines represent the electricity flow into the EV's battery. If only one CS is present it also performs the CSM tasks as far as required. If the EMS can directly control several CS, it can include the CSM tasks, such that EMS and CSM merge into one meta-actor. In both cases, the logic entities, i.e., their tasks, remain as shown, only the interfaces vanish. The billing ID of the EV driver is actually transferred to the CPO via the user interface of the CS and the data link connecting the CS with the CPO.[8]

Depending on the performance needs raised by the information that is exchanged, different standards specify what is needed to enable the required inter-system communication.

The interfacing between the actors, i.e., the communication protocols and interfaces, can be realised based on different standards, as shown in Figure 1.2.7, and communication means (wireless radio, copper cable, optical fibre, Ethernet, IP, HTTP, etc.) that are supported by the chosen standard.

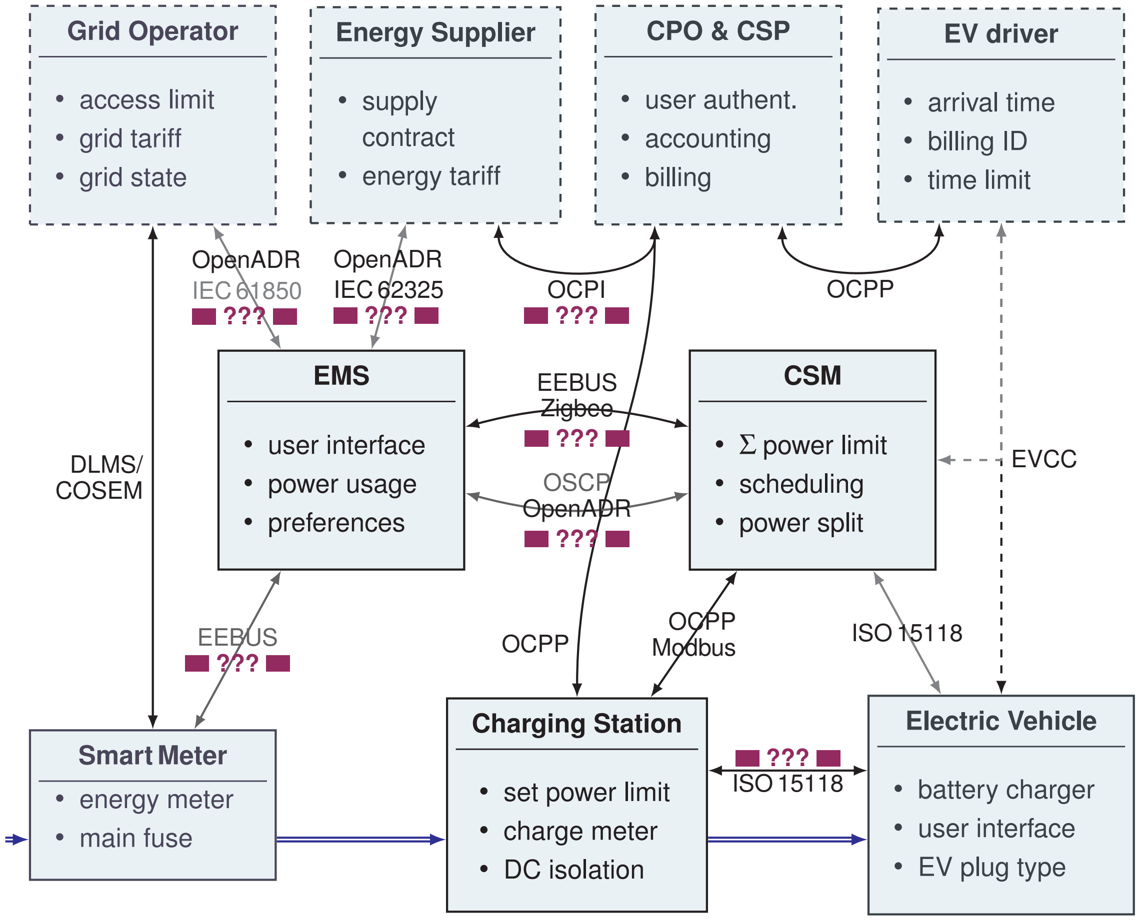

Figure 1.2.7: Smart-Charging IT-Interfaces

Standards Overview: Recently, international (automotive) stakeholders developed a number of open communication protocols, i.e., OCPP, OSCP and OCPI, in relation to Smart Charging and the energy system stakeholders added features and non-free standards to their portfolio of tools as well. Which standards shall be used for different interfaces is specified in Vol. 2 in the context of Integration Profiles and essential details are outlined in the collection of Solution Building Blocks at the end of Vol. 2.

◇ **ISO 15118** is an international protocol for communication between the EV and the CS. It focuses on security and can communicate also the EV's intended departure-time (timestamp) and the EV's energy requirement (kWh) from the EV to the CS. This makes it possible to charge smarter, i.e., more efficiently and matching the EV driver's wishes. It also supports bidirectional exchange (communication) of the *smart charging control signal* between EV and CS.

[8] The interface between the CPO and the CSP to check the validity of the ID is here irrelevant because that is considered a part of the contract between the CPO and the CSP and nowhere implemented in the charging hardware and it's management on-site. Where the site owner covers the CPO role, the interface is assumed part of the CPO software package.

◇ **OCPP** (Open Charge Point Protocol) is an open protocol for communication between the CS and the central backend system of the charging point operator. It controls the entire charging transaction. OCPP was initiated by ElaadNL in the Netherlands and developed further in recent years by a broad international group of EV-industry stakeholders. OCPP is the de facto international standard and is currently applied in more than 100 countries worldwide. OCPP is now managed by the *Open Charge Alliance*, an international industry alliance with 136 members from dozens of countries on five continents. OCPP makes it possible to pass on Smart Charging signals from the central backend system to the CS.

◇ **OCPI** stands for Open Charge Point Interface between a charge point operator (CPO) and some third party, usually being a charging service provider (CSP). However, any other party including the energy supplier or some aggregator could likewise use this interface. Originally, OCPI worked peer-to-peer only, yet also supports data roaming platforms (e.g., e-clearing.net) via a hub-to-peer connection. OCPI is a Dutch initiative with wide international support. The protocol provides real-time information about the CS, i.e., location, availability, prices, and billing, and ensures bilateral roaming capability. Smart Charging features are included since version 2.2 (2020).[9]

◇ **OSCP** (Open Smart Charging Protocol) is an open communication protocol between the CS management system and the regional distribution grid operator (DSO) or the national transmission grid operator (TSO). It communicates the capacity limits within which charging can occur without causing grid overload. This protocol also originated in the Netherlands, but it is not often used in practice. Possibly because DSOs and TSOs prefer to use established non-free standards, e.g., IEC 60870-5-104 or IEC 61850-7-420:2021.

◇ **IEC 61850-7-420:2021** is the part on DER integration of the non-free IEC 61850 standards family, where the features and functionalities of so called *Intelligent Energy Devices* (IED) are represented by *Logical Nodes* (LN). Loading an IED's configuration file into a SCADA system, a 'digital twin' is established and connected with the device in the field, integrating the remote features and functionalities into the SCADA system. It is a modern open IT standard, object oriented throughout, rich in loads of metadata, and fully adaptable and extendable to user needs. Thus, an IED that represents an EV charging station can be designed based on the LN DLOD (distributed load) and V2G integrated using the LN DBAT (distributed battery).

◇ **OpenADR** (Open Automated Demand Response) is an open standard for exchanging 'Demand Response' signals, or signals related to price or charge control. This enables Smart Charging signals to be sent between parties, for example from the distribution grid operator (DSO) to a CPO. The communication is based on IP, making deployment easy but demanding reliable access control for secure operation. This protocol is widely supported, e.g., in the United States of America it is commonly used.

◇ **EEBUS** is a protocol suite for the *Internet of Things* that aims to standardise the interface between electrical consumers, producers, storage, and (logical) managing entities, primarily intended for energy demand management. It establishes a standard for interoperability, enabling coordination between different actors with different objectives. By defining device behaviour and signal coordination, EEBUS streamlines data exchange for improved energy efficiency, cost savings, and environmental impact reduction for building owners, while providing managing entities greater flexibility and reliability in pro-actively managing energy insertion and consumption. The standardisation of the EEBUS protocol suite is driven by the members of the *EEBus Initiative e.V.*, a non-profit association located in Germany. EEBUS primarily uses standardised message formats based on the JSON[10] data interchange format. Additionally, EEBUS may utilise other standard formats or protocols for specific communication needs. The EEBUS documentation includes multiple use cases in the E-mobility sector, for example, Coordinated EV Charging, EV Commissioning and Configuration.[11]

1.3 Energy Management Systems

To best utilise the different energy resources of a flexible EV charging infrastructure, including a sufficient grid access capacity, optional energy buffering, and smart EV charging operation, some overarching management means seem

[9] `https://evroaming.org/app/uploads/2020/06/OCPI-2.2-d2.pdf`
[10] JavaScript Object Notation, `https://www.json.org/json-en.html`
[11] `https://www.eebus.org/wp-content/uploads/2023/04/20221222-EEBUS-Overview-Use-Cases-v1.7.pdf`

appropriate and required.

First, monitoring is required because without knowing the current state of the local infrastructure, management decisions can be based on assumptions only. The more detailed the knowledge of component states is, the better can these components be managed. However, more data does not necessarily yield better decisions. Understanding the available data and how the data is achieved can be essential. For example, billing related data on the energy charged per charging event will hardly reveal that the fast charging performance of EVs depends on the state-of-charge and the temperature.

Many different options for EMSs are available on the market, which differ in price, applicability, and management options. A deliverable from the WHY project provides examples of EMS for Open Source, Research, and Commercial categories. [todo: add ref.: `https://www.why-h2020.eu/fileadmin/user_upload/20WHY_D1.2.pdf`]

◇ **OpenEMS** [12] is a modular platform for energy management applications written mainly in Java. It was created with the need to integrate, monitor, and manage energy storage with renewable energy sources, as well as supplementary equipment and services like heat pumps, electric vehicle charging stations, and time-of-use power tariffs, among other things. The OpenEMS project is driven by the OpenEMS Association e.V.[13].

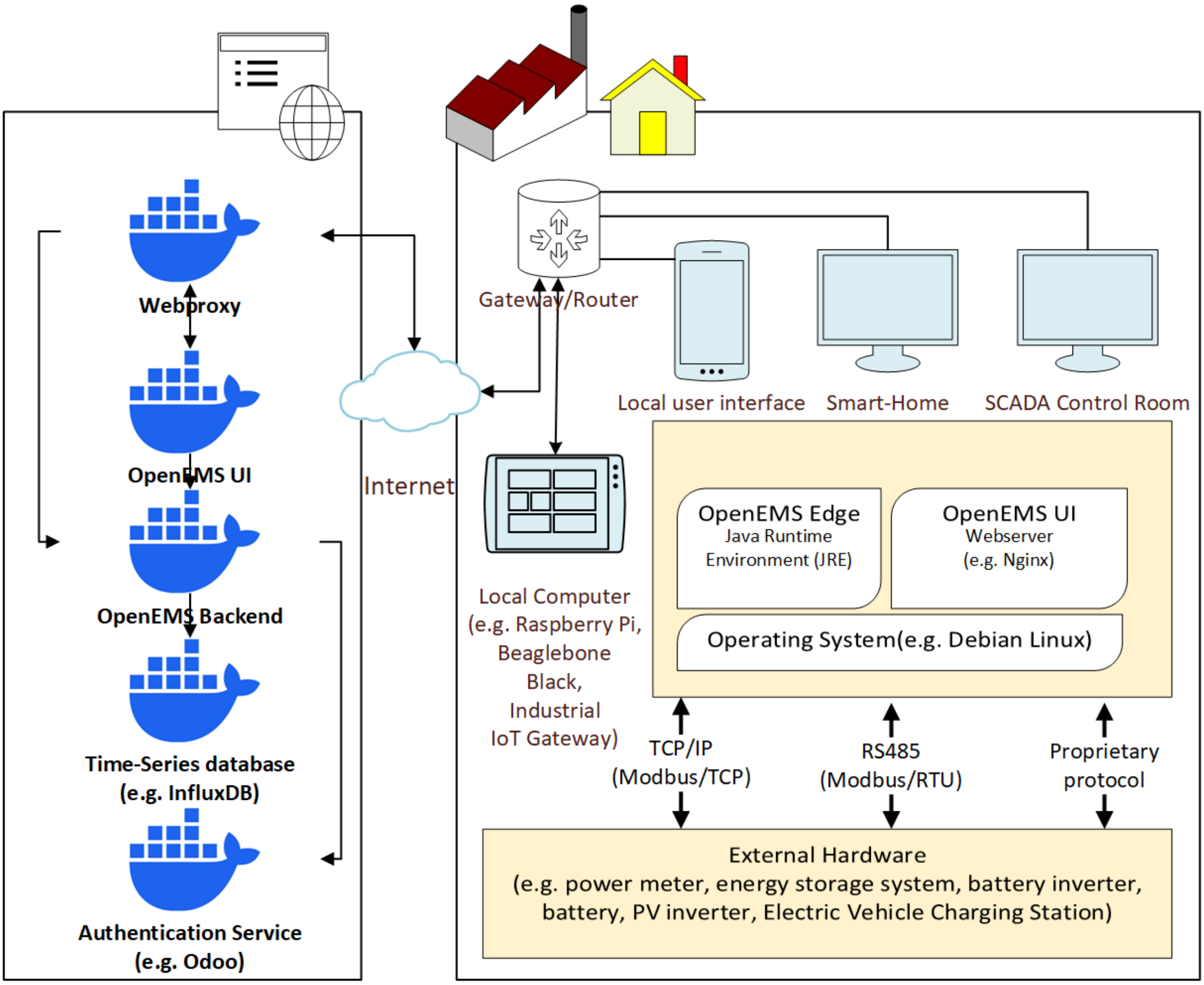

Figure 1.3.1: OpenEMS system architecture

[12] `https://github.com/OpenEMS/openems`
[13] `https://openems.io/association`

The OpenEMS IoT stack contains OpenEMS Edge, OpenEMS UI, and OpenEMS Backend. OpenEMS Edge and OpenEMS Backend can be used under the terms of the Eclipse Public License version 2.0 [14], and OpenEMS UI can be used under the terms of the GNU Affero General Public License version 3 [15]. Physical hardware is abstracted in OpenEMS Edge using Natures. A Nature defines a set of characteristics and attributes that need to be provided by each OpenEMS component that implements it. These characteristics are defined by Channels. Technically Natures are implemented as OSGi API Bundles. Also, the Nature provides an EVCS (Electric Vehicle Charging Station). The following devices and services are provided by the OpenEMS Edge[16].

- EVCS: Controls an Electric Vehicle Charging Station (EVCS) in different modes, like "Force-Charge" and "Surplus Energy Charging".
- EVCS Fix Active Power: Sets the maximum charge power offered by the EVCS. These are a couple of steps that should be helpful to implement a new EVCS component. Note: some parts may still be missing.
- Electric Vehicle Charging Station OCPP Common: The whole bundle contains a library of the OCPP functions. It also provides a default abstract ocpp EVCS component that can be used by every specific charging station and an OcppServer interface that provides the minimum functionality to send data to a charging station.
- OCPP Server
- dezony IQ Charging Station
- Go-e Charger Home Charging Station
- Hardy Barth Charging Station (Salia)
- KEBA KeContact c-series Charging Station
- ABL Charging Station
- IES KeyWatt Charging Station
- Webasto Next Charging Station
- Webasto Unite Charging Station

1.3.1 SCADA

Supervisory Control and Data Acquisition (SCADA) serves as a centralized system that allows operators to monitor, control, and manage various aspects of energy generation, transmission, and distribution in real-time.

SCADA systems gather real-time data from various sensors, meters, and devices deployed throughout the energy network, and enable operators to remotely monitor and control energy generation, transmission, and distribution processes. Through a centralized interface, operators can view the status of equipment, adjust settings, and issue commands to optimize system operation.

SCADA systems often integrate with EMS to provide a comprehensive solution for energy monitoring and control. While SCADA focuses on real-time monitoring and control at the operational level, EMS offers higher-level functionalities such as energy forecasting, demand management, and optimization of energy resources. Integration between SCADA and EMS enables seamless coordination and decision-making across all levels of the energy infrastructure.

1.4 Legal and regulatory constraints

The re-selling of electric energy purchased by an end-customer from an energy supplier is in general not legitimate. Energy trading is a regulated business. Thus, the charging of EVs with energy purchased from an energy supplier, i.e., via an EV charging point supplied with energy from behind the energy meter, is restricted to charging EVs owned and operated by the end-customer that signed the supply contract with the energy supplier.

[14] https://github.com/OpenEMS/openems/blob/develop/LICENSE-EPL-2.0
[15] https://github.com/OpenEMS/openems/blob/develop/LICENSE-AGPL-3.0
[16] https://openems.github.io/openems.io/openems/latest/edge/device_service.html

However, the energy used for charging an EV not owned and operated by the energy customer may be provided for free without legal consequences. Self-produced renewable energy, e.g., from a customer owned PV system buffered in a customer owned battery, may be forwarded peer-to-peer (independent of the energy market) according to the RED II EU directive 2018/2001, at least if generation and buffering are not connected to the public grid, i.e., constitute a grid independent energy island. However, operating an independent micro-grid with highly volatile demands is challenging and the battery capacity required for reliable operation probably rather not affordable.

The only legal entity that can operate public EV charging stations completely on their own, are the energy suppliers. All others need a legitimate energy trader to perform the billing. But everyone can install and operate an own CS for private use.

1.4.1 EV charging and Energy Communities

An interesting exception may be EV charging points that belong to a Renewable Energy Community (REC). For Energy Communities, the sharing and trading of self-produced energy is legitimate. Thus, if EV charging points have an own energy meter that is registered as part of a REC, the energy provided by community peers can be sold, but not the shares provided by an energy supplier. How big the share from community peers is, can only be determined a posterior when all the contributing meter values become merged to calculate the static or dynamic shares assignment. To assure no shares purchased from regular energy suppliers are used for the charging of EVs not owned by the community itself, the charging point would need to be curtailed to use no more than the share provided by community peers. Real-time energy flow monitoring across all REC members and real-time charging power curtailment would be required to achieve that; as of today, a requirement that is considered not achievable.

In the case of Citizen Energy Communities (CEC), the purchase of the energy produced and consumed by the community peers is possibly concentrated in the CEC operation entity. The management of a CEC is more market oriented and comparable to a peers owned and peers governed aggregator. If the CEC purchases energy from the energy market and participated in the balancing, it probably can fulfil the regulatory obligations for energy trading as well. In that case, the CEC can operate both, the EV charging stations of peers and those jointly owned by the CEC, and covers both, the CPO and the CSM role.

1.4.2 Outsourcing the billing to charging point operators

The common solution is to outsource the billing to a charging point operator (CPO) that fulfils all legal and regulatory obligations applicable for energy trading. The EV driver wishing to charge an EV at the provided charging point registers with the CPO using an ID from a charging card operator or via a credit or debit card, and purchases the energy charged from the CPO, not from the CS owner/provider.

In case the CS has no dedicated grid access point and meter, i.e., is supplied from behind the meter, the CPO has to remunerates the CP provider for the share of self-produced energy that is sold to EV drivers and has to purchase the remaining energy share used for the EV charging on the energy market on its behalf. Latter shares need to be deducted from the energy demand metered for the grid access point prior being forwarded to the energy supplier of the CS provider.

Note: If the CS owner/provider charges at a such managed CP an own EV, or the EV of a friend to whom the charged energy is forwarded for free, no billing is required because the energy charged is either self-produced or covered by the energy meter of the CS provider. However, to inform the CPO about the self-consumption, and for the unlocking of the CP, registration with a dedicated ID (or a physical key) is still required.

CPOs commonly rely on the OCPP communication protocols to connect to the charging points they operate and receive the information required to perform the billing. The interruption of this vital connection can cause lost revenue and inoperable charging points due to the inability to register payment means with the CPO.

1.5 Remarks on bidirectional charging (V2X)

In average, an EV battery with a usable capacity of 60 kWh can supply a regular household with an annual energy demand of 3600 kWh, for 6 days or 146 hours. Basically, the battery of an EV could power any DC load that can handle the operation voltage of the battery and does not draw more power than the battery can deliver. Typical EV battery voltage levels range from about 400 V to beyond 800 V and short-circuit protection is evidently required to prevent sever harm. Thus, a direct DC connection to the battery itself is commonly not provided. The available V2X (vehicle-to-something) options include:

- **12 V DC** → supply for low power onboard devices (e.g., smartphone charger)
- **48 V DC** → supply for an 48 V onboard grid (e.g., trucks, camping, etc.)
- **230 V AC** → 1-phase 16 A supply for regular household loads (V2L)
- **230/400 V AC** → 1-/3-phase supply for charging another EV (V2V)
- **230/400 V AC** → 1-/3-phase supply for a private grid island (V2H)
- **230/400 V AC** → 1-/3-phase grid synchronous power insertion (V2G)

The first three are dedicated for common customer applications, i.e., limited to low power levels, vehicle to load (V2L) up to 3.7 kW. Charging one EV from another EV (V2V) is an interesting emergency option in case an EV completely emptied its battery along the road. Knowing that the power is transferred via DC-AC ∼ AC-DC return conversion, the quality of the AC power is secondary, a clean sinus is not required. Thus, connecting a different electric device might cause unexpected problems. Supplying a private home (V2H) offers short term energy autonomy (island) until the EV needs to be re-charged. An interesting option for private black-out provisions and the owners of real properties that cannot be connect to the public grid, e.g., a chalet/lodge with low electricity demand. Grid-connected discharging of electricity from the EV battery into the household grid (V2G) can be economic if the EV is either used as PV buffer-battery or as intra-day-battery. Former, to use the own PV energy at different times, latter, where the energy prices vary such that timely scheduling the EV charging and discharging can save energy costs or even gain profit from offering ancillary grid services.

Any V2G solution needs to comply with the technical requirements raised by regional regulation for energy inserting assets. These regulations prevent the asset from harming the stability of the public grid, e.g., prevent the insertion of AC out of phase, and at the same time protect the asset from harm by forcing disconnection whenever irregular grid conditions persist. Short irregularities have to be tolerated (ride through) to prevent avoidable disconnection avalanches and exponential error propagation.

2 Business Functions

Different functionalities are required to enable a business. In a top-down approach, and for layered systems in general, the technology used to implement a functionality shall be exchangeable. Therefore, the so called *Business Functions* are defined technology agnostic, i.e., independent of their actual implementation. Business Functions specify which (meta-)actors are involved and what is achieved, i.e., the *use case*, no more. High level UML use case diagrams are a common approach to achieve this.

Figure 2.0.1 shows an overview of the primary *use cases* required to perform managed EV charging. On the right, it shows the local actors directly involved in the charging execution, and on the left, the functionally remote (optional) actors that are required to support public and smart charging only.

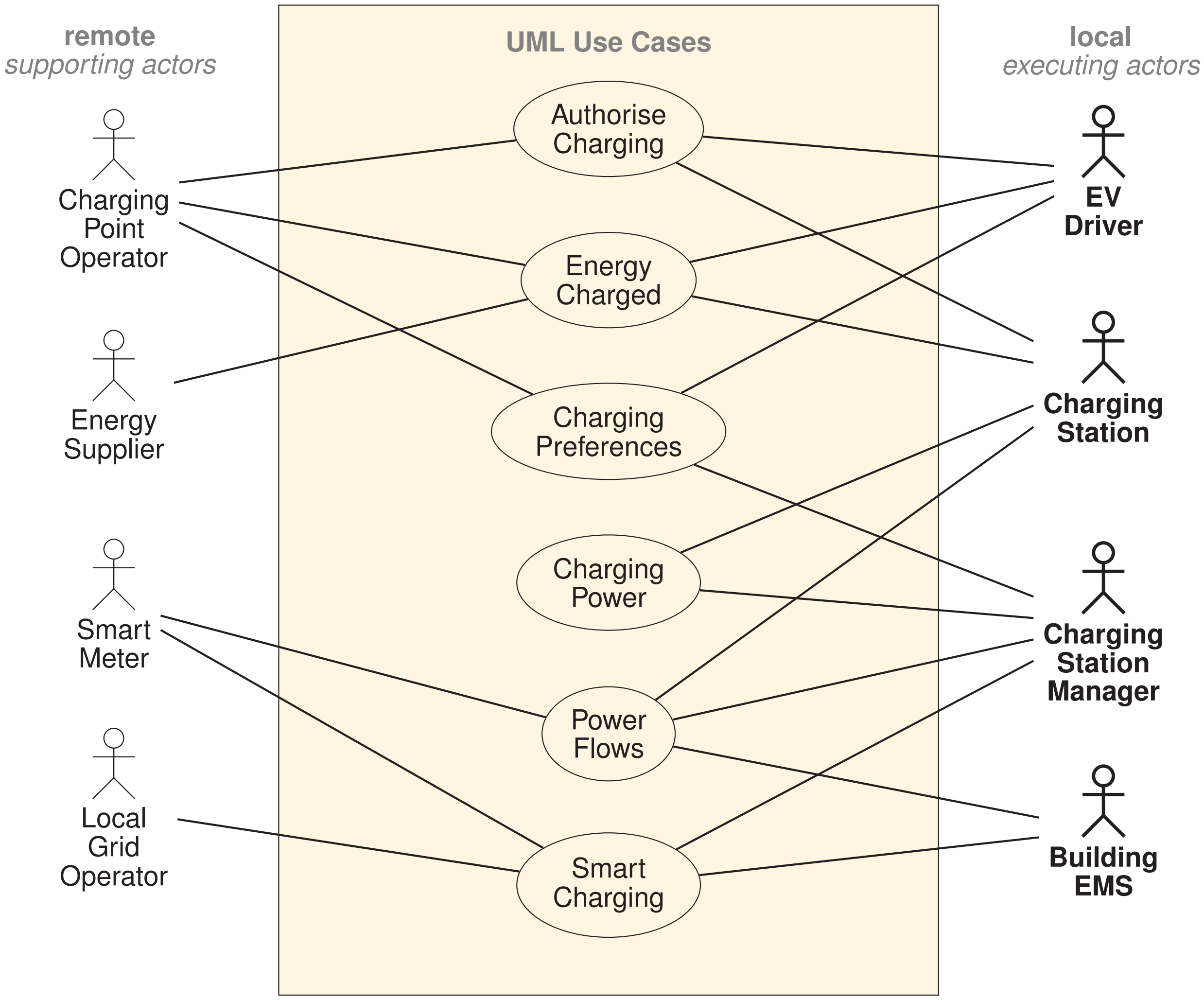

Figure 2.0.1: EVC Business Functions Overview

In the case that an actor is not present, also the according links vanish and some use case(s) may become obsolete. If CSM and ESM are implemented by one actor, some links merge. Without either, the CS performs remaining CSM features, i.e., may dynamically set the charging power dependent on the current power flow reported by the SM.

The *use cases* are:

◇ **Authorise Charging** is executed by the CS internally if no CPO and/or CSP is involved.

◇ **Energy Charged** is performed by the CS and forwarded to CPO, and EV driver.[1]

◇ **Charging Preferences** provides EV driver wishes, either via user interface or data from the CSP.

◇ **Charging Power** is dynamically performed by the CSM or statically set when the CS is installed.

◇ **Power Flows** is performed by both, the SM and the CS. CSM and EMS are receivers only.

◇ **Smart Charging** is the most complex use case, essentially needed to perform charging management: Based on the information provided by the SM on the currently drawn power, the grid access limit set by the DSO, and from the BEMS the building's current power demand, the total available power for the entire group of managed CSs is determined. Recorded data may be used to do solid predictions based on normalised power profiles, trend prediction, machine learning, or AI including also correlated environmental data. For complex predictions, their generation might be better covered by a dedicated generic "Prediction" use case.

The business functions to which these relate are outlined next.

2.1 Accounting

The site owner, the CPO, the EV driver, and the CSP need to know the amount of energy that is consumed by the EV charging.

- **Site owner:** to calculate cost versus profit of providing EV charging on its premises.
- **CPO:** to dynamically control the power used by the managed charging points.
- **EV driver:** to see for how much energy/time the charging bill may be issued.
- **CSP** (Energy Supplier): to correctly bill the EV driver and buy energy on the energy market.

The use cases relevant for this Business Function are:

- Authorise Charging
- Charging Preferences
- Energy Charged

The entities involved are:

- EV Driver
- Charging Station (CS)
- Charging Station Manager (CSM)
- Charging Point Operator (CPO)

If the energy for EV charging is provided by a dedicated "EV-charging as a Service" supplier (e.g., an CSP), this entity may be included in addition to the listed. However, if no real-time charging control via control signals from the CSP is implemented, the information provided in the billing process is in general sufficient.

Note: Recording the charged energy is commonly performed by the EV (charging electronics) to calculate the state-of-charge, which is not directly mensurable. However, that information is displayed to the driver on-board and maybe via a web-app, but that recording does not include charging losses and is in general not disclosed to third parties.

[1] If the charging is paid via some CSPs *charging card*, the CPO forwards the charging information to the according CSP to whom the EV driver ID belongs.

2.2 Billing

For public accessible charging points, some billing opportunity is commonly required. Direct on-site billing, as it is still common for conventional petrol stations, is yet rarely provided for EV charging.

Most common is authorisation and billing via a *charging card* provided by an CSP. Prices are negotiated with the CSP, and are commonly considerably cheaper than for direct billing using a credit or debit card. In latter case, the electronic acceptance of the credit/debit card works as authorisation.

To correctly bill the EV charging, the CS needs to record the charged energy and/or the time the EV is connected to the CS. This information is commonly stored and displayed locally, and forwarded to the CPO, and further on to an CSP or a debit/credit card operator.

The use cases relevant for this Business Function are:

- Authorise Charging
- Charging Preferences
- Energy Charged
- (Charging Power)

The *Charging Power* use case is relevant if the price for the charged energy depends on the charging power provided by the charging station.

The entities involved are:

- EV Driver
- Charging Point Operator (CPO)
- Charging Service Provider (CSP)

Note: When the CPO (or the site-owner acting as local CPO) bills the EV driver directly, i.e., in cash, via bank transfer, or by credit-/debit-card, the CSP is not involved.

2.3 Optimising

This Business Function is the most complex and needs the inter-operation of several systems. Optimisation can be achieved in different flavours and for different aims. In general, a multi-objective approach is required to cover the needs and wishes of the involved entities.

- **EV driver:** wants cheap, fast, reliable charging whenever the EV is plugged in.
- **Site owner:** wants minimal operational costs and satisfied EV drivers (clients).
- **CPO:** wants maximally flexible charging demands that can be perfectly spread over time.
- **DSO** (Local Grid Operator): wants a smooth grid load and no violation of grid access limits.
- **CSP** (Energy Supplier): wants an aggregated demand over time that matches with the energy purchased.

Optimisation can be achieved by real-time feedback loops or by prediction, or combinations thereof, e.g., forecasting and machine learning. Where sufficient in-time feedback is not possible, prediction is the only solution. However, the demand for data is the same, only the timing constraints are different.

The use cases relevant for this Business Function are:

- Smart Charging
- Charging Preferences
- Charging Power
- Power Flows

The *Power Flows* use case provides the information on the current on-site power production and consumption. The $\pm$ power change for the smart EV charging is thereby determined as

$$\Delta P_{\text{max}}^{\text{EV}}(t) = P_{\text{max}}^{\text{grid}} + P_{\text{prod}}(t) - P_{\text{cons}}(t)$$

where '$+$' indicates a possible EV charging increase and '$-$' states a required EV charging decrease. However, only a decent *Building EMS* can provide the currently produced and consumed power separately. Smart Meters provide the $\pm$ power drawn from the grid only, i.e., $P_{\text{meter}}^{\text{SM}}(t) = P_{\text{cons}}(t) - P_{\text{prod}}(t)$, such that

$$\Delta P_{\text{max}}^{\text{EV}}(t) = P_{\text{max}}^{\text{grid}} - P_{\text{meter}}^{\text{SM}}(t)$$

assuming that currently inserted power is communicated as negative power demand.

The entities involved are:

- Charging Station (CS)
- Charging Station Manager (CSM)
- Local Grid Operator (DSO)
- Smart Meter (SM)
- Building EMS
- EV Driver

Until EVs reveal their charging capacity (in kWh) to the CS via the digital communication over the charging cable, the energy that the EV can charge is not known to the CSM and needs to be provided by the EV driver, i.e., transferring the on-board SoC information either manually or via some cloud service to the CSM. The time until the EV shall be charged and to which minimal SoC it shall be charged until that time always needs to be provided by the EV driver and is considered to be included in the *Charging Preferences*. If not available, the expected charging time and demand need to be guessed (i.e., predicted).

Note: Internal processes, e.g., how the charging of several connected EVs is performed – in parallel, sequential or somehow else, are operation problems and not interoperability issues. How the power limiting is enforced by the CSM via the managed CSs and how the CSM receives the required information from the other entities involved, are interoperability issues.

3 Actors-Transactions-Diagram & Use-Case-Overview

The Actors-Transactions-Diagram presents the system architecture on the meta-actor level and depicts the required connectivity and implicitly the inter-operation demand. Each connection states the applicable technical Use Cases outlined in Section 3.2 or the business function it refers to.[1]

3.1 Actors-Transactions-Diagram

The transactions relevant for integrated smart charging management are summarised in Figure 3.1.1. The abbreviations included refer to the technical use cases outlined in section 3.2, the variables refer to the information that needs to be mutually shared among the involved systems.

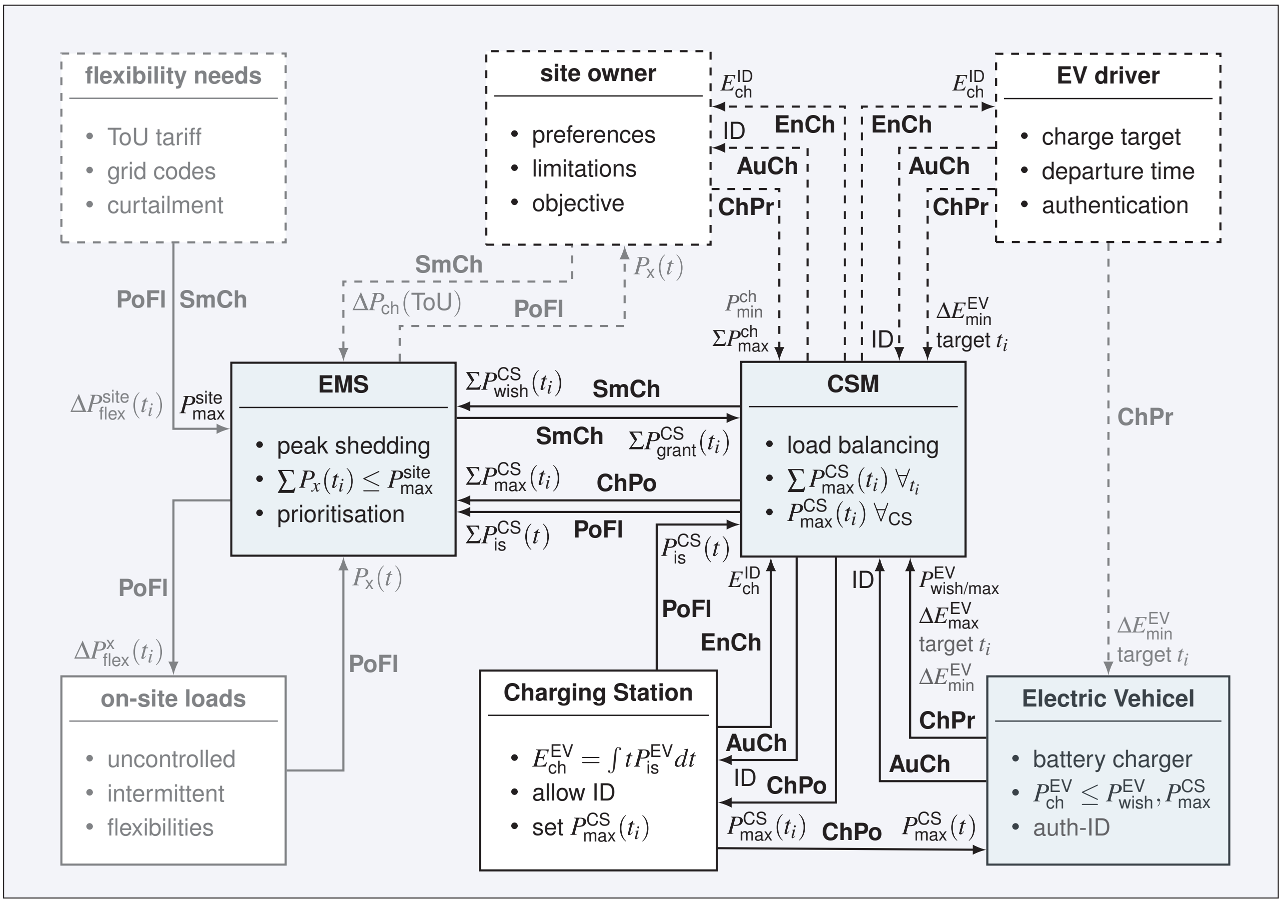

Figure 3.1.1: Actors-Transactions-Diagram

If we compare the actors in Figure 3.1.1 with the business functions outlined in section 2 we can identify some differences because we now look at the system-of-systems from a slightly lower perspective. Due to that focus, some meta-actors are no more visible because they are not involved here (e.g., energy supplier, CSP, DSO), others appear because from a higher viewpoint they were hidden underneath a meta-actor but now become relevant (e.g., grid codes, flexibility needs, on-site loads). However, all these are peripheral actors not directly involved in the CSM

[1] Multiple connections are used if multiple Business Functions cause a connection of the same meta-actors because the connected software modules (actors) are in general different for different Business Functions. If different IES Integration Profiles are available for the same connection, they are listed in parallel.

integration (shown greyed). That the information exchanged with these systems is available is a precondition only. The systems relevant for cooperative CSM integration with ESM are:

- EV driver
- electric vehicle (EV)
- charging station (CS)
- charging station management (CSM)
- building energy management system (EMS)
- site owner

These, and the intermediary systems required to digitally connect them, e.g., user interfaces, need to be interoperable to enable smart charging in utile cooperation with a local EMS.

3.2 Identified Use Cases

The identified Use Cases that shall be considered for developing Integration Profiles in case interoperability issues exist, are briefly described and where relevant commented in respect to their needs and the variety of their demands and implementation.

3.2.1 Authorise Charging (AuCh)

For EV charging at private premises, authorisation is in general implicitly included with the access to the charging point, which in general is not openly accessible. Where this is not the case, e.g., at company parking spaces, the charging point my be activated with a mechanical key-lock or a private RFID chip provided by the owner. The energy charged is always paid by the owner of the charging point, separate billing is not foreseen.

For public accessible charging points, some billing opportunity is commonly required. Direct on-site billing, as it is still common for conventional petrol stations, is yet rarely provided for EV charging.

Most common is authorisation and billing via a *charging card* provided by an CSP. Prices are negotiated with the CSP, and are commonly considerably cheaper than for direct billing using a credit or debit card. In latter case, the electronic acceptance of the credit/debit card works as authorisation.

To authorise the charging, the CPO needs a contract with the credit/debit card operator and/or the CSP, and a digital connection to that authority. The card ID is than sent electronically to the according authority, which checks the validity of the provided ID, how the charging price is determined, e.g., per minute or kWh (or a combination), and thus, which price is billed to that authority, which then issues the (monthly) bill to the EV driver.

3.2.2 Charging Preferences (ChPr)

In general it is nowadays assumed that the EV shall be charged instantly when connected to the charging point. This is straightforward but not always necessary, in particular when the EV remains connected for a prolonged time, e.g., while an employee is at work or overnight while the EV driver sleeps.

In these cases, the EV driver may provide preferences on:

- the minimum & maximum charging demand $\Delta E^{\mathrm{EV}}_{\mathrm{min}}$, $\Delta E^{\mathrm{EV}}_{\mathrm{max}}$ [kWh]
- the target time t_i until the EV shall be charged [`yyyy.mm.dd hh:mm`]
- the maximum energy cost C_{max} [$/kWh]
  (a) until minimum charging demand $\Delta E^{\mathrm{EV}}_{\mathrm{min}}$ is fulfilled
  (b) for charging beyond the minimum demand $\Delta E^{\mathrm{EV}}_{\mathrm{min}}$ up to $\Delta E^{\mathrm{EV}}_{\mathrm{max}}$

To get these parameters, the CSM needs to provide a user interface and/or a digital interface to get this information from the EV driver and/or the EV itself via the charging cable (IEC 15118) respectively.

Note: In the case of EV drivers that regularly connect to charging points managed by the CSM, the preferences might also be derived automatically from recorded charging events. However, a UI allowing the EV driver to occasionally overrule the learned charging pattern needs to be provided in any case.

For public charging, the preferences might also be provided by the CSP, in particular when the EV driver has a contract that requires managed charging, e.g., exclusively from renewable sources or at times the CSP specifies. The interface is in that case completely digital, i.e., an API instead of UI or charging cable. However, the exchanged information shall be the same, both in the semantic meaning and the syntactic format, such that no extra specification is needed.

3.2.3 Energy Charged (EnCh)

To correctly bill the EV charging, the CS needs to record the charged energy and/or the time the EV is connected to the CS. This information is commonly stored and displayed locally, and forwarded to the CPO, and further on to an CSP or a debit/credit card operator.

The data commonly includes (at least):

- the start time t_{start} [`yyyy.mm.dd hh:mm`]
- the end time t_{end} [`yyyy.mm.dd hh:mm`] or charging duration Δt [`hh:mm`]
- the energy charged $E_{\text{ch}}^{\text{ID}}$ [kWh]
- the billable price $C_{t_{\text{end}}}^{\text{ID}}$ [$/kWh and/or $/h]

Where the site owner is not the CPO, he might be bypassed. To learn charging patterns for predictive charging control, that data would be required. To overcome this shortcoming, refer to the *Power Flow* subsection.

Note: Recording of the charged energy $E_{\text{ch}}^{\text{ID}}$ is commonly performed by the EV's charging electronics to calculate the state-of-charge, which is not directly mensurable. However, that information is displayed to the EV driver on-board and maybe via a web-app, but that recording does not include EV internal and external charging losses and is not used for the billing and thus in general not disclosed to any third parties.

3.2.4 Charging Power (ChPo)

The actual charging power $\text{P}_{\text{is}}^{\text{CS}}$(t) [kW] is the minimum of the following four limits:

- the power supported by the EV charging electronics $P_{\text{max}}^{\text{EV}}$
- the power supported by the charging station (plug type) $P_{\text{max}}^{\text{CS}}$
- the dynamically set power limit set by the CSM $P_{\text{max}}^{\text{CS}}(t_i)$
- the power the EV charging electronics wishes to get $P_{\text{wish}}^{\text{EV}}(\text{SoC,T,etc.})$

The first two, $P_{\text{max}}^{\text{EV}}$ and $P_{\text{max}}^{\text{CS}}$, are the technical limits defined by the EV and the CS respectively. The dynamically set $P_{\text{max}}^{\text{CS}}(t_i)$ introduces the smart charging option. Finally, the $P_{\text{wish}}^{\text{EV}}(\text{SoC,T,etc.})$ considers environmental impacts on the practically possible charging power, e.g., the state-of-charge and temperature dependence.

For fast DC charging, $P_{\text{ch}}^{\text{EV}}(t)$ cannot be assumed constant. With smart charging, higher price for fast charging needs to be reconsidered, and time based billing needs to be queried.

3.2.5 Power Flow Management (PoFl)

Basically, this feature is provided by a fuse box to prevent dangerous over-current on circuits. However, if circuits are cascaded and accordingly protected by fuses, in general the hierarchically upper fuse (e.g., grid access fuse) restricts the current to less than the sum of the fuses on the layer below because it is very unlikely that all lower layer circuits k are fully utilised simultaneously. Power Flow Management shall ensure that this rare event never happens:

$$\sum_k P_{\text{used}}^{i\in k}(t) \leq P_{\text{max}}^{\text{grid}} \leq \sum_k P_{\text{fuse}}(k) \quad \forall t \tag{3.2.5.1}$$

To actively manage power flows, manageable loads are required. Smart EV charging is a perfect candidate, like all appliances where energy is in some way buffered, e.g., hot water boilers and electric room heating systems.

The data required includes:

- the grid access limit $P_{\text{max}}^{\text{grid}}$ from DSO
- the maximum power a circuit can handle $P_{\text{fuse}}(k)$
- the power drawn and inserted along circuit k $\pm P_{\text{used}}^{i\in k}(t)$ from assets or attached meters
- the power variation that an asset can be adjusted $\pm\Delta P_{\text{max}}^{i\in k}(t)$ from assets or EMS

If $\sum_{i\in k} P_{\text{used}}^{i\in k}(t) > P_{\text{max}}(k)$ the $\pm\Delta P_{\text{max}}^{i\in k}(t)$ are used as much as required to restore $\sum_{i\in k} P_{\text{used}}^{i\in k}(t) \leq P_{\text{max}}(k)$. However, the $\pm\Delta P_{\text{max}}^{i\in k}(t)$ commonly depend on the current state of the asset and thus, cannot be guaranteed. Emergency load shedding by disconnecting devices, for example executed by blowing a fuse, cannot be substituted by power flow management; preventable load shedding can be mitigated only. Still, the attached capacity can be significantly increased if a sufficient $\sum k\Delta P_{\text{max}}^{i\in k}(t)$ can be assured available $\forall t$.

3.2.6 Smart Charging (SmCh)

This functionality is the most complex and needs some calculation. On the back-end, it involves the local DSO, which sets the grid access power limit $P_{\text{max}}^{\text{grid}}$, the Smart Meter, which states how much power is currently drawn from the grid or is currently inserted $\pm P_{\text{meter}}(t)$. On the front-end, it involves the building EMS, which states the demand of building/company appliances $P_{\text{used}}^{\text{EMS}}(t)$ and the available local generated power $P_{\text{gen}}^{\text{EMS}}(t)$ and stored renewable energy $E_{\text{stored}}^{\text{ESS}}(t)$, and finally the CSM, which states the power that might currently be used to charge the currently connected EVs $P_{\text{wished}}^{\text{EV}}(t)$ and the minimum total charging power required to charge the connected EVs to their driver's needs $P_{\text{needed}}^{\text{EV}}(t)$.

The task is to calculate $P_{\text{granted}}^{\text{EV}}(t)$ such that

$$|\pm P_{\text{meter}}(t^+)| = |P_{\text{used}}^{\text{EMS}}(t) - P_{\text{gen}}^{\text{EMS}}(t) + P_{\text{granted}}^{\text{EV}}(t^+)| \leq P_{\text{max}}^{\text{grid}} \tag{3.2.6.1}$$

constrained by

$$P_{\text{needed}}^{\text{EV}}(t) \leq P_{\text{granted}}^{\text{EV}}(t^+) \leq P_{\text{wished}}^{\text{EV}}(t) \tag{3.2.6.2}$$

If the condition in 3.2.6.2 cannot be met and stored energy is available from a local ESS ($E_{\text{stored}}^{\text{ESS}}(t) > E_{\text{min}}^{\text{ESS}}$), stored energy needs to be used to fulfil the minimum needs:

$$P_{\text{gen}}^{\text{ESS}}(t^+) \geq P_{\text{used}}^{\text{EMS}}(t) - P_{\text{gen}}^{\text{EMS}}(t) + P_{\text{needed}}^{\text{EV}}(t^+) - P_{\text{max}}^{\text{grid}} \tag{3.2.6.3}$$

constrained by

$$P_{\text{gen}}^{\text{ESS}}(t) \leq P_{\text{max}}^{\text{ESS}} \qquad \& \qquad E_{\text{stored}}^{\text{ESS}}(t) - E_{\text{min}}^{\text{ESS}} \geq \Delta t P_{\text{gen}}^{\text{ESS}}(t^+) \tag{3.2.6.4}$$

where the former constraint implements the ESS discharging power limit and the latter assures that until the next re-calculation in Δt time units, the ESS is not discharged beyond $E^{\text{ESS}}_{\text{min}}$.

The above calculations do not consider any prediction based optimisation. These calculations state the boundary at time t only. Any consideration of expected power demand/generation changes can be included within the stated limits only. Therefore, the grid access limit $P^{\text{grid}}_{\text{max}}$ will in general not always be exploited, neither will the granted EV charging power $P^{\text{EV}}_{\text{granted}}(t^+)$ always be the maximum possible at time t. In many situations it might be more smart to load the EVs less fast and save the energy in the local ESS for later use.

The required *transactions* (data exchange procedures) among involved systems concern:

- EMS gets $P^{\text{grid}}_{\text{max}}$ and $\pm P_{\text{meter}}(t)$ from Smart Meter
- EMS gets $P_{\text{gen}}(t)$ and $P^{\text{ESS}}_{\text{max}}$, $E^{\text{ESS}}_{\text{stored}}(t) - E^{\text{ESS}}_{\text{min}}$, etc. from local DERs
- EMS gets $P^{\text{CSM}}_{\text{needed}}(t)$ and $P^{\text{CSM}}_{\text{wished}}(t)$ from CSM
- EMS returns $P^{\text{CSM}}_{\text{granted}}(t^+)$ to CSM
- CSM sets $P^{\text{CS}_k}_{\text{max}}(t^+)$ for each individual charging point CS_k

The second core challenge of smart EV charging is the splitting strategy: Shall all EVs be aliquot charged in parallel or shall they be charged more sequential, one group after the other. In case the charging power is not adjustable, the individual charging processes need to be shifted in time as a whole. However, that is a CSM internal problem; the CSM needs to get the required information only, anything else needs no normative specification.

The information needed by the CSM can be split in two groups, static parameters and dynamic states:

- $P^{\text{grid}}_{\text{max}}$, $P_{\text{fuse}}(k)$, $P^{\text{ESS}}_{\text{max}}$, $P^{\text{ESS}}_{\text{min}}$, etc.
- $\pm P_{\text{meter}}(t)$, $P_{\text{gen}}(t)$, $\pm\Delta P^{i\in k}_{\text{max}}(t)$, $P^{\text{CSM}}_{\text{needed}}(t)$, $P^{\text{CSM}}_{\text{wished}}(t)$, $E^{\text{ESS}}_{\text{stored}}(t)$, $\pm\Delta P^{\text{CS}_k}_{\text{max}}(t)$, etc.

Latter may also be predicted, which than allows to shift some current loads into the near future, or vice versa, partly fulfil expected future demands earlier than needed, i.e., at times when ample power is expected to be available.

The result provided by the EMS is $P^{\text{CSM}}_{\text{granted}}(t^+)$, which than the CSM splits into individual charging power limits $P^{\text{CS}_k}_{\text{max}}(t^+)$ per charging point k to dynamically (re-)set the maximum available power.

Among EMS and CSM, only $P^{\text{CSM}}_{\text{needed}}(t^+)$, $P^{\text{CSM}}_{\text{wished}}(t^+)$, and $P^{\text{CSM}}_{\text{granted}}(t^+)$ are exchanged.

The exchanged values commonly cover some time window into the near future and may be temporally misaligned due to missing clock precision, misconfiguration, and varying communication delays. These issues can be relevant for the interoperability because without consideration, the internal processes and calculations of EMS and CSM my become derailed if potential misalignment needs to be bounded for stable operation.

3.3 Assignment of Use Cases to the Transactions specified in Vol. 2

{*Note, as of now Vol. 2 is not composed and therefore are the Transactions to be listed and assigned to use cases yet undefined and the Tables accordingly empty. Likewise can no recommendations be stated on the software modules the meta-actors shall incorporate or on the protocols required to achieve the required information exchange.***}**

The relevant transactions for the different use cases compose Vol. 2. Which transactions are required for which use case is stated in Table 3.3.0.1, and vice versa, which meta-actors participate in a transaction is stated in Table 3.3.0.2.

Table 3.3.0.1: Transactions required by a Use Case

Use Case	required Transactions
AuCh	...
ChPr	...
EnCh	...
ChPo	...
PoFl	...
SmCh	...

Table 3.3.0.2: Meta-actors involved in a Transaction

Transaction	meta-actors involved
...	EV driver (UI), EV, CS, CSM, EMS, site owner (UI)
...	EV driver (UI), EV, CS, CSM, EMS, site owner (UI)
...	EV driver (UI), EV, CS, CSM, EMS, site owner (UI)

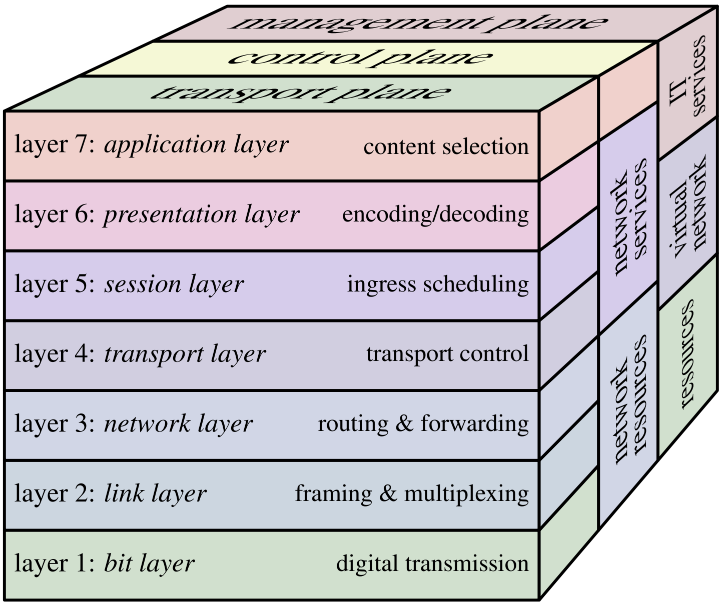

Figure 3.3.1: ITU-T X.200 – Open Systems Interconnection (OSI) model [5]

3.3.1 Digital connections

For digital communication, here-2-there & now-2-then, a digital connection is required. These connections are commonly composed by a stack of *protocols* that implements all the required functionalities and features one-by-one. Accordingly are digital connections a composition of hierarchically stacked protocols.

According to the ITU-T X.200 standard, i.e., the OSI model sketched in Figure 3.3.1, shall intermediary layers be seamlessly exchangeable. Thus, if their utility for the information exchange is equivalent, these layers comprise no interoperability issue and need no dedicated specification. If they are mentioned, than as a Solution Building Block (SBB), e.g., as an example on how the functionality can be achieved, but not as a normative requirement.[2]

Digital connections are always established layer-by-layer, as shown in Figure 3.3.2, where the lower layer connections serves the upper layer connection. Therefore, an upper layer connection can be composed of a sequence of lower layer connections (hops). To achieve that, a protocol that forwards the content transported

[2]The responsibility to choose compatible communication stacks remains with the system-of-systems designer and indirectly with the systems vendors, which need to sufficiently specify and implement the communication stacks supported (e.g., approved by certification).

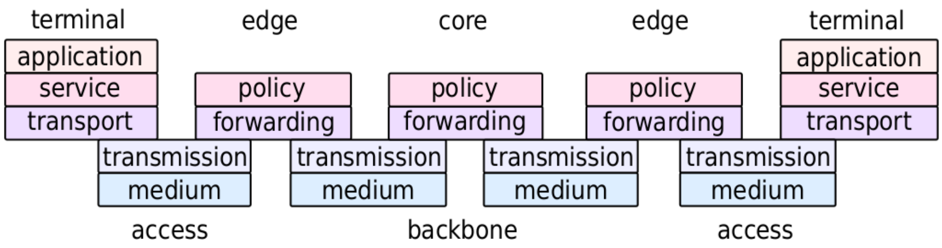

Figure 3.3.2: Composition of a generic digital connection via a hierarchy of protocol layers [5]

from one hop to the next is required. Accordingly are different software actors required to implement the protocols needed at and below the according layer.

Comparably thereto, Table 3.3.1.1 states the software actors specified in Vol. 2 that are required to implement the different connections shown in Figure 3.1.1.

Table 3.3.1.1: Actors required to operate a specific digital connection

Connection	involved actors (software modules)
driver UI – CSM ...	... to be specified in Vol. 2 ...
owner UI – CSM ...	... to be specified in Vol. 2 ...
EV – CSM ...	... to be specified in Vol. 2 ...
EV – CS ...	... to be specified in Vol. 2 ...
CS – CSM ...	... to be specified in Vol. 2 ...
CSM – EMS ...	... to be specified in Vol. 2 ...

3.3.2 Meta-actor Composition

For digital communication (here-2-there & now-2-then) a software module, i.e., an *actor*, is defined by a standards stack. Commonly, each standard specifies the features and protocols required within one layer of the ITU-T X.200 OSI model and for the interaction with the layer above and below.

To implement the Transactions specified in Vol. 2, the meta-actors need to incorporate the software modules (actors) that contribute to implementing the required features and functionalities of the specified transactions as listed in Table 3.3.2.1.

Table 3.3.2.1: Software actors required by meta-actors

Transaction	T1	T2	...
Meta-Actor	involved actors (software modules)		
driver UI	...	...	...
EV	...	...	...
CS	...	...	...
CSM	...	...	...
EMS	...	...	...
owner UI	...	...	...

Abbreviations

Every abbreviation used anywhere in the Technical Framework and accompanying documents shall be included. Product and company names that only look like being abbreviations need not be included.

AAA	Authentication Authorisation Access-control
ABB	Architecture Building Block
ABB_spec	Architecture Building Block Specifications
ADU	Application Data Unit
AMD	AMenDment
AMI	Advanced Metering Infrastructure
APDS	Application Protocol Data Units
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
BESS	Battery Electric Storage System
BF	Business Function
CAPEX	CAPital EXpenditures
CC	Creative Commons
CCTS	Core Components Technical Specification
CEC	Citizens Energy Community
CEP	Clean Energy Package
CF	Common Feature
CHP	Combined Heat and Power
CIM	Common Information Model
COAP	COnstrained Application Protocol
COSEM	Companion Specification for Energy Metering
CPA	Collaboration Protocol Agreement
CPP	Collaboration Protocol Profile
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CSM	Charging Station Management (Smart Charging)
CSO	Charging Station Operator
CSP	Charging Service Provider
CSV	Comma-Separated Values
C/EMS	Community Energy Management System
DA	Data Attribute
DACH	Germany, Austria, Switzerland
DER	Distributed Energy Resource
DLC	Direct Load Control
DLMS	Device Language Message Specification
DO	Data Object
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
EC	European Commission
EDA	Energiewirtschaftlicher Datenaustausch
EDI	Electronic Data Interchange
EHV	Extra High Voltage level
ElWOG	Elektrizitätswirtschafts- und organisationsgesetz
EMS	Energy Management System
eMSP	e-Mobility Service Provider (= CSP)
EnCo	Energy Community
ESMP	European Style Market Profile
EU	European Union
EV	Electric Vehicle
FPGA	Field-Programmable Gate Array
FSK	Frequency-Shift Keying
GNU	GNU's Not Unix!
GPIO	General-Purpose Input/Output
GPL	GNU General Public License
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HAL	Hardware Abstraction Layer
HEMS	Home Energy Management System
HDLC	High-Level Data Link Control
HTTP	Hypertext Transfer Protocol
HV	High Voltage level
I2C	Inter-Integrated Circuit
IBF	IES Business Function
ICT	Information and Communication Technology
ID	IDentifier
IEC	International Electrotechnical Commission
IED	Intelligent Energy Device
IEEE	Institute of Electrical and Electronics Engineers
IEM	Internal Electricity Market
IES	Integrating the Energy System
IETF	Internet Engineering Task Force
IHE	Integrating the Healthcare Enterprise
IIP	IES Integration Profile
IIT	IES Interoperability Testing
IMA	IES Meta-Actor
IopL	Interoperability Level
IP	Internet Protocol
ISBN	International Standard Book Number
ISO	International Organization for Standardization
IT	Information Technology
ITU	International Telecommunication Union
IUC	IES Use Case
JSON	JavaScript Object Notation
LD	Logical Device
LEC	Local Energy Community
LN	Logical Node
LN	Local Network
LV	Low Voltage level
L/GCI	Local Grid Control Instance

M/EMS	Member Energy Management System
MQTT	Message Queuing Telemetry Transport
MUC	Meta Use Case
MV	Medium Voltage level
OBIS	OBject Identification System
OFDM	Orthogonal Frequency-Division Multiplexing
OPEX	OPerational EXpenditures
OSGi	Open Services Gateway initiative
OSI	Open Systems Interconnection
OT	Operations Technology
PAN	Personal Area Network
PCC	Point of Common Coupling
PDU	Protocol Data Unit
PLC	Power Line Communication
PLC	Programmable Logic Controller
PPP	Public-Private Partnership
PSTN	Public Switched Telephone Network
PV	PhotoVoltaic
RDF	Resource Description Framework
REC	Renewable Energy Community
RES	Renewable Energy Source
REST	REpresentational State Transfer
RFC	Request For Comments
RPC	Remote Procedure Call
RTU	Remote Terminal Unit
R&D	Research and Development
SBB	Solution Building Block
SCADA	Supervisory Control And Data Acquisition
SES	Smart Energy System
SGAM	Smart Grid Architecture Model
SME	Small and Medium Business
SML	Service Modelling Language
SMTP	Simple Mail Transfer Protocol
SNMP	Simple Network Management Protocol
SOAP	Simple Object Access Protocol
TCP	Transmission Control Protocol
TE	Technische Einheit / Technical Entity
TF	Technical Framework
TSO	Transmission System Operator
UA	User Association
UBL	Universal Business Language
UCMR	Use Case Management Repository
UDP	User Datagram Protocol
UI	User Interface
UML	Unified Modelling Language
URL	Uniform Resource Locator
W3C	World Wide Web Consortium
WG	WorkGroup
Wi-Fi	trademark of the Wi-Fi Alliance
WPAN	Wireless Personal Area Network
XML	eXtensible Markup Language

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All references used to prepare, extend, or amend the Technical Framework shall be listed; possibly with embedded link.