Deliverable D1.1: Requirements for advanced charging technologies

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Executive Summary

The overall project objective of XL-Connect is to optimize the entire multidirectional charging and discharging chain - from energy provision to the end user - to create a clear benefit for all stakeholders. Therefore, ubiquitous on-demand charging solutions and controls based on an optimized charging network considering human, technical and economic factors along the entire charging chain shall be developed in XL-Connect. To meet the various challenges, a consortium of different companies and institutes with good reputation was formed, capable of viewing on the problem from all important sides and willing to contribute with their knowledge and capacities to the specific challenges. The XL-Connect consortium is composed by relevant actors from 10 European member states and associated countries: energy providers, grid operators, charge point operators, electric vehicle supply equipment providers as well as vehicle manufacturer.

As starting point for an optimal smart charging conceptualization, Work Package 1 (WP1) deals with the identification and determination of requirements for various smart charging scenarios like V1G, V2G, V2X to answer the question “what is still missing for Smart Charging?”. Therefore, a questionnaire was set up and circulated within the XL-Connect consortium to exploit the pooled competencies for the status quo analyses of commonly used V2X techniques today and to define the requirements for advanced charging concepts (to be pursued and developed in WP4). These requirements for smart charging are in line with the requirements of the different elements involved in charging and aim to exploit optimization potentials for the energy exchange (in both directions) of EV fleets (improved energy use). The relevant elements involved in charging are the EVs, the charge points (or charging stations, respectively, including the charge point operator), the smart charging providers, the distribution system operators, and the users.

The deliverable 1.1 deals with an overview of the updated requirements for the smart charging technologies (to be used in WP2 and WP3) considering the various elements involved in charging and provides an updated overview of a possible charging point installation configuration used as case study for advanced charging concepts in WP4, WP5 and WP6. This use case is also intended to be evaluated for being analysed in Task 3.1 within WP3.

Keywords: multidirectional charging and discharging, benefit for all stakeholders, elements involved in charging, smart/advanced charging, V1G, V2G, V2X.

1. Introduction

The increasing number of electric vehicles (EVs) is a major challenge for the energy system in Europe from the point of view of the charging infrastructure, but at the same time an opportunity to use promising vehicle-to-grid technologies, since V2G/V2X technologies allow charged battery energy to be fed back into the grid to compensate balance fluctuations in energy production and consumption[2]. V2G/V2X technologies can therefore play an important role in increasing grid stability and help to mitigate power quality issues. To develop optimal smart charging technologies, bidirectional charging and control strategies (to enable the use of masses of EVs in different environments and energy exchange needs), the smart combination and implementation of innovative charging concepts and technologies are necessary and pursued in the XL-Connect project and will form the basis for the virtual and real evaluations/demonstrations conducted in WP4 and WP5.

The subsequent chapters try to answer the question "what is still missing for Smart Charging?". The outcomes of the questionnaire (circulated within the XL-Connect consortium to exploit the pooled competencies[3] for the status quo analyses of commonly used V2X techniques today) are evaluated (SotA-analysis of smart charging technologies) and structured according to the relevant elements involved in charging. Then the requirements for advanced charging concepts (to be pursued and developed in WP4) will be elaborated in the form of an updated requirements agenda for smart charging technologies, leading to an innovative charging point installation configuration used as case study for advanced charging concepts in WP4, WP5 and WP6.

2. Requirements for advanced charging technologies

Figure 1 shows an overview of the key steps of the XL-Connect project concept. The development of advanced charging technologies and control mechanisms as well as advanced charging and sector coupling concepts, will form the basis for the virtual and real evaluations/demonstrations conducted in XL-Connect, while the investigation of the user behaviour as well as the analysis of the energy system and grid are crucial, to predict the future behaviour of EV owners and fleet operators as well as possible shortcomings in the electric grid and energy system.

[2] V2G/V2X technologies allow the possibility to solve the major issue that grids show nowadays: the lack of an energy storage system that offers a good efficiency.

[3] The XL-Connect consortium is composed by relevant actors from 10 European member states and associated countries: energy providers, grid operators, charge point operators, electric vehicle supply equipment providers as well as vehicle manufacturer.

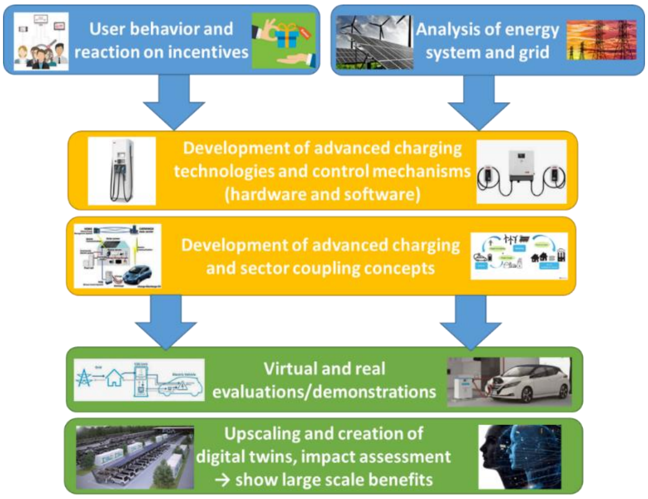

Figure 1 Key steps of the XL-Connect project concept

To attain the proposed project concept D1.1 deals with an overview of the updated requirements for the various elements involved in charging to pave the way for the smart charging technologies development within XL-Connect.

2.1. Analysis of smart charging technologies

The following subchapters are dealing with the investigated requirements (derived from the questionnaire, cf. Appendix) for the various elements involved in charging. These elements are: the EVs (incl. vehicle sizes, battery and drivetrain characteristics), charge points (incl. position; charging characteristic / power, no. of charging connectors etc.), the smart charging providers (incl. energy management, pricing), the distribution system operators (incl. required power, energy density for defined areas), and the users (incl. accessibility, easy application).

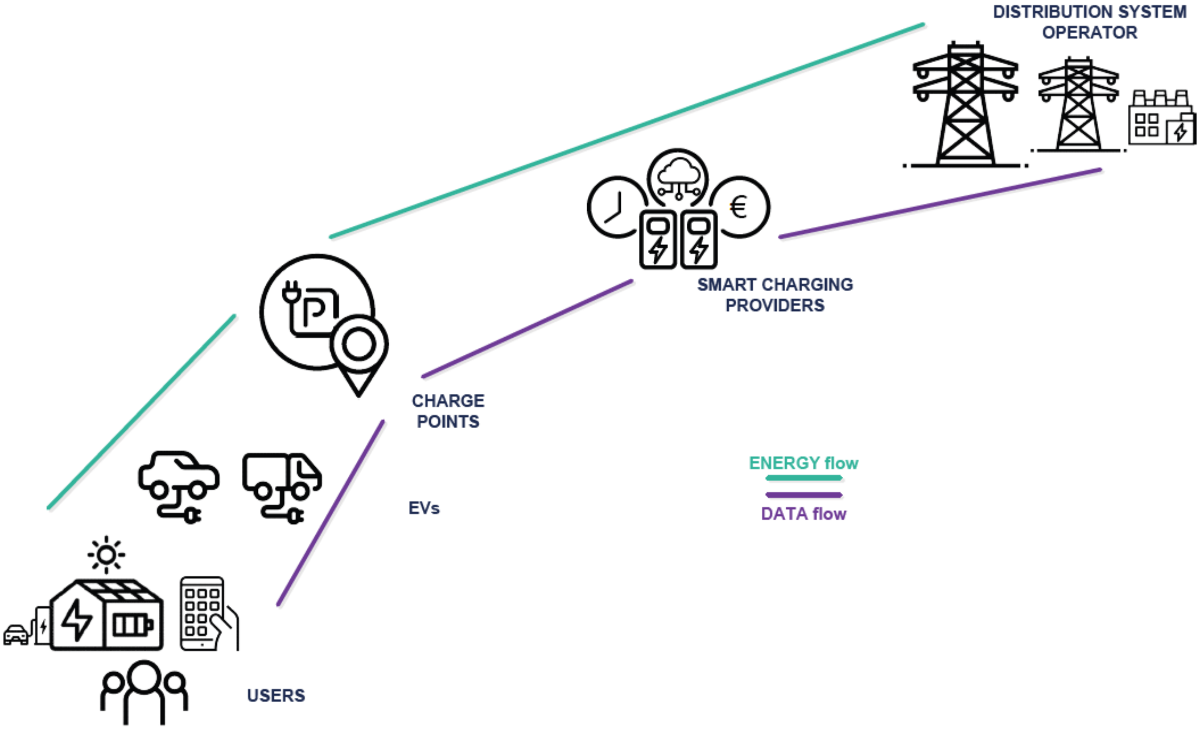

Figure 2 Various elements involved in charging

2.1.1. EV (electric vehicle)

From an EV point of view (considering the variety of various vehicle sizes and different kinds of operable vehicle types) the requirements analysis for different smart charging mechanisms can start with a SotA analysis about current standards for bidirectional charging. Their advantages and disadvantages in terms of power-quality and voltage problems for the grid as well as the impact on battery degradation associated with different bidirectional charging techniques (AC vs. DC) on EV-side will be determined and help to formulate updated requirements for advanced charging technologies on how EVs could contribute to grid stabilization, for example.

AC- and DC bidirectional charging

A basic distinction can be made between AC- and DC bidirectional charging. With bidirectional charging is meant, that the EV can be either charged or to be used to provide backup-power (V2X) e.g., to the grid (V2G) or to a building (V2B). For example, vehicles charged using solar power at work during the day could power a home through the night, without pulling power from the grid.

In addition to similarities (regarding existing plugs), the differences between the two charging methods predominate presenting distinct advantages and disadvantages.

In Figure 3 examples for commonly used plugs for AC- and DC charging of EVs in Europe according to the Combined Charging System (CCS) Type 2 (IEC 62196-2) and Combo 2 (IEC 62196-3[4]) standard are depicted. The CCS standard (CCS2 is becoming the market leader in Europe) and its establishment is driven and supported by a non-profit global association, the Charging Interface Initiative e.V. (CharIN)[5]. The Type 2 connector for AC charging is often associated with the term Type 2 Mennekes, corresponding to the German company "Mennekes Elektrotechnik GmbH & Co. KG." involved in the development.

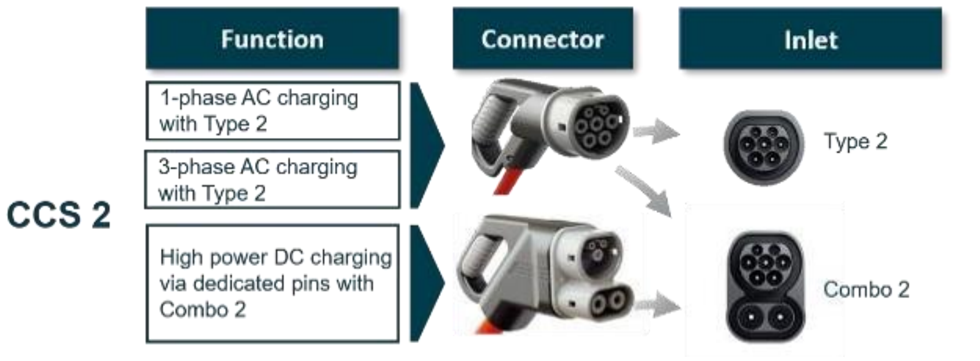

Figure 3 CCS2 connectors/plugs commonly used in Europe[6]

[4] https://en.wikipedia.org/wiki/IEC_62196
[5] https://www.charin.global
[6] https://www.charin.global/media/pages/technology/knowledge-base/8b6c60c4ad-1615552574/017charin_one_pager_connectors_used_worldwide.pdf

In addition to the Type 2/Combo 2 connector (CCS2) which is the preferred solution for AC- and DC charging in Europe, also the Type 1/Combo 1 connector (CCS1) is available, which is the preferred solution in North America (cf. Figure 4). Currently the CCS is the most promising solution covering all available types of charging: single-phase or 3-phase charging using alternating current (AC charging from 3.7 kW, Type 2) as well as DC charging using a house connection up to 22 kW or public charging stations up to 350 kW to quickly charge passenger cars (high power DC charging, Combo 2). In this context it is important to mention, that home charging is still based on SchuKo to Type 2 adaptors for many users by using small power converters i.e., an on-board charger (OBC) with 1.5-2 kW typical power.

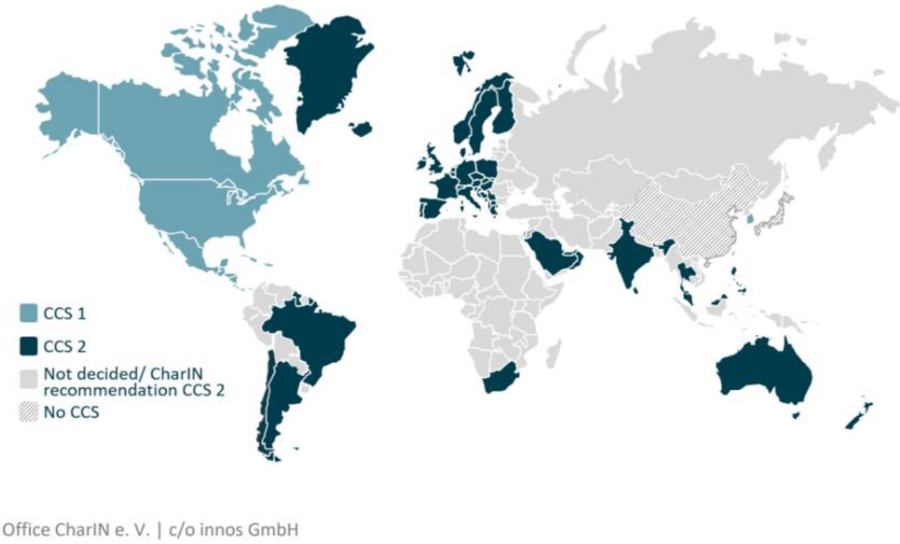

Figure 4 Connectors used worldwide[7]

Since many countries have already incorporated CCS Type 1 or Type 2 into their regulatory frameworks, other countries and regions have not yet adopted regulations supporting a specific CCS connector type. Therefore, different plug types are still used in different regions of the world, like SCAME (which was used in Italy for first generation of EVs, now it has been mostly removed there), or CHAdeMO (developed by an association, formed by the Tokyo Electric Power Company and five major Japanese automakers). One of the advantages of CHAdeMO in the past was the availability of bidirectional charging. Since the release of the ISO 15118-20 standard in April 2022, bidirectional charging is not a unique feature of CHAdeMO anymore and is used less and less in Europe.

As mentioned above, high power DC charging standards enable to quickly charge passenger cars but currently these standards are not sufficient for electrically driven commercial trucks or buses, because they will require power levels of over 2 MW to charge e.g., 500 kWh batteries in 30 minutes. In 2018, CharIN initiated the Task Force "Megawatt Charging System (MCS)" to develop a system approach based on

[7] https://www.charin.global/media/pages/technology/knowledge-base/8b6c60c4ad-1615552574/017charin_one_pager_connectors_used_worldwide.pdf

CCS which shall also guarantee the full interoperability between MCS and CCS. Currently the work is focused on establishing details of this future standard for megawatt charging (requirements and specification document) and on iterative testing (cf. Figure 5) and validation of selected features (like voltage range, current capability, required thermal performance and plug/socket geometry) [8].

Figure 5 MCS Connector testing at NREL facilities[9]

Current standards for bidirectional AC charging

To perform AC charging, a charging control unit (CCU) is required to communicate with the charging station e.g., a wallbox, in general called electric vehicle supply equipment (EVSE) and with the vehicle control unit (VCU), which is an integral part of the EV. The CCU coordinates both the digital power line communication (PLC) with the EVSE and the Controller Area Network (CAN) communication with the integral parts of the charger. The CCU is an intelligent charging and generic electronic control unit which can fulfil all standards for e.g., bidirectional AC charging. It implements the e-mobility communication protocols for an AC charger and basic communication according IEC61851-1 for low level communication (LLC) and ISO15118 for high level communication (HLC) via pulse width modulation (PWM) controlled pilot signals. The particular normatives for HLC are:

- ISO 15118-1 → General information and use-case definition
- ISO 15118-2 → Network and application protocol requirements
- ISO 15118-3 → Physical data link requirements (e.g. PLC, CAN)
- ISO 15118-8 → Physical layer, wireless physical layer and data
- ISO 15118-20 → Network and application protocol requirements

[8] https://www.charin.global/media/pages/technology/knowledge-base/c708ba3361-1670238823/whitepaper_megawatt_charging_system_1.0.pdf
[9] https://www.charin.global/technology/mcs/

If the EVSE needs to be remotely controlled, OCPP 2.0.1 shall be supported. Currently, the supported protocol is OCPP 1.6.

Current standards for bidirectional DC charging

DC charging requires a charging control unit (CCU) as well to communicate with the charging station (EVSE) and with the vehicle control unit (VCU).
Again, the CCU implements the e-mobility communication protocols enabling bidirectional DC charging and basic communication according to IEC 61851-1 for LLC and IEC 61851-23 (2nd Edition) for HLC (e.g., PWM controlled pilot signals). The particular normatives for HLC are the same as for AC charging, i.e.:

- ISO 15118-1 → General information and use-case definition
- ISO 15118-2 → Network and application protocol requirements
- ISO 15118-3 → Physical data link requirements
- ISO 15118-8 → Physical layer and data
- ISO 15118-20 Network and application protocol requirements

As already commented above, if the EVSE needs to be remotely controlled, OCPP 2.0.1 shall be supported. Currently, the supported protocol is OCPP 1.6.

In the following subchapters the advantages and disadvantages of AC charging vs. DC charging (SotA) will be presented.

Advantages of AC charging

Alternating current (AC) charging has the advantage of being technically simple. No high infrastructure costs are required (AC current is easier/cheaper to transmit over long distances since there is already an AC grid infrastructure everywhere), and the available AC charging powers are optimal for home charging. AC chargers are remarkably cheaper than DC chargers (smaller dimensions, less electronics) and their installation is simple and faster (less expensive home installations). Charging EVs with AC occurs by using an on-board charger (OBC) inside the EV. The OBC converts the AC into direct current (DC) which can then be used to charge the car battery. Since most of the electronics (CCU, inverter/rectifier) are in many cases already integrated in the OBC in the vehicle, also lower investment costs and higher robustness for the EVSE (e.g., charging hardware, wallboxes) are beneficial consequences.

Furthermore, AC charging requires basically LLC for unidirectional power flow (V1G), while in case a V2X charge is improved then ISO15118 needs to be considered.

As a final observation, for certain vehicles on the market AC charging is the only possible solution (e.g., Dacia Spring).

Disadvantages of AC charging

AC charging requires the OBC to be carried in the vehicle, which requires additional space and is a limiting factor in EV weight (vehicle costs and complexity increase) and charging speed, as AC charging has lower charging power, resulting in long charging times. Currently there are few OBC available that can support up to 43kW charging power but the vast majority support charging power to 11 kW or 22 kW, depending on the installed wall boxes and the implementation of the OBC e.g. multi-phase or single phase (e.g. small power converters from Schuko to Type 2 can provide 1.5-2kW typical power). Hence AC charging is not suitable for all use cases, e.g., charging during short stops at motorways.

For bidirectional AC charging, the OBC must be designed to also provide dephasing capability when not using all phases. This in turn leads to a larger OBC design (impact on EV regarding production prize) and lower efficiency (because the OBC is intended to remain as simple/small as possible but small converters offers less efficiency than large converters) as well as EMC properties and it is therefore possible that a large fleet of AC charging vehicles contributes significantly to power quality degradation of the grid.

Finally, an OBC usually has few working points where it is efficient. Hence, the OBC only can provide a discrete number of fixed power throughputs, penalizing the use of smart charging techniques when interacting with the grid.

Advantages of DC charging

In a way, DC charging is the opposite of AC charging since the power charger is part of the charging station and not of the EV or the OBC, respectively. Therefore, the DC charging station (EVSE) is more complex since appropriate power modules must be installed to handle both functions: battery charging and discharging.

However, the EV complexity decreases as there is no need to install additional hardware for charging/discharging in the car (lower vehicle costs) and most of current EVs can convert basic DC charging into bidirectional DC charging by a software update (if the new ISO 15118-20 communication protocol (scope of WP3) is applied).

The significant advantage of DC charging is the highspeed charging capability offered with high efficiency and bidirectional power transfer will spread widely in the near future using the CCS2 plug. For buildings or districts, DC microgrids without AC/DC conversion are being considered for potential efficiency gains as no rectifiers are required. The grid operator has fully control of power quality, of instantaneous power and of infrastructure DC power distribution because grid codes are implemented and maintained via the EVSE not via Evs (grid codes are parameters for consumers/generators connected to a public electric grid to ensure safe, secure and economic proper functioning of the electric system).

Disadvantages of DC charging

For certain markets (like home charging), DC charging is not the best choice (e.g., not cost-effective for overnight charging) and the price of DC chargers is 5-10 times higher than the price of comparable AC chargers with similar power ratings. Therefore, from an economic point of view, a DC charger represents a suboptimal solution for home use, even if V2X features are supported. In addition, (high-power) charging requires high-power grids, but common residential grids are unsuitable, which entails additional infrastructure costs, since installing DC cables in residential buildings from the distribution board to the basement/garage/parking lot is often very expensive and difficult to implement (i.e., EV owners must bear these additional costs through higher charging prices).

The infrastructure impact on the grid could be significant (usually, DC charging hubs are designed to supply more power than AC charging hubs). Relevant costs arise for public infrastructure installations (e.g., for specific DC power distribution lines) and a relevant volume for converters must be considered (which often cannot be reconciled with historical centres).

Though also the DC charging stations itself (EVSE) are more expensive, since more complex and expensive power electronics (elaborate design, prone to failure) are required for the hardware in the wallboxes.

Impact on battery degradation

In general, it can be said that bidirectional charging with lower power, whether AC- or DC charging, is beneficial for the battery in terms of aging and degradation since high currents and thus high temperatures are avoided. An impact on battery degradation is possible during frequently occurring operation scenarios where a significant amount of energy is taken from the battery resulting in high deltas of state of charge (SOC). The number of high Δ-SOC events (i.e., the big differences between the SOC_{max} and SOC_{min}) should be kept as low as possible since frequently occurring high Δ-SOC events have (similar to high currents and high temperatures) a negative impact on battery ageing (cyclic aging). Therefore, in many Evs preventing limits regarding charging and discharging parameters (SOC_{min}, SOC_{max}, power flow limits, etc.) are controlled by the battery management system (BMS) to minimize battery degradation and to extend the battery lifetime. This is particularly important for bidirectional DC charging since there peak values of about 50-100 kW could be covered/provided by an EV short-term, but such large powers should be used only if really required to improve grid stability and with a properly preconditioned battery only (e.g., properly regulated battery temperature into an optimal range, proper SOC level, etc.).

Hence, battery degradation depends strongly on the strategy chosen and the limits to control the charging performance according to the BMS of the battery, independently from the type of charging. It is worth to note that if the so called “cycling” ageing is usually determined by the Δ-SOC, the “calendar” ageing is determined by the time spent at non-optimal SOC (especially high SOC). Since simple communication tools between user and EV (e.g., app-based) can be used to set the SOC_{max} during charging, the related improvement in battery life thanks to such approach can mitigate overall ageing even in case of increased cycling due to V2G. As an example, the target SOC value can be set to 100% only before long traveling events.

Regarding the cyclic aging is it worth to mention, that Lithium-iron-phosphate (LFP) batteries can last up to 10,000 cycles (for comparison: other lithium-ion batteries with different cell chemistries manage a service life of around 3,000 cycles, complete discharge to load). LFP batteries are known for their resilience against cyclic aging and improved resistance to battery degradation [1], which could potentially increase the lifetime of the battery when used in bidirectional DC charging applications.

Bidirectional OBC vs. bidirectional DC charging stations

Bidirectional onboard chargers (OBC) are currently very rare on the market, while prototypes exist for bidirectional DC charging stations and the establishment of the first series products has been announced (e.g., Ambibox, Quaser, EVTec) [2].

Since the ISO 15118-20 also defines novel use cases for AC bidirectional OBC, the question arises which technology will prevail on the market. This will heavily depend on necessity and application but also if the automotive manufacturers (OEM) are willing to provide the bidirectional OBC in Evs or if they support the expansion in charging stations. There is some evidence, because fixed bidirectional DC charging stations offer on one hand the possibility to remove complex hardware and software from the Evs (and hence decreased production costs), and, on the other hand, they are providing a bunch of services to the grid manager (like power/energy management, power quality improvement, voltage and frequency control for short-time phenomena etc.).

In any way, bidirectional fixed DC charging stations can operate at much higher power levels and higher performance than OBC (due to limited space and cooling requirements) whereby in case of bidirectional AC on-board chargers are available in Evs, the car owners do not have to use expensive DC charging infrastructure to feed power into the grid. This circumstance could still help to ease mass market introduction for all EV users, even if charging power via bidirectional OBC is limited.

2.1.2. Charge points

The most problematic limitations of common charging technologies (including V2G) encountered from charge point perspective are: limitations from technical perspective (i), limitations from user perspective (ii), and limitations from normative perspective (iii).

The charging technology (which is further pursued in XL-Connect) is analysed from the point of view of the charging station operator, considering details on the position of charging stations or important charging characteristics (such as type and number of charging connections, high power charging: HPC → yes/no, etc.).

The current situation regarding the charge point management by the charge point operator, but also questions about planned grid support solutions in the future and which protocols for data and communication interfaces play an important role are dealt with in the following subchapters.

Current limitations of common charging and bidirectional charging technologies from technical perspective (i)

Notably restrictions for charging technologies today include the lack of interoperability among different charging networks, the limited availability of fast charging stations (complex technology for bidirectional charging), and the high cost of fast charging infrastructure[10].

V2G is “brand new” which means that interfaces for bidirectional charging are not fully standardized yet, the compatibility with Evs from various manufacturers is currently not given and no serial bidirectional OBC are available on the market. Hence, only few suitably equipped Evs are presently (2023) on the marked and only a few charging stations are installed. The real implementation of the V2G technologies in the real world (charging stations, communication protocols, etc.) need therefore more time to become a standard and a major challenge will be to obtain effective solutions in terms of costs and in terms of energy efficiency (e.g., EV standby losses for bidirectional charging exceed 200 W, which is far too high).

For V1G, potentially many charging points are suitable, but most users are probably not aware. Smartphone app or other solutions can help here to better promote V1G. Local initiatives have been set in certain countries to push users to the adoption of early V1G implementations, as an example through the improvement of maximum total power available without increase of “fixed” energy cost in case of acceptance of variable charging power (Italian ARERA/GSE framework).

Current limitations of common charging and bidirectional charging technologies from user perspective (ii)

From a user perspective, charging stations are not common and the lack of availability of charging stations in some areas and hence not being able to charge at the desired charge point during a route is impractical. Frequently, also standard charging (V1G) might be quite difficult to understand for a typical user (lack of information about charging environments) or it is not user-friendly, for example when for each charging network a separate RFID (radio frequency identification) card is needed.

Bidirectional charging concepts most likely can be challenging for the user as they require more background knowledge to understand the V2G context and related questions such:

- What is the real benefit for the user to offer their battery to the grid (lack of real practical use cases e.g., for using the EV as power buffer for smart home or providing power to an energy provider for grid supply)?
- How can V2G-concepts be operated by the car?

[10] The electrical grid is currently not ready for a massive charging point increase and even less for a multi-point high power consumption and generation.

- How it influences the daily routine?
- How it affects battery degradation (benefit vs. battery degradation over lifetime concerns vs. vehicle value concerns)?
- Are the different kind of business model related to V2G understandable?
- Unclear business models for vehicle owners but also energy providers: what are the costs for the bidirectional charging infrastructure e.g., at home, in public or office environments?

Therefore, to reduce objections, users should be rewarded for providing their battery by receiving other benefits when using V1G or V2G, such as reduced costs for energy or for installed power.

Current limitations of common charging and bidirectional charging technologies from normative perspective (iii)

The technical implementation of smart charging use cases in Europe requires legal frameworks, laws, and adapted grid codes to enable smart charging and V2G, and ISO 15118-20 in principle lays the foundation for an easier implementation (currently the charging protocols and norms do not cover all V2G functionalities). However, the market fixes the preferences and although standards for V2G are being prepared, the charging station operators do not prefer V2G concepts so far. Potentially, V1G and V2G can provide economic advantages for large operators which are able to get remuneration for grid services (e.g., they use dynamic hourly cost for energy) but for home charging concepts or small users (e.g., small companies) such advantages are not accessible because certain regulations limit the remuneration for energy recovery into the grid (to avoid speculation for example). Standards may be modified here in such a way, that also small users could possibly benefit from dynamic cost allocation models.

Currently the grid connection is depending on each country regulations and hence restricted. Though many levels of grid integration have already been determined and CCS with ISO 15118-20 is cutting-edge for grid integration since it is ready for V2G. How the levels of grid integration can generate value for a wide range of use cases is summarized in Figure 6.

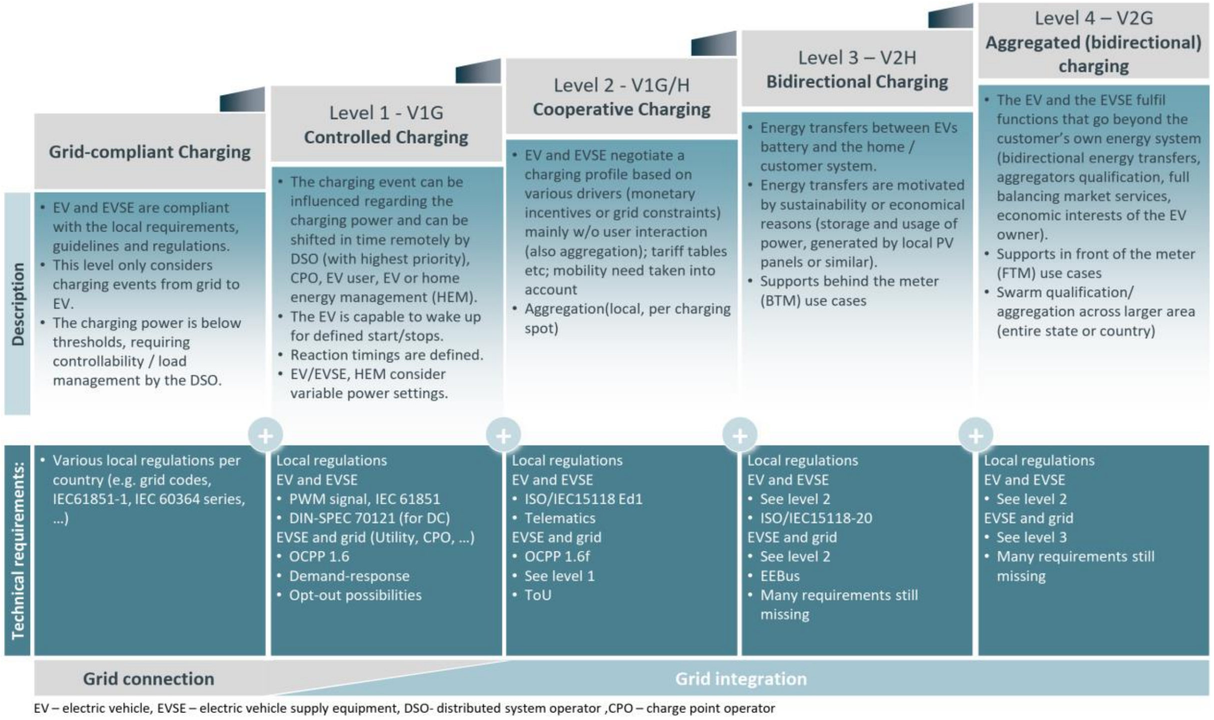

Figure 6 Grid Integration Levels[11]

[11] https://www.charin.global/media/pages/technology/knowledge-base/60d37b89e2-1615552583/charin_levels__grid_integration_v5.2.pdf

Charging technology to be followed up in XL-Connect

The aim of the XL-Connect project will be to overcome the restrictions mentioned above and to make contributions towards them. The developments enabling bidirectional charging to a large number of EV users in the near future and in the most attractive way are in progress. Promising use cases for advanced charging concepts (e.g., DC microgrids) as promoted e.g. in [3] and [4] are representing important reference points for XL-Connect as similar charging point installation configurations will be pursued later in WP4, WP5 and WP6.

For an optimal design of advanced charging concepts, the charging point operators are analysed in the following providing an overview about practical positions of charging stations, charging characteristics, charging power, type and number of charging connectors.

<u>Charging point installation configuration</u>

With AC charging points, the charging unit is usually relatively compact, and all the hardware (controller and contactors) can be easily implemented in the charging station, on the condition that bidirectional power flux is accepted by the operator metering system.

For DC charging points it is different. Depending on the characteristics of the parking lot and depending on the technical realisation, the comprehensive hardware (including inverter, controller, contactors etc.) can be either implemented completely within the charging unit, or the charging unit is reduced and includes only control interface and connectors. Then the inverter hardware must be installed separately somewhere else.

<u>Position of charging points</u>

Depending on the position of charging points the EV user will encounter different power classes, and hence different minimum charging power available. Common DC charging power classes are currently grouped as follows:

- FC 50 → fast charging: 50 kW...149 kW
- HPC 150 → high power charging: 150 kW...249 kW
- HPC 250 → high power charging: 250 kW...349kW

Table 1 depicts the minimum requirements for power classes with a higher level of detail (according to the CharIN overview of power classes).

Power Class	Power*	U_{min} in [V]	U_{max} in [V]	I_{min} in [A]	I_{peak} in [A]	$I_{derated}$ in [A]	P_{ref} in [kW]	Duration I_{peak}	Name (EN)
LPC	*xx (kW)*	≤200	≥920		**<20**	*<20*	**<8**	*inf*	*Low-Power Charging*
DC	*xx (kW)*	≤200	≥920	≤1	**≥20**	*≥20*	**≥8**	*inf*	DC Charging
FC	*xxx (kW)*	≤200	≥920	≤1	**≥125**	*≥94*	**≥50**	≥ 30 min	Fast Charging
UFC	*xxx (kW)*	≤200	≥920	≤5	**≥250**	*≥188*	**≥100**	≥ 20 min	Ultra-Fast Charging
HPC	*xxx (kW)*	≤200	≥920	≤5	**≥500**	*≥375*	**≥150**	≥ 10 min	High-Power Charging
* P_{ref} values (provided by the manufacturer) shall be used (e.g.: HPC 300, FC 50). Validation will be done within CCS quality assurance program.									

Table 1. CharIN Minimum requirements for Power Classes[12]

Lower charging power in DC are anyway possible, usually in the range of 25-50 kW. A couple of market examples are SCAME 25 kW DC systems[13] for "home" DC charging or Kempower 20 kW DC movable chargers[14] (40 kW total), to be used where moving charging point is preferable than moving vehicles (e.g. bus deposits, workshops etc.); even if a potential overlap with 22 kW AC charging systems is envisable, it should be noted that not all market vehicles are really capable to accept more than 7kW or 11kW due to manufacturers choices. As an example, such charging system can perfectly fit the need of vehicle different from M1-N1 class (e.g., L-class vehicles, such as Energica motorcycles). Such systems are expected to be suitable for intermediate charging time, such as frequent travellers' household, small/medium enterprise parking lot, etc.

Hence, DC high power charging should be preferably installed on highway- and on heavy vehicles parking lots, whereby for large rotation parking platforms or large parking areas less power installed would also be acceptable, if keeping at least FC 50.

An example of a provider of e-chargers for flexible power supply (FC 50...HPC 250) is ENERCON[15]. Complete EV charging installations (at any kind of position of the of charging point) are offered e.g., by one-stop shops like Parking Energy Ltd.[16] Using charging solutions developed from ABB[17], Keywatt[18] or DELTA[19]. Examples of providers for charging points positioned at home or at locations for small user areas

[12] https://www.charin.global/media/pages/technology/knowledge-base/c6574dae0e-1639130326/charin_dc_ccs_power_classes.pdf
[13] https://www.scame.com/web/scame-italia/catalogo/-/catalogue/E-Mobility_Stazioni+di+ricarica+in+DC_Wall+box_Serie+BE-D/206.D91-E12
[14] https://kempower.com/charging-solutions/
[15] https://www.enercon.de/fileadmin/Redakteur/Service/EC_E-Charger_600_en_web.pdf
[16] https://www.parkingenergyservices.com/home
[17] https://new.abb.com/ev-charging
[18] https://www.ies-synergy.com/en/
[19] https://www.deltaevcharging.com/

(e.g., low power AC-wallboxes or post installations of DC-wallboxes) are Zaptec[20], Wallbe[21] or EVBox[22].

Charging characteristic / power

As mentioned above, the EV user encounters different power classes that vary depending on the application. For “high priority” charging situations (highway parking lots), DC charging stations above 100 kW should be typical, along with a comparable number of traditional AC chargers (22 kW), as certain Evs use AC solutions and do not accept DC charging (e.g., certain Dacia/Renault models, ZERO Motorcycles models, etc.). Conventional charging (e.g., workplace parking lots) would benefit from a certain “mix” to best manage infrastructure costs and provide users with efficient charging services.

Number of chargers and charging connectors

Standards for specific numbers of required chargers and charging connectors (to enable suitable, comfortable, and efficient handling of charging activities for EV users) are not yet enforced. Observations indicate that it is advisable that the number of chargers should account for 5-10 % of the total number of parking slots (i.e., 5-10 chargers per 100 car places), and of these a separation into 10-20 % for FC 50, 20-30 % for medium power (< 50kW DC) and 50-60 % for low power (AC) could be feasible. However, depending on the growing number of Evs and the context these indications vary (e.g., in cities home parking is available for most users, hence, percentages for high- and medium power could be reduced) which will be studied in detail in WP4 based on simulation models and user surveys.

Regarding the number of connectors, it could be distinguished between charging points that are facing one side of the parking and such that are facing two sides of the parking. For the first variant 2 connectors per unit would be suitable (infield chargers normally are capable to support 2 connectors per unit and per category, i.e., AC or/and DC combined) for the latter one 4 connectors per charger (currently, only few brands offer the possibility to have 4 x DC connectors or combinations, e.g., 3 x DC and 1 x AC connector).

Use of local power supplies for charge points (grid support via microgrids) – SotA

The installation of DC microgrids, which include local energy sources (from renewable ones mainly photovoltaic sources[23] but also wind energy, waterpower plants and hydrogen generators), static storage batteries[24] and conversion systems

[20] https://zaptec.com/en-uk/
[21] https://www.compleo-charging.com/en/
[22] https://evbox.com/en/
[23] https://circutor.com/en/sectors/electrical-self-consumption/self-consumption-and-electric-vehicle-charging/
[24] https://numbat.energy/en/high-power-charging-retail

to power households or vehicle charging points[25], are already available on a commercial scale and offer remarkable functionalities such as data logging or instantaneous power control. Local power controllers ensure that the power consumption of the entire installation does not exceed the grid restrictions i.e., excessive energy and power draw from the grid can be avoided by using the local power supplies[26] connected to the microgrid.

In Figure 7 an overview of available V2G solutions with local power injection and data exchange by various participants (or stakeholders) is depicted.

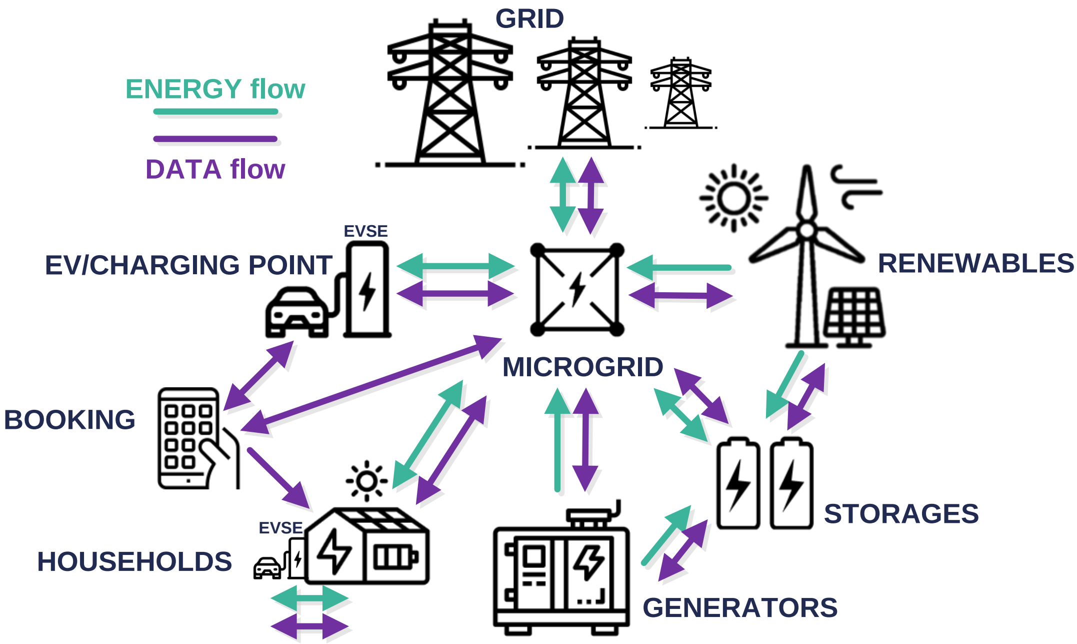

Figure 7 V2G solutions with local power injection by various participants

[25] https://www.press.bmwgroup.com/global/article/detail/T0338036EN/bidirectional-charging-management-bcm-pilot-project-enters-key-phase:-customer-test-vehicles-with-the-ability-to-give-back-green-energy?language=en

[26] https://www.mobilityhouse.com/int_en/magazine/e-mobility/vgi-projects-of-tmh.html

Charge point management

Figure 6 summarizes the different levels of grid integration. The ISO 15118-20 standard enables V2G solutions unfolding a wide range of use cases for grid integration. The technical framework for different variations of integrating Evs and other participants in intelligent grid networks has been developed but not yet widely implemented since ISO 15118-20 is still under conformance testing (on the agenda of CharIN[27]) because of its recent release in 2022. Therefore, charging point management is currently more established for grid connection than for grid integration (cf. Figure 6, up to Level 1, V1G / controlled charging).

<u>Protocols currently used to interface with the various participants</u>

The Open Charge Point Protocol (OCPP 1.6, cf. Level 1 in Figure 6) is commonly used to interface with the chargers in the field but is not officially standardized yet by the IEC or ISO. To communicate with other participants, the charge point operator (CPO) can use protocols like OpenADR or EEBUS.

In order to advance active grid support solutions to use the available flexibility for congestion management (e.g., smart load management[28], local power control or voltage control), the next generation of communication protocols must be defined and standardised to enable smart data communication between the CPO and the microgrid through a distributed system operator (DSO).

Data and communication

In Figure 7 the data flow for smart communication is represented by purple arrows which corresponds to a level 3 grid in Figure 6. Relevant communication protocols for grid integration already exist[29] as well as scientific publications on the subject [5] but in fact these protocols are not fully finalised yet or have limited diffusion in Europe (like the CHAdeMO protocol).

2.1.3. Smart charging providers

Currently, there are no established clear rules for the interaction between the distribution system i.e., the charging providers and charging platforms i.e., the charging points. Concerning energy management, grid, pricing, opportunities for savings or revenue, the knowledge of the V2X ecosystem (different use cases) for the regulatory framework is important, especially regarding provision of supplementary services with EV batteries and generally the participation in energy markets.

<u>Pricing and savings/revenue opportunities</u>

Hourly pricing is already possible in most European countries, for example through arbitrage offers by charging at low price periods. However, other factors such as the

[27] https://www.charin.global/technology/v2g/
[28] https://blog.mi.hdm-stuttgart.de/index.php/tag/iso-15118-20-dis/
[29] https://sysarc.ffe.de/en

pricing policy of energy suppliers and governmental subsidies for the construction and sale of bidirectional chargers can also have a strong influence on charging behaviour of EV users.

<u>More opportunities for savings or revenues</u>

Scientific articles or short studies on the subject are available [6], [7]. The possibilities and characteristics of price-controlled charging are diverse, and the level of smart charging strongly depends on the specific use case associated to a specific location with a specific set of features. Table 2 gives an overview of typical use cases linked to their specific locations for revenue/expenses (e.g., household, street parking, small- and large parking area).

Household	Street parking	Small parking area	Large parking area
One-family	Urban street parking	Small store	Bus Depot
Two-Family	Suburban parking	Small office	Commercial Parking Lot e.g., next to shopping centre
Energy community neighbourhood	Highway charging	School facilities	University Campus
Residentials		Taxi stand	Train Stations
			Airports
			Park and ride
			Supermarket
			Industrial Site
			Hospitals
			Big Company Offices
			Parking garage privately owned
			Company vehicle fleets

Table 2 Typical use cases

The specific set of features enabling opportunities for savings or revenues and hence to reduce expenses comprises measures like utilization of locally generated energy (i.e., local power injection e.g., by a PV plant), frequency balancing (i.e., keeping the grid frequency within the permissible range e.g., by frequency dependent load control), peak shaving (i.e., local grid services of flexible appliances offer to shift peak loads to times of low load demand since peak load demand occurs only at certain times of the day and varies in intensity) or reward for providing batteries, arbitrage offers by charging during low-price hours, redispatch and increase of self-consumption (i.e. the increase of self-consumption leads to a minimization of the electricity procurement costs).

Redispatch refers to the intervention to prevent grid overloads or to eliminate grid overloads. This can be achieved by reducing the feed-in power of one or more power plants while simultaneously increasing the feed-in power of one or more other power plants or – by local power injection by various V2G participants, cf. Figure 7 – outside the bottleneck region, so that the total feed-in power remains unchanged.

A comprehensive position paper dealing in detail with the topic concerning provision of system services can be found here [8].

Price-controlled charging with direct and indirect price control.

Direct price control occurs when an EV adjusts the charging strategy solely based on time-resolved price signals. The price signals can vary highly dynamically in the minute range (e.g., on the continuous intraday market) or have a constant value over a longer period of several hours (e.g., high tariff day electricity or low tariff night electricity). An indirect price control represents a charging strategy based on an overall optimization that includes price signals.

The directly price-controlled features (use case dependent) include the use of time arbitrage on the electricity market and tariff-optimized charging. In price-driven charging based on time arbitrage, price differences on the day-ahead and intraday markets are exploited by shifting the charging period to times when exchange prices are favourable. With tariff-optimized charging, the dynamic tariffs offered by the energy supplier are used to charge the EV at times when electricity prices are low. Favourable prices can be justified for low loads, high feed-in of renewable energies (based on exchange prices) or due to low grid utilization (variable network fees).

Other features use indirect price signals to adapt the charging strategy of the EV. The increase in self-consumption leads to a minimization of the electricity procurement costs, which are significantly influenced by the level of the electricity procurement costs and the renewable energy feed-in tariff, while peak shaving in companies aims to reduce network charges by charging the EV at times when the company-load is lower.

Use case requirements

The hardware and communication requirements vary considerably from use case to use case, depending on the installed power and the characteristics of the grid[30]. In principle, a distinction can be made between critical and non-critical applications. Critical applications can include those use cases providing a relevant power absorption which can potentially modify grid stability on the local context (e.g., bus depot with installed power capacities in the MW range). Such critical applications should use dedicated communication protocols with high reliability (e.g., dedicated ethernet, modbus/canbus etc.). Non-critical applications, such as home-level power

[30] https://sysarc.ffe.de/en (interactive tool for visualising hardware and communication requirements)

(< 10 kW) which potentially include a large number of users (and each single user is not responsible for large power adoption), should be able to adopt simplified communications systems such as internet-based solutions (IoT), with local gateways on the system (e.g. ISO15118 on the charging station + TCP/IP gateway trough WIFI or 2g/3g/4g/5g + TCP/IP for home inverter).

2.1.4. Distribution system operator

Distribution system operators (DSOs) are responsible for secure and reliable operation of their distribution power systems, which are transferring energy among energy generation, consumption and storage systems while maintaining desired level of power quality. A DSO implements a wide range of technical processes relevant for various time horizons, where different datasets are available. In the context of massive integration of Evs into power systems, two processes at different time horizons are considered in this project: (i) long term planning and (ii) real-time operation. Long-term planning procedure focuses on a robust distribution system modification and extension preparing the grid to long-term regional development, macroscopic technological trends or expected changes in stakeholders' behaviours (e.g., consumers, prosumers, aggregators etc). On the other hand, real-time operation procedures maintain a distribution power system in reliable operation under consideration of actual physical properties of the grid and its state.

Power system data model aspects

Although both processes are focused on the different goals (e.g., integration of massive volume of EVs to a grid, optimization of a grid operation), core technical calculations such as load flow, state estimation or power system operation optimization rely on an abstract mathematical model, which incorporates a closed set of data inputs regardless to data sources of their origin. In the following, various aspects of data models of a power systems are specified (cf. Figure 8), and consequently different data formats are presented.

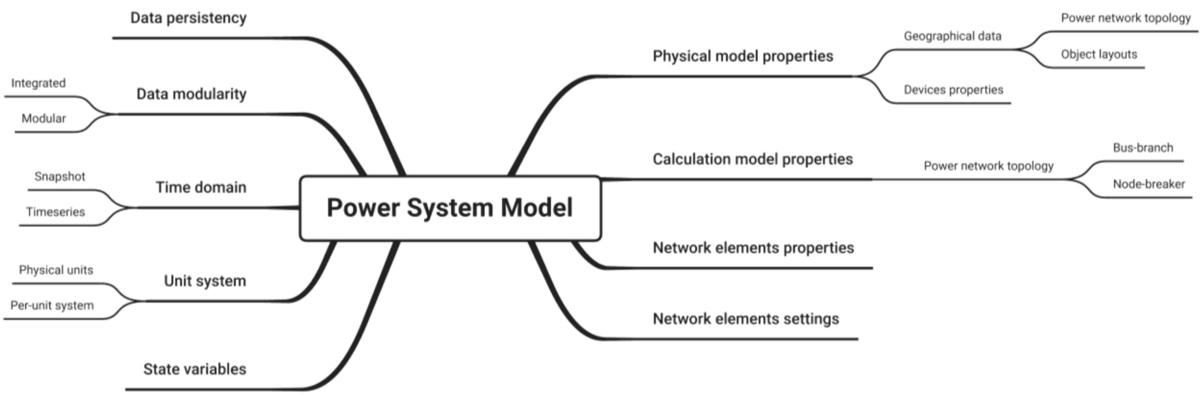

Figure 8 Different perspectives of a Power System Model

Physical properties

This category embraces aspects related to physical properties of devices or power systems located in a real world.

Geographical data

Geographical data capture localization and geometric properties of power systems and installed equipment as well as objects on a geographic surface. Frequently data origins from GIS systems deployed on a DSOs.

Power network topology

Power network topology includes information about real world installation power lines (e.g., location, length, type of power lines), which reflect geographical restrictions (e.g., minimal distance from road infrastructure) and deployment possibilities. It covers particular technical fractions of long power lines according to geographical installation for example.

Object layouts

Objects layouts describes geographical date (e.g., GPS positioning) of relevant objects such as buildings, transformer stations and others.

Devices properties

These data captures information about physical devices and equipment, which are mostly obtained by design parameters or special measurement. Information is strongly device specific and frequently differs by the manufacturer. For example, minimal and maximal charging current of an EV charger, installed peak power a photovoltaic unit.

Calculation model properties

These properties relate to an abstract calculation model, which is commonly used for the power network calculation such as load flow, state estimation and others.

Power network topology

In this context, a power network topology is represented by a unoriented graph, which is consisting of sets of nodes and interconnecting branches. In a calculation model, network topology is mainly used for creation of special calculation structures (e.g., admittance matrix in a load flow calculation) or topology operations (e.g. topology island detections) and other actions.

The type of a topology model strongly affects its processing and consequent calculations. From the electrical point of view, two main categories of topology model (cf. Figure 9) can be considered:

- Bus-branch – these models represent power system networks as a collection of node and single line branches, where each substation is modelled as a single bus at certain nominal voltage level. Generally, these models are model widely used in processes related to day-ahead and longer planning horizon [10].
- Node-breaker – on the other hand node-breaker models replace the simplified bus by stations defined by node-breaker topology, which considered a set of

breakers (i.e., busbar couplers) between particular buses of a substation. These models are more relevant for short-term operational planning and real time operation.

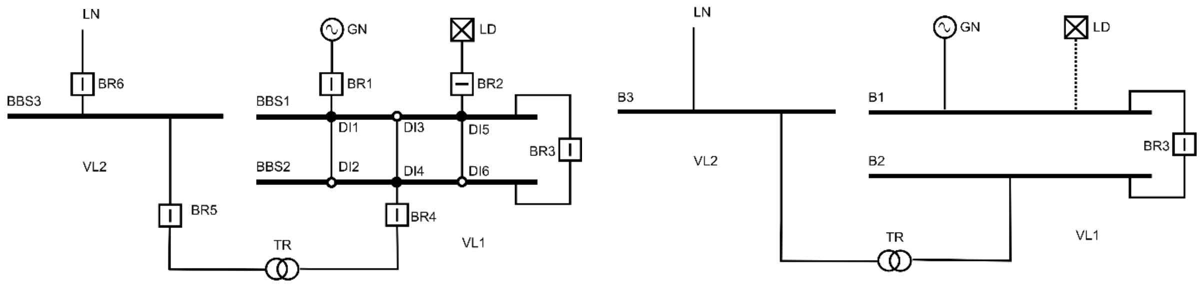

Figure 9 Node-breaker topology (left), Bus-branch topology (right)[31]

Network component properties

This category contains "static" properties of a network element, which are almost constants over the time (e.g., design parameters of power lines). Each power network element (e.g., power lines, power transformers) has its own unique set of electrical properties, which are important for technical calculations in a power system domain. For example, electrical properties of a power network branch (e.g., power line) are described by set of parameters such as resistance (R), reactance (X), susceptance (B), or conductance (G).

Network component settings

Some network components contain parameters or variables, which are controllable and can vary over time dynamically based on the decision of an operator (e.g., DSO). For example, position of a tap changer on a power transformer, which can vary its ratio or state of switching equipment modifying network topology.

State variables

As each dynamic system, power systems can be described by set of state variables, which reflect full history of the system trajectory and serves to no noncontradictory determination of future system trajectory based on applied inputs. In the case of power network, several approaches to specify a system state can be applied. In the XL-Connect, four state variables are considered for each node of a power network:

- Active power injection
- Reactive power injection
- Voltage magnitude
- Voltage angle

Power injections are considered in the Cartesian coordinates and voltage properties in polar ones, which is efficient for calculation methods such a load flow. Generally, only two state variables are necessary to describe power system state, while the rest of state variables can be calculated by a numerical method. Usually, power injections

[31] https://www.powsybl.org/pages/documentation/developer/tutorials/topology.html

are used as inputs to calculation methods (e.g., load flow) and voltage variables result from the computation. The most important variables are active power injections, which reflect consumption, storage or production nature of demand side equipment (e.g., EVs, photovoltaic panels, domestic loads etc.). Values of active power injections can be obtained in several ways such as real-rime or historical measurements (e.g., EV charging profiles), simulation or prediction models or other approaches. Always depends on the purpose of a technical calculation and available datasets.

Unit system

Power systems models can be defined in several unit system based on their purpose and use.

Physical units

First, power network models can be defined in physical units, which reflect commonly used notification in real world. For example, voltage magnitudes are defined in Volts or active power injections are specified in Watts. In this unit systems, various volage levels for different parts of distribution grids are considered.

Per-unit system

Per-unit system stands for relative expression of variables in physical units. All state variables are transferred to relative form based on selected or calculated baseline (e.g., base apparent power as 100 MW). This unit system is mainly used in models dedicated to technical calculation due to enabling of better convergence properties. Moreover, the per-unit system transfers various voltage level to unified relative one.

Time domain

In power system domain, the incorporation of time domain into data models can be done in several ways, which shall be complaint with their use and purpose.

Snapshot

Due to process complexity related to processing and assembly of large power system models, snapshot models capturing system-wide power grid mode for one time frame can be beneficial in some cases (e.g., batch calculation of sets of power system models). For assessment of a power system trajectory over considered horizon, a set of several power network snapshots is needed to evaluate.

Timeseries

In this approach, a power system model is more static in its structure. However, dynamic variables changing over time (e.g., active power injections) are stored in separate timeseries objects capturing their time-evolutions.

Data modularity

Data formats can have various form in terms of their modularity, which partially relates to the time domain discussed before.

Integrated

Integrated data formats contain all information in one comprehensive file. The advantage of this arrangement is a consistency of datasets. However, datasets cannot be processed in parallel.

Modular

In these formats, various aspects of a power system data model are stored in separate files, which significantly improves a processing performance (i.e., parallelism) of input data and incorporation of changes in the model initialized by various stakeholders. On the other hand, the significant attention must be put on the data consistency.

Data persistency

This property of a power network data model defines in which data format or technology is a model persisted.

Relevant data formats

In the following sections, relevant data formats describing power systems are briefly described. Full descriptions of data formats can be found in provided references.

Geographic data formats

ArcGIS Shapefile

ArcGIS[32] is a product of the ESRI corporation and gives utilities a complete data model, providing ease of editing, expanding connectivity capability, and scaling to any size. ArcGIS integrates all types of data, gives all users access to the data they need for better collaboration, and supports digital transformation. ArcGIS includes many data formats. For example, the shapefile format is a vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.

GeoJSON

GeoJSON[33] is a format for encoding a variety of geographic data structures. In this open-format, Although the data format definition is simple, various power system models can be captured [11].

[32] reference to www.esri.com
[33] www.geojson.org

Power system data formats

Common Data Format

Common Data Format (CDF) is an old school, but still used, data format for exchange of load flow data among systems [12]. The format strictly defines the structure of a text file sufficiently describes a power system model.

MatPower format

Matpower[34] is an open-source Matlab toolbox for calculation of load flow and partial optimization of power systems. It relies on rapid prototyping tool (Matlab), which is widely used by academic and research community. The data format strictly defines the structure of the text file, which contains definition of matrix structures for Matlab environment. The text file is divided into five sections:

- Bus data
- Generation data
- Branch data
- Generator cost data
- Area data

UCTE-Def

The UCTE-Data Exchange Format[35] is adopted for data exchange and provides all the necessary instructions about its use. The data refer to load flow and three phase short circuit studies and describe the interconnected extra high voltage networks. The format is defined in unformatted standard US ASCII file. The text file is divided into seven different blocks:

- Comments (C)
- Nodes (N)
- Lines (L)
- Two windings transformers (T)
- Two windings transformers regulation (RR)
- Two windings transformers special description (TT)
- Exchange powers (E)

PSS/E

PSS/E[36] is a commercial product of Siemens, which offers a wide variety of analysis functions, including power flow, dynamics, short circuit, contingency analysis, optimal power flow, voltage stability or others.

PSS/E uses different types of files to exchange data about a power network. One of the widely used data format is the RAW file (power flow data file), which contains a collection of text data specifying Bus/Branch network model for the establishment of

[34] www.matpower.org
[35] https://cimug.ucaiug.org/groups/model%20exchange/ucte-format.pdf
[36] https://www.siemens.com/global/en/products/energy/grid-software/planning/pss-software/pss-e.html

a power flow working case. The RAW file has multiple groups of records (data blocks), with each group containing a particular type of data needed in power flow. The last record of each data block is a record specifying a value of zero to indicate the end of the category. Each record in a data block contains a set of data items separated by a comma or one or more blanks where alphanumeric attributes must be enclosed in single quotes [13]. The RAW format is still developing (e.g. latest version of RAWX is defined in a JSON format) and has already comprehensive structure, where couple of sections is defined:

- System-wide data
- Bus data
- Load data
- Fixed shunt data
- Generator data
- Branch data
- System switching device data
- Transformer data
- Area data
- Two-terminal DC data
- Voltage source converter data
- Impedance correction data
- Multi-terminal DC data
- Multi-section line data
- Zone data
- Inter-area transfer data
- Owner data
- Facts control device data
- Switched shunt data
- GNE (Generic Network Element) device data
- Induction machine data
- Substation data

CIM-GMES

The Common Information Model is a modern data standard based on norms from family of IEC 61970. CGMES (Common Grid Model Exchange Specification) is an data model standard captures uniqueness of transmission power networks. The standard relies on several profiles located in separate RDF files [14]:

- EQ (Equipment) Profile: This profile contains data describing equipment deployed in the power system and their physical properties.
- SSH (Steady State Hypothesis) Profile: The profile includes variables and parameters, which are necessary for the load flow calculations (e.g., active power injections, voltage magnitude setpoints etc.).
- TP (Topology) profile: Electrical interconnections among power network components as well as definition of power flow buses are contained in this profile.

- SV (State Variables) Profile: It includes all the information required to describe a steady-state power flow solution over the network.
- EQBD (Equipment Boundary) Profile: The profile contains definitions of the equipment in the boundary.
- TPBD (Topology Boundary) Profile: This profile includes topology information associated to the boundary.
- DL (Diagram Layout) Profile: Information about electric diagram positions are included in this profile.
- GL (Geographical Layout) Profile: Specification of geographical positions are contained in this profile.

Assessment of power system data formats

Table 3 includes the assessment of suitability of selected data formats to power network model aspects. The table contains the qualitative assessment of the compliance of the data format to given criteria.

		Physical model properties			*Calculation model properties*					*Unit system*		*Time domain*		*Data modularity*		
		Geographical data			Power network topology											
	Data format	Power network topology	Object layouts	Devices properties	Bus-branch	Node-breaker	Network elements properties	Network elements settings	State variables	Physical units	Per-unit system	Snapshot	Timeseries	Integrated	Modular	Data persistency
Geographic data formats	ArcGIS Shapefile	✓	✓	✓											✓	SHP
	GeoJSON	✓	✓													JSON
Power system data formats	Common Data Format				✓		✓		✓		✓	✓		✓		CDF
	MatPower format				✓		✓		✓	✓	✓	✓		✓		MAT
	UCTE-Def				✓		✓	✓	✓	✓		✓		✓		UCTE
	PSS/E - RAW				✓	✓	✓	✓	✓	✓		✓		✓		RAW
	CIM (IEC 61970)	●	●	●	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	RDF

Table 3. Assessment of suitability from power network model aspects regarding data formats

Based on the assessment in Table 3, no data format is fully complaint with the needs of long-term planning processes and short term / real-time operation ones. Usually based on geographical data formats (i.e., models), computation models for power system operation are derived, which puts strong requirements on functionalities enabling transformations between core power system data formats. Nowadays, Common Information Model (CIM) stands for a data format with the most significant potential of interoperability, because of its comprehensiveness, modularity and modification possibilities. However, processing of this data format is challenging in terms of performance and therefore time consuming to be utilized for real time interactions among wide range of stakeholders. In the XL-Connect, data interfaces between technologies developed or used by particular partners will be inspirated by the CIM, however a lightweight, most suitable and efficient data model will be designed and specified to accelerate research activities planned in the project (i.e., methods enabling massive integration of EVs into power system).

2.1.5. Users

From the user point of view user-friendly, smart, and bidirectional charging solutions (V1G, V2G, V2H, V2B) that consider quantity and quality of driver's needs (i.e., taking serious range anxiety, duration and preferred time slot for charging, acceptance of incomplete charging levels, conditions for allowing a shared control of battery SoC, seamless payment, billing) are crucial to improve the user experience.

Easy accessibility and easy application are also fundamental to user experience, and there is already detailed work ongoing e.g., the co-funded EU project eCharge4Drivers[47] is dedicated to these issues with two deliverables (D1.1[48] and D1.2[49]) or the scientific study [9] from ISEA RWTH[50] should be mentioned here, which deals with a summary on charging point data and on charging events at different locations throughout Germany.

<u>Current user experience</u>

The most common user concerns about electromobility are range anxiety, lack of charging infrastructure, high charging times (fossil fuel solutions require for a full recharge only a few minutes), but also high electric energy costs (users often do not readily accept high electric energy costs if they are comparable or higher than conventional fuel costs). Since the charging infrastructure needs to be expanded, availability is an issue (and problems are foreseeable when charging stations are occupied by conventional cars). Aside from the range anxiety of EVs also battery ageing and the associated loss in value of the EV have a sobering effect on users and the benefits of bidirectional charging use cases are still unclear to most of them.

In addition, services providers often are hardly interconnected and are not collaborating closely as it would be required. This also leads to too many apps being available for each charger in a city location for example (i.e., one different app for each smart charging provider or for each different EV per OEM). To simplify bidirectional charging, the handling for all use cases should be ideally made possible over one app, however.

The communication strategy for the users also shows shortcomings. Users are not really informed about V2G opportunities, possible incentives, drawbacks, and there are plenty of operators and conditions to access to charging points that can vary from one city to another in the same countries.

Currently only V2H (Vehicle-to-Home) seems to be applied with customers.

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47 https://echarge4drivers.eu/
48 eCharge4Drivers_D1.1_Study-questions-and-KPIs_v1.0_FINAL.pdf
49 eCharge4Drivers_D1.2_Apriori-users-concerns-expectations-relevant-to-EV-charging_v1.0_FINAL.pdf
50 https://www.isea.rwth-aachen.de/cms/~ojnv/ISEA/lidx/1/

2.2. Updated requirements for smart charging technologies

Figure 10 shows a representation of the overall system of the electricity grid and a possible smart charging chain: at the centre is the end user, who concludes a contract with an e-mobility service provider (eMSP) or with the distribution system operator if the customer charges the EV at home. The eMSP or the distribution system operator has knowledge about the occupancy of the charging stations and their performance requirements. Ideally, it receives information about the battery's SOC (this is done via data exchange with the vehicle, which must be enabled by the respective OEM). For planning a trip, the data exchange with the navigation service provider (NSP) is important for the end user, who can calculate charging options and charging duration (depending on the available charging power) in addition to route planning. The smart charging service provider (SCSP) has knowledge of local network requirements.

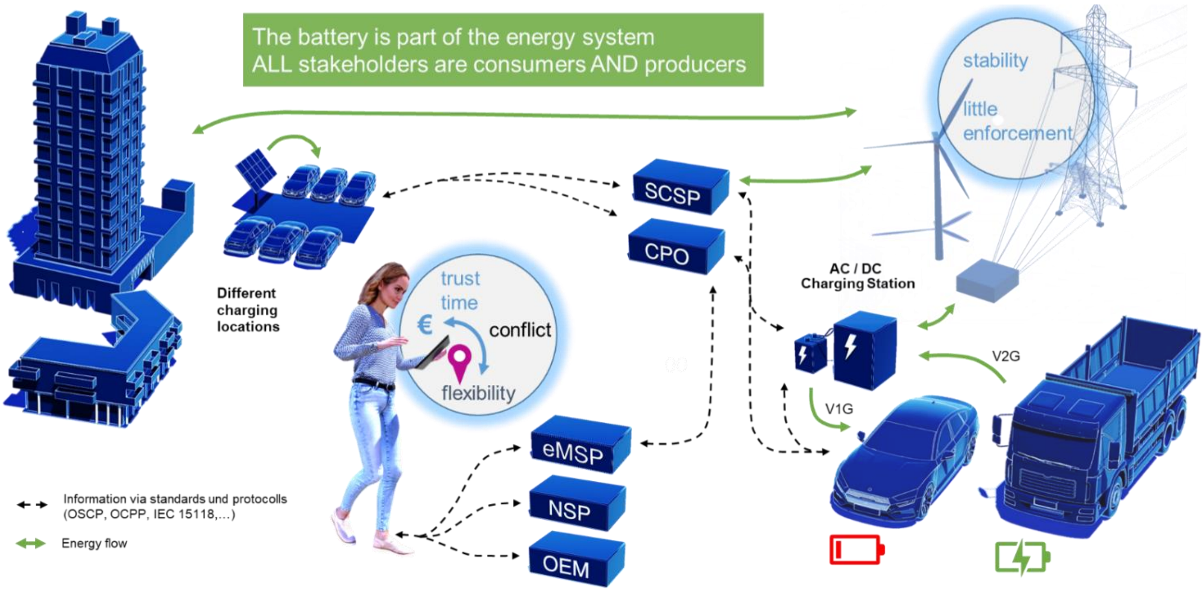

Figure 10 The end user and its needs as central point in the smart charging system

To enable smart charging innovation, XL-Connect pursues the improvement on a large scale so that not only the end user but also all other network elements and participants in the smart charging chain can benefit.

The following sections address an updated requirements agenda for the elements involved in smart charging systems that will be pushed to WP4, WP5 and WP6 for further development and demonstration of advanced bidirectional charging concepts.

2.2.1. EV (electric vehicle)

Plug types

There is an urgent need for a European standard for a common plug for public and private charging points. It is crucial to deploy the same technology and business organization to all shareable charging spots.

As the Type 2/Combo 2 connector (CCS2) is the preferred solution for bi-directional AC and DC charging in Europe and CCS2 becomes the market leader there, XL-Connect will rely on this connector type to progress advanced charging technologies.

EVs contribute to grid stabilization

A large number of EVs/charging stations which operate in existing utility grids can cause power-quality and voltage problems. Especially, (AC) OBCs create harmonics (due to cheaper and simpler electronics) that affect the distribution grid and can create power unbalances and voltage deviations, while DC charging stations cause less unbalances over the grid (number of harmonics is lower due to high-quality power systems).

But EVs in an advanced charging infrastructure can even contribute to grid stabilization and XL-Connect contributes to develop beyond SotA standardization and hardware installation configurations for that. As mentioned in chapter 2.1.3, a specific set of features (which are use case and location dependent) provide opportunities for savings or revenues and some of these features are using grid stabilization as incentive, such as redispatch and local power injection (reactive power can be provided by the EV to the grid (V2G) or the energy can be used in a DC microgrid or at a mobility hub) as well as peak shaving (just with V1G realizable in a timely manner: EVs can help to lower the peak power and distribute the power demand more uniformly).

Furthermore, future smart charging of EVs can help to store the excessive energy produced by a high amount of intermittent renewable energy sources, or non-stop energy generators, as nuclear plants at nights (with low grid power consumption and energy surplus production). Later then, the EV batteries can contribute providing energy to the electrical companies in case the demand overcomes the production (emergency power supply).

XL-Connect will fostering the technical implementation and the communication between stakeholders to take the actor EV to the next level by elaborating recommendations for the regulatory and legal framework.

2.2.2. Charge points

Data and communication

So far, the DIN 70121 and ISO 15118-2 are the reference communication standards in Europe. ISO 15118 has multiple fully released standards and the last one released is ISO 15118-20[51]. However, several requirements related to V2X electrical manoeuvres are not still considered through IEC61851-23 (in fact, Ed2 is not released yet). CharIN is working on standardize these points to speed up V2X deployment:

- IEC 61851-1: General Requirements
- IEC 61851-21-1: EMC Requirements
- IEC 61851-23: DC Charging Station Requirements
- IEC 61851-23-1 DC ACDP (Pantographs)
- IEC 61851-24: Digital communication between charging station and EV
- IEC 61980-1 WPT

To foster interoperability and active demand response from CPOs via DSOs, the so-called UMEI could be extended. The UMEI (Universal Market Enabling Interface) was developed as part of the European Union funded project EUniversal[52] for the interaction between market platforms and aggregators/flexibility providers. It aims to develop a universal approach on the use of flexibility by DSOs and their interaction with the new flexibility markets, such as DC microgrids in the context.

Higher-layer communication and potentials to improve ISO-15118-20

Since special and high-quality power electronics are required for bidirectional charging, hardware manufacturers will have to adapt their charging products to enable higher-layer communication properly. Some charging communication vendors such as Vector[53] provide support for the novel ISO 15118-20 standard, which is developed for V2X. A complete communication channel between EV and EVSE must be carried out over ISO15118-20. However, the software-implementation takes time and will become widespread on communication boards during the coming years (meanwhile, certain simulations can be done manually in a controlled way without the protocol implementation).

Within XL-Connect there is a suggesting approach, that in case many EV users are interfacing a specific use case (e.g., small company), an intermediate aggregator could be used to manage the higher-layer communication between the grid and the users (such as EV charging points, AC loads, storage batteries).

For example, a use case specific control unit that collects inputs from EV- or storage batteries, renewable energy sources and the grid should be able to communicate with an EV charging point and modulate power to get the best service considering user needs (e.g., slow or fast charging), energy costs, instantaneous energy production and availability of energy from local storage batteries (if available). Key technology for the aggregator is the presence of gateways to communicate (via the Internet, via Ethernet, via Modbus, etc.) with all other relevant participants the areas.

[51] https://www.iso.org/standard/77845.html
[52] https://euniversal.eu/
[53] https://www.vector.com/gb/en/news/news/iso-15118-the-future-of-charging/

2.2.3. Smart charging providers

In the future, there will be an increasing need for flexibility to allow customers to consume electric energy during periods of high generation and/or feed power into the grid during periods of low generation. This flexibility can be achieved through an improved interaction of the smart charging providers with the various participants within an advanced charging infrastructure. Table 4 depicts an overview about possible field of applications (set of features) for bidirectional charging and the interaction between the stakeholders, the revenue location, the customer group, and control type (centralized or in situ).

Feature	Revenue	Customer	Control
Peak shaving	Business	Business	Central
Increase of self-consumption	Household	Household	Local
Time arbitrage	Charging Provider/Grid/Market	Household, Business	Central
Real green electricity	Business	Business	Central
Primary balancing power	Charging Provider/Grid/Market	Household, Business	Local
Local network service	Charging Provider/Grid/Market	Household, Business	Central
Redispatch	Charging Provider/Grid/Market	Household, Business	Central
Provision of reactive power	Charging Provider/Grid/Market	Household, Business	Central
Tariff optimized dis-/charging	Household	Household	Local
Fleet management	Business	Business	Local
Emergency power supply	-	-	Local

Household (small areas) Business (large areas) Charging Provider/Grid/Market

Table 4. Field of applications for bidirectional charging[54]

With digital twin models to be developed in WP4 XL-Connect substantiate the most urgent features to be implemented for the use cases (cf. Table 2) and to be demonstrated in WP5.

Another crucial factor to open participation in the electricity market in the future is, that concession fees must no longer be an obstacle to the integration of EVs. Hence, a regulatory classification of EVs as stationary electric energy storage for temporarily stored electric energy and thus a strong tax exemption for temporarily stored electric energy would make sense.

XL-Connect will contribute with regulatory recommendations on that.

[54] https://www.ffe.de/projekte/bdl/

2.2.4. Distribution system operator

For distribution system operators an interconnected data basis should include comprehensive information about predictive EV usage, charge points and smart charging stations, grid characteristics and degree of capabilities.

Required data and power system data formats

For each of the digital twin models, as well as for the solutions that need to be developed for the XL-Connect use cases, each WP leader, together with the specific task members, identifies and aggregates the specific data sources and stores them in a database (e.g., grid fee data is used in the digital twin models to determine which scenarios are advantageous and helpful for the grid). A general guideline for the database will be created as part of WP3, as the tasks of WP3 include the assessment of EV charging technologies and the communication ecosystem, the seamless integration of the electrical grid and the smart charging units. This is required to access and use the same data formats for the same data objects from different sources to ensure efficient interoperability. Hence, in XL-Connect, a lightweight, most appropriate and efficient data model based on emerging standards (as summarized in Table 3) is designed and specified to accelerate the research activities planned in the project (i.e. methods enable a massive integration of electric vehicles into the power supply system). The most promising candidate for XL-Connect is the power system data format CIM (Common Information Model), since it stands for a data format with the most significant potential in terms of interoperability, completeness, modularity, and modification options.

2.2.5. Users

Users need to be aware that, like every single person, they can contribute to overcoming energy/CO_2 emission problems with their EV, for example by providing their batteries (smart home situations) during the day as a buffer for renewable energy sources or by sharing charging points in private parking places, for people who cannot charge at their own premises.

Incentives

In order to make (bidirectional) charging more attractive for the user, incentives must be set (e.g., reduced electricity bills, free parking, etc.). Such economic or energy incentives must be in relation to the additional loss in value of the EV due to battery ageing. As these are a new aspect for users, they must be convinced about how to use and provide the energy on their batteries (a certain level of charging or range needs to be ensured) in an economic way and how much money they can save on the final energy invoice (the users must receive any kind of benefits in the form of cost reductions in charging fees, money refunds, priority access, etc.). EV owners can be encouraged to delay charging their vehicles or reduce their energy usage during peak hours, helping to stabilize the grid and avoid power quality and voltage problems. Affordable charging solutions for single users should be deployed. Considering that the uptake of EVs requires financial efforts, a value assessment of the technology must be done to achieve the best cost-effectiveness, especially for private charging points. The cost of an installed private charging point must be considered as reasonable by the user/the customer not to represent a barrier to electric mobility.

To improve the user's confidence and awareness, public charging spots should enable the possibility to choose electricity supplier in the future. But this would require big investments and hence, the first step should be to enable charging points without focusing on the possibility to choose an electricity supplier.

User behaviour

Furthermore, within the XL-Connect project models for the prediction of the user behaviour are developed and demonstrated virtually by a predictive digital twin in WP5. Currently implemented models represent the user behaviour in terms of charging times, duration etc. but are not reflecting the user-reaction on different incentives. The XL-Connect models will be able to dynamically predict the user behaviour considering the influence of different incentives (different prices, payments for V2G, free parking etc.) as well.

In WP2, and in the context for the improvement of the user experience a vehicle independent mobile app for the end user with Gaia-X[55] based backend services supporting all relevant charging process steps (i.e., planning trips, booking location based charging services, charging at the charging point, seamless payment, billing) will be developed. The main architectural concept exists already, as well as the basic design app idea, the geolocation concept, and the interface idea.

XL-Connect also contributes to improve communication strategies about new services that consider the expectations and behaviour of customers (EV owners, fleet operators). Therefore, in WP2, an end-user survey (guided and easy to understand) will be conducted to explore user expectations regarding smart charging and all other central topics (e.g., availability, accessibility, user data protection[56], incentive approaches through gamification[57,58,59], etc.).

[55] https://gaia-x.eu/

[56] EV charging platforms that collect user data are subject to data protection regulations, such as the European Union's General Data Protection Regulation (GDPR). In terms of liabilities, companies that fail to comply with data protection regulations may face fines, lawsuits, or other legal consequences [15].

[57] Example Northern Powergrid (NPg): NPg have cut their electricity consumption by an average of 11% as a result of a new trial testing the effectiveness of mobile gaming to incentivize residential demand side response (DSR). If they see an increase in electric vehicles in one area, they could run a GenGame and reward people for charging their car when there is spare capacity on the network [16].

[58] Example IKEA: IKEA offers to "IKEA Family" and "IKEA Business" card holders the opportunity to recharge electric cars at the stores, offering the first 5 kWh/day for free). This kind of reward may increase the loyalty of the customers that will be more willing to come back to the store if they have this additional service [17].

[59] Example C+Charge: C+Charge empowers (for the first time) EV drivers to receive carbon credit rewards every time they charge up [18].

Conclusions

To give the project consortium of XL-Connect a useful starting point, the identification and determination of requirements for various smart charging mechanisms like V1G, V2G, V2X were summarised in this deliverable D1.1 “Requirements for advanced charging technologies”.

The deliverable D1.1 shall be helpful to show the needed target for advanced charging technologies and can act as updated requirements agenda for smart charging technologies to be implemented within the project XL-Connect.

The insights into the updated requirements for smart charging technologies (considering the various elements involved in charging) shall provide a profound starting basis for the work packages WP2 and WP3 leading to an innovative charging point installation configuration used as case study for advanced charging concepts to be developed in WP4, WP5 and WP6 by the project consortium.

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Abbreviations and Definitions

AC	Alternating Current
CAN	Controller Area Network
CCS	Combined Charging System
CCU	Charging Control Unit
CDF	Common Data Format
CGMES	Common Grid Model Exchange Specification
CIM	Common Information Model
CharIN	Charging Interface Initiative e.V.
CP	Control Pilot
CPO	Charge Point Operator
DC	Direct Current
DL	Diagram Layout
DSO	Distributed System Operator
eMSP	e-Mobility Service Provider
EMC	Electromagnetic Compatibility
EQ	Equipment
EQBD	Equipment Boundary
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FC	Fast Charging
GL	Geographical Layout
GIS	Geographic Information System
GNE	Generic Network Element
HLC	High Level Communication
HPC	High Power Charging

IEC	International Electrotechnical Commission
IOP	InterOPerability
ISO	International Organization for Standardization
LLC	Low Level Communication
NSP	Navigation Service Provider
OBC	On Board Charger
OEM	Original Equipment Manufacturer, here automotive manufacturers
OCPP	Open Charge Point Protocol
PLC	Power Line Communication
PWM	Pulse Width Modulation
RFID	Radio-Frequency Identification
SCSP	Smart Charging Service Provider
SOC	State Of Charge
SoTA	State of the Art
SSH	Steady State Hypothesis
SV	State Variables
TP	Topology
TPBD	Topology Boundary
UMEI	Universal Market Interface
V1G	Unidirectional charging
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2B	Vehicle-to-Building
V2X	Vehicle-to-everything
VCU	Vehicle Control Unit
WP	Work Package

Appendix

QUESTIONNAIRE ABOUT THE VARIOUS ELEMENTS INVOLVED IN CHARGING

Questions about the EV

- Depending on vehicle sizes, battery, and drivetrain characteristics:
  a) What are the current standards for bidirectional AC charging? (up to 22 kW on a Wallbox, ISO-15118-3 defines the hardware physical connection with the CCU, which is crucial for PLC, CAN communication between CCU and VCU)
    (i) Which plugs are common?
    (ii) Advantages of AC charging? (Car owners do not have to pay extra costs)
    (iii) Disadvantages of AC charging?
    (iv) Impact on battery degradation?
  b) What are the current standards for bidirectional DC charging? (up to 350 kW on a fast charger, ISO-15118-3 defines the hardware physical connection CCU, which is crucial for PLC, CAN communication between CCU and VCU)
    (i) Which plugs are common? (CCS 1-2, CHAdeMO, etc. advantages, disadvantages)
    (ii) Advantages of DC charging?
    (iii) Disadvantages of DC charging? (Car owners have to pay extra costs)
    (iv) Impact on battery degradation?
- A large number of EVs/charging stations in existing utility grid results in power-quality problems. These elements create harmonics that affect the distribution grid and can create power unbalances and voltage deviations.
  a) How can EVs contribute to grid stabilization to develop to develop beyond SotA standardization and hardware installation configurations for EVs, charging infrastructure and grid (V1G, V2G, V2X)?

Questions about charge points

- What are their most problematic restrictions for the most common charging technologies today?
  a) From technical point of view?
  b) From user point of view?
  c) From norms and regulations point of view?
- Charging technology to be followed up in XL-Connect.
  a) What are SotA solutions for large parking areas? (DC-microgrid -> possible use-case?)
    (i) Position?
    (ii) Charging characteristic / power?
    (iii) Number of charging connectors?
    (iv) Charging point installation configuration?
  b) Fast, high power charging with reduction of energy and power adsorbed from grid using local power supplies connected to the microgrid (e.g., renewable energy sources, storage etc.).

      (i) Are there approaches meanwhile already realized since the proposal creation?
   c) Grid support (frequency support, reactive power injection) using local power supplies connected to the microgrid
      (i) Are there similar solutions meanwhile already implemented since the proposal creation?

- Charge point operators: what is the current situation concerning the charge point management?
   a) Which protocols are used commonly to interface with the various stakeholders
   b) Which active grid support solutions are planned, e.g., P(U) control?
- Concerning data and communication: The ISO 15118 standard (Road vehicles – Vehicle to grid communication interface) is the implementation standard.
   a) What communication protocols already exist, and which are still not defined?
   b) Higher-layer communication with the VCCU: via control pilot signals (e.g., PWM). Potentials to improve ISO-15118-20.
      Who can emulate bidirectional interaction between EV & EVSE-CCS using ISO15118-20 or other key enabling protocol for bidirectional charging?

Questions about smart charging providers

- Concerning energy management, pricing, grid and energy
   a) Currently, there are no established clear rules for the interaction between the distribution system and charging platforms. First the knowledge of the V2X ecosystem for the regulatory framework regarding provision of supplementary services with EV batteries and generally the participation in energy markets would be interesting.
      What are the differences throughout Europe?
   b) There exist many publications regarding Vehicle-to-Home, Vehicle-to-Building and Vehicle-to-Grid development.
      On which use cases XL-Connect will contribute (Digital twin model, norms and regulations, etc.)
      (i) Customer household?
      (ii) Commercial site/workplace?
      (iii) Bus depot?
      (iv) Virtual Power Plant?
   c) What is the needed hardware setup for each use-case?
      There is an interactive tool that might be helpful: https://sysarc.ffe.de/en
   d) Most common implemented revenue opportunities?
      (i) How are they mapped with regulations?
      (ii) How are they mapped with the various element configurations?

Questions about distributed system operators

- In order that we can structure data, we must know which data are needed.
   a) Geodata: what is included in geodata and how it is structured?
   b) EV and grid interaction data: what is included in this data and how it is structured?
   c) Grid fees data: what is included in this data and how it is structured?
   d) Grid-topology data: what is included in this data and how it is structured?

e) Grid data (e.g., from CZ): what is included in this data and how it is structured?
f) V2G-data from Customers (e.g., from a small fleet at BMW): what is included in this data and how it is structured?
g) Primary data from energy operators: what is included in this data and how it is structured?

Questions about users

- Concerning accessibility, easy application, etc. ...
  a) Who has access to already aggregated user data, e.g., from earlier surveys for instance?
  b) How does the current communication strategy for users looks like?
  c) Where do users have objections?
  d) Where is potential to make (bidirectional) charging more attractive for users?
  e) Are gamification strategies meanwhile (since the proposal creation) present/spread?
- Current situation concerning user data protection.
  a) Liabilities?