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Review on Smart Charging of Electric Vehicles via market based incentives, grid-friendly and grid-compatible measures

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Summary

Smart charging of electric vehicles is a promising concept for solving the current challenges of the sector coupling mobility and electricity within the context of the ongoing sustainable energy transition. It enables cost savings for the expansion and operation of the power grid and a more efficient use of renewable energies. For an economic implementation, technical and regulatory issues, the connectivity of standard need to be further developed. A fully automated process as well as customisable offers, e.g. via flexible tariffs are requested. The German funding program "Elektro-Mobil" made visible under which interaction of standards the communication come to reality in the pilot projects and should be applied for further use cases.

Keywords: regulation, smart charging, standardization, V2G, V2H

1 Smart Charging via price incentives, grid-friendly and grid-compatible charging

The transition to electrically powered vehicles is associated with the goal of reducing the consumption of fossil resources and minimizing emissions that contribute both locally and globally to the ongoing process of climate change. At the same time, the expansion of electric mobility poses new challenges to the existing power grid, especially with regard to distribution grid level. For example, it increases the number of systems consuming electricity and thus the overall load demand. For this reason, the introduction of electric mobility will ultimately lead to a higher simultaneity of demand for electricity – and this at a time when the fluctuating nature of the generation of renewable energy is increasing and exercising its own effects on the distribution grid. To address these challenges and to minimize the investments necessary in the power grid, smart charging concepts should be considered from the beginning when expanding the charging infrastructure.

Smart charging can be understood in the two categories grid-friendly and grid-compatible charging. Grid-compatible charging offers several opportunities to incorporate price incentives into the charge management. Price-controlled charging is one way to realize a more efficient utilization of distribution grids and consequently to save costs thereby freeing up resources which can be invested in grid expansion and balancing measures. It allows furthermore the adaptive timing of electricity demand and the generation of renewable energy, as well as an active contribution to environmental and climate protection through more efficient use of fluctuating renewable energies. In addition, this could create scope for reducing the operating costs of the charging infrastructure. For example through lower grid connection costs, the charge point operator (CPO) can be motivated to reduce the price for the charged energy.

The term price-controlled charging used in the following describes a charging management system that plans and implements the charging process of one or more electric vehicles (EV) depending on price signals from the electricity market. During times of high demand for electricity, the point in time for charging the vehicle is delayed – and where bidirectional charging is possible, the EV feeds energy into the grid.

The projects of the funding program “Elektro-Mobil” of the German Federal Ministry for Economic Affairs and Climate Action (BMWK) demonstrate within pilot-projects that smart charging can be effectively implemented utilizing price and other control signals [1]. The projects of the “Elektro-Mobil” funding program jointly published a study on smart charging as well as a whitepaper together with the accompanying research [1, 2]. In this study, the authors outline concrete needs for action to promote or to implement smart charging via price signals. Several subject areas were identified which are delineated in the following.

In addition the accompanying research of the funding program “Elektro-Mobil” moderated an agreement process on standards for the communication of the control signals to assure the continuity of the communication between all process steps. The results of this process were published in a whitepaper on control of charging processes in electro mobility [2] and are described in this paper as well.

Similar pilot projects are initiated worldwide [3]. In order to implement smart charging, it will be necessary to ensure the transmission of the control signals according to specific standards. In addition, the implementation of regulations is necessary to enable the stakeholders to fulfill the whole process from identifying market signals, grid challenges, processing and orchestrating different control signals as well as measuring and accounting the delivered electricity.

1.1 Use Cases

Smart charging depends strongly on the specific use case. Various use cases, which include smart charging via price incentives and measures by the power grid will be presented in the following. Potentially, all use cases which include smart charging via price incentives or grid-measures can be realized unidirectionally and bidirectionally.

To interpret the tables appearing in this paper correctly, it is necessary to understand the meaning of the following icons:

Grid and grid operator | Industry / public use | Home / private use

1.1.1 Smart charging via price incentives

The possibilities and characteristics of price-controlled charging are diverse. Table 1 classifies use cases of price-controlled charging with direct price control. Direct price-control means that the EV charging strategy is adjusted exclusively based on time-resolved price signals. In this case, the price signals can vary in a highly dynamic way.

Table 1: Use cases of smart charging via price incentives ([1], Source: BDL project)

Use case	**revenue location**	**customer group**	**regulation**
Time arbitrage through trading on the electricity market (day ahead, intraday) (V2G)			in front of the meter
Tariff-optimized charging (stock market-oriented, variable grid charges) (V2H)			behind the meter

When using <u>*time arbitrage through trading on the electricity market*</u>, the charging process depends on the price differences of the intraday or day-ahead markets. The EV is charged during periods when the electricity price is low. If bidirectional charging is possible, power is fed back into the grid when the price of electricity is high.

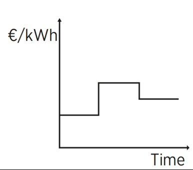
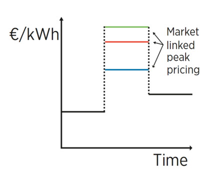
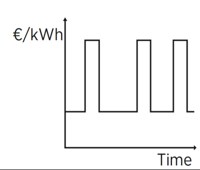
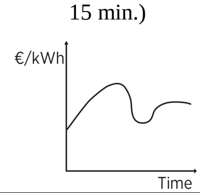
<u>*Tariff-optimized charging*</u> in contrast uses dynamic tariffs that are time-dependent. When the time is identified in which the EV is supposed to achieve the set battery level, the EV additionally is charged when the electricity tariff is low and the energy is fed back into the grid when the electricity price is high. This use case has its revenue location in the specific home instead of the grid.

Tariffs for price-controlled charging of EVs

Similar to these diverse possibilities for price-controlled charging, there are also different forms for setting dynamic prices. Dynamic pricing refers to retail electricity prices that pass on at least some of the volatility of wholesale prices to end consumers. These marginal costs of electricity generation are expressed in the short run through spot prices and in the long run through forward prices. Dynamic pricing means that prices and price periods correspond so that they actually provide incentives to shape energy consumption behaviour in line with wholesale price trends. According to Table 2, four types of tariffs can be classified.

From a technical point of view, the implementation of dynamic tariffs that follow the electricity market requires load profile measurement. This is the measurement process utilised by the energy supplier on location by the customer. This metering process has been ensured for decades for customers with registered load profile metering (RLM) and will be introduced in Germany by so-called "smart meters" (intelligent metering systems, iMSys) for smaller consumers between 6 and 100 MWh per year of electricity demand on the distribution network level.

Table 2: Smart charging based on price signals ([4] and [5])

Type of tariff	**time-of-use pricing (TOU)**	**variable peak pricing (VPP)**	**critical peak pricing (CPP)**	**real time pricing (RTP)**
Setting prices	static	static & dynamic	static & dynamic	dynamic
Description	usage over large time blocks of several hours (e.g. day and night pricing)	different periods for pricing are defined in advance, but the price for the on-peak period varies dependent on market conditions	rate in which electricity prices increase substantially for a few days in a year	prices are determined close to real time consumption of electricity on fine granularity (e.g. 15 min.)
Graphical representation				

1.1.2 Grid-friendly and grid-compatible charging

The capability of price-controlled charging is not the only factor which influences the implementation of smart charging. Grid-serving measures also have a great impact on how smart charging is realized at home or at the workplace.
Table 3 presents three use cases in which grid-serving measures are used for indirect price-controlled charging. Indirect price control represents a charging strategy based on an overall optimization that includes price signals.

Table 3: Use cases of smart charging via grid-friendly and grid-compatible charging ([1], Source: BDL project)

Use case	revenue location	customer group	regulation
Peak load capping (V2B)			behind the meter
Increase of self-consumption (V2H)			behind the meter
System services (V2G)			in front of the meter

When realizing *peak load capping* e.g. in a company, the overall peak load is reduced by charging the EVs during times of reduced load. The vehicles can feed electricity into the system when consumption of different electrical consumers is high.

Increase of self-consumption means that an EV is charged to intermediately store the surplus electricity produced by an electricity generator (e.g. solar panel). This use case is part of Vehicle to Home (V2H).

System services can be used to minimize the shortage of electricity, if network bottlenecks occur. The vehicles are charged or uncharged based on signals by the Distribution System Operator (DSO). This use case is part of Vehicle to Grid (V2G).

1.2 Application of the use cases

Pilot projects in the funding program “Elektro-Mobil” of the BMWK

The projects of the funding program “Elektro-Mobil” of the BMWK demonstrate how smart charging can be implemented with consideration of control signals. The projects use different solutions which address diverse use cases and different forms of potential implementations in Germany. The solutions range from charging at the workplace or in residential areas and on the properties of municipal companies to bidirectional charging in private homes [1].

The BSR-Li-Flx project deals, among other things, with solutions for price-controlled charging on the premises of municipal companies. It is based on developing a decentralised solution for an electricity customer with registered power measurement (RLM customer) in addition to the company's own energy management system and the existing measurement technology. The control is based on a 15 minute timetable. The calculation of the reduced purchase price is based on the subsequent measurement of the flexibility services realised by the customer.

In the project LamA - Charging at Work, the focus is on the nationwide development of charging infrastructure at locations of the Fraunhofer Society. In the project, a platform architecture for intelligent load management is being developed, which can take into account various control signals, such as simulated price signals from the electricity exchange, user requirements, and other consumers. In this way, the charging management ensures a peak load management for all consumers on the company site.

In the project ELBE, over 7,000 charging points are being set up under the premise of avoiding grid expansion in the distribution network. It is implemented exemplarily in the form of a "minimum valuable product", which connects the charging infrastructure to the electricity grid via a direct interface. This project presents pragmatically how the implementation can be carried out while considering business models that have already been established in a similar form in the USA. In this project, the communication standard openADR 2.0 is used to connect the CPO to the distribution grid operator (DSO) or other entities, which has meanwhile been transferred to the IEC standard 62746-10-1 ED1.

Next to the exemplary mentioned projects above, there are more “Elektro-Mobil” projects which deal with smart charging in different use cases. Projects like ARNi, BDL, DatenTanken, Resigent and unIT-e² are working on uni- and bidirectional smart charging including a working standardized charging system. All these projects were involved in the consensus process of the above mentioned whitepaper.

Further Market applications to price controlled charging

If smart metering is available, more and more companies offer variable energy prices for households or companies for different applications and initial situations - not only for the charging of EVs. A solution for time-variable grid tariffs has been developed under the leadership of the distribution grid operator MitNetz in Germany. The energy management system of a property or a smart wallbox controls the charging processes of the vehicles based on price signals (based on time-variable grid charges) as well as on information about available grid capacity, received from the DSO via an interface. There is no direct intervention by the DSO in this approach. Instead, the DSO uses the specification of the time-variable grid tariffs of the load management as a control instrument. With these instruments, critical grid situations can be prevented. The German company Easy Smart Grid, for example, implemented a so-called Walrasian auctioneer in the pilot project SoLAR [6], which ensures that the local real-time price always reflects the balance of supply and demand. In contrast to traditional markets such as EPEX, this means that participants are actively involved in the price formation. Other companies such as Awattar from Austria or Tibber from Germany offer flexible tariffs, where electricity is purchased cheaply from the stock exchange and the price is passed on to the customer. Most of them promote the use of renewable energy with their flexible tariffs. In addition, Tibber also provides a public Application Programming Interface (API), which can be used independently for integrating applications or for smart home control. The company Stromdao offers a variable tariff throughout Germany based on a green electricity index to ensure a low carbon footprint for its customers [7, 8, 9].

Even though there are already some variable electricity tariffs where lower purchase prices are passed on to the customer, the technical and legal implementation of the entire process is not yet feasible in Germany. The integration of the tariffs into the control of the vehicle's charging profile is also not directly offered by these companies, as most of them do not distinguish between different end-user equipment, such as EVs or heat pumps. In domestic use, this can be implemented via the energy management system (EMS) of a property or alternatively via the CPO backend, although the realisation of both solutions is still very complex for private households.

International experiences to price controlled charging

Worldwide, most experience has been gathered using dedicated static time-of-use (TOU) charging for EVs [3]. This model is currently offered in California by Pacific Gas & Electric (PG&E) [10] and by San Diego Gas & Electric (SDG&E) [11]. Both provide different TOU tariffs of which the customers can choose depending on their individual energy profile. They define peak hours, in which the consumption of electricity is more expensive than in off-peak hours. One project with a critical peak pricing (CPP) tariff was started in France [12], where the price increases significantly for a determined period of time, which is communicated in advance. If consumers shift their electricity use to off-peak hours (outside this time frame), they will receive a fixed cost reimbursement [13].

Further pilot projects were launched to implement dynamic pricing for EVs as, for example, by SDG&E which offers three different pricing plans for EVs at home with off-peak and “super off-peak” rates. These depend on the seasons and time of the day [14]. To introduce dynamic pricing, another pilot project started in Norway in 2019 by the Norwegian Water Resources and Energy Directorate (NVE) [15]. The charged tariff depends on the electricity demand in a given period, which provides a direct incentive to avoid EV charging during peak hours.

Comparison of first solutions

It was found that static TOU is easier to realise and easier to understand. Excluding the standard tariff, TOU is the most common pricing model, even though the acceptance and adaption have to be increased by further incentives. However, an optimal grid load and usage of renewable energy can only be achieved by implementing dynamic pricing models. Although the introduction of real time pricing (RTP) has already begun [13], much development is still necessary before dynamic pricing can be realised as a standard. The developments required depend on technical and regulatory issues, standards needs to be compatible. What is needed is both a fully automated process as well as customisable offers, which provide customers with flexible tariffs. Usually, the DSOs offer tariffs with mixed calculation on the side of the supplier as well as offers for pilot projects with special conditions.

2 Implementation options and needs for actions

As a result from the activities of the "Elektro-Mobil" funding programme, relevant needs for action to promote or to implement smart charging via price signals were derived in a variety of subject areas outlined below. At the same time, a consensus between the funded projects on standards regarding the communication for smart charging under the German legal framework for specific use cases was reached [2].

To create an economically working system for smart charging there are different aspects to be considered. The following chapters will focus on exemplary aspects.

2.1 Economic aspects

"The integration of EV charging in a smart and connected environment will be a key success factor, enabling annual revenue growth of up to 5 billion euros in Europe by 2030. A reliable and intelligent charging infrastructure is the key for the mass transition to electric mobility", states the consultancy P3 [16].

Their full potential for the energy system is realised when they are charged intelligently and also feed electricity back into the grid. In the future, electricity will be temporarily stored in the car and fed back into the grid at a later point in time. This will help avoid having to throttle the generation of renewable energy. EVs capable of bidirectional charging make an important contribution to the stability of the electricity grids. Electricity fed back into the grid can be utilised as large-scale storage by pooling vehicles. A legal framework must be created to ensure that both grid integration and the flexible use of smart and bidirectional charging succeed at all grid levels. Finally, people who own an EV will only make their mobile storage available for flexibility services if they can generate income from it and thus reduce their total cost of ownership. The investment costs for all participants in the business model of bidirectional charging (vehicle users, aggregators, charging point operators) will only be refinanced on the market if the necessary investment costs can be recovered through corresponding profits.

2.1.1 Raising ecological potentials economically

In addition to measures to control charging processes, pooled storage of bidirectional vehicles can make an important contribution to reducing investments in grid expansion, ensuring grid stability, guaranteeing supply security and increasing the share of renewable energies in the electricity system. Bidirectional charging will avoid investment of gas power plants by up to 25 billion Euro by 2050. The load procurement costs at the European stock market in 2050 can be reduced by 45 billion Euro per year. In the scenario of bidirectional charging, the average European electricity price will be reduced by 3 Euro/MWh and the European system costs in total in 2030 will be reduced by 9 billion Euro per year. [17]

As shown in [18], smart charging of EVs can also have positive effects on household electricity prices, grid load and emissions in Germany. With more EVs in use, the overall demand for electricity increases. Charging EVs in a non-controlled way will cause load peaks, because most of these vehicles tend to be charged at home after work, while household consumption is high. Controlled charging can help flatten the load curve by shifting the charging process to night hours. Hence, the need for grid expansion is reduced despite the overall increase of demand for electricity. This improves the general grid load. Network charges, which can be described as a temporary rent of the grid network, are reduced due to the more efficient use of the grid. However, it is necessary to research further on whether the demonstrated cost differences between smart and non-controlled charging are sufficient incentives to nudge EV owners to participate in charging management. To leverage these positive effects, the regulatory framework needs to be adapted in a way that the ecological incentives can also be reflected in monetary terms for the implementing persons or actors [18]. Another, even higher incentive can be implemented by bidirectional charging, which can reduce the pressure on the grid even more.

The integration of economic or control signals into the charging management is mandatory for the implementation of smart charging. With no standards existing for this important interface yet, the integration of signals is currently the most urgent need for action especially for smart charging. In consequence, generally accepted standards are necessary to simplify access and usage of economic signals for charging management. The achievements concerning standardization of the funded pilot-projects are highlighted in chapter 2.2.

2.1.2 Creation of incentives, regulation and user aspects

When designing incentives for smart charging, two target groups are to be considered – commercial addresses and private drivers of an EV. It is primarily important for users from both target groups to receive a financial compensation. Also important, even though secondary, is their contribution to the turnaround in energy policy as well as their impact on grid stability. The users choice of the charging management system depends highly on their personal and economic preferences [1]. If a private person is generally interested in environmental protection, they usually select more eco-friendly tariff models. Companies are increasingly forced by customers to reduce their carbon footprint. Further non-financial incentives – especially for private customers – could be created by installing appealing user interfaces, e.g. in the form of app-based feedback on the individual contribution to climate protection (gamification). For drivers of EVs in particular, other less obvious motivators such as a positive user experience and the assumption of a pioneering role in society are relevant for the use of intelligent charging systems [1, 19].

The access to price signals and the financial leverage differ between private households, small companies and companies with high energy consumption and individual contracts, so-called “customers with registered power measurement” (CRPM). Compared to small energy customers, customers with registered power measurement have an easier starting position for the introduction of a price-controlled charging management due to the already existing measurement technology and the individualizable contract design. For these customers, the current possibilities to use price signals from the electricity market and grid for charging management are currently less characterized by technical factors, but more by organizational and contractual factors such as contracts which include peak load shaving and respective capping in a large range.

Data privacy, data availability and data economy need to be ensured for all business models. Smart charging requires data to optimize the charging process, which must be provided or exchanged in particular by users, CPOs and electro mobility service providers (eMSP). It must be ensured that the data is provided by the respective players and that data protection and the principle of data economy are observed for the critical infrastructure of charging points.

Creating attractive incentives is not only a question of business models. It is also a question of regulation to enable envisaged developments. Particularly in view of the fact that in Germany the household electricity price currently accounts for more than 70 % of the total price on taxes and grid fees [20], a variable electricity exchange price would only have a very limited financial incentive effect on the charging behavior under the current legislation. In other countries such as the USA, more attractive price incentives could be achieved due to the different market and regulatory frameworks that prevail there [**Fehler! Verweisquelle konnte nicht gefunden werden.**]. In consequence, it must be clarified how a higher incentive can be achieved via regulatory intervention and how regulatory measures can be effectively utilized to push controlled loading. It should also be identified how the incentive system can be designed most efficiently for the desired goals and thus achieve the greatest effect. This could mean that e.g. not only reduced prices for off-peak times are focused. Additionally, also static price components could be used, e.g. the reduction of the building cost contribution with stipulated controlled charging. Here, the incentive would lie in the reduction of the initial investment and not in the ongoing operation and would directly allow a lower connected load to be realized. The business segment of smart charging is already seen as central by relevant actors and is considered to be a significant source of revenue. An important question in this respect is how a critical mass of flexibilities, which is traded on the electricity market, can be provided by electric mobility. The bundling of flexibilities could help incentivize stakeholders or aggregators to invest, despite the high costs of hardware and software, as well as the ongoing operating costs which have to be covered. Regulations need to be adapted accordingly based on the knowledge of user behavior – depending on differences between private and commercial customers [**Fehler! Verweisquelle konnte nicht gefunden werden.**, 17].

2.2 Standardization

Building a system architecture that connects the charging infrastructure, the backend of the charging infrastructure, the energy management system, the preferences of EV users while at the same time controlling the charging processes based on grid- and market-oriented information is an extremely complex task. This complexity requires a large number of interfaces and necessary standards.

Much work has been done by the German standardization-committees yet. While in the year 2021 the ISO 15118 lacked a comprehensive implementation of a standard in vehicles and charging infrastructures to ensure that information from battery management in the EV are passed on to the electric vehicle supply equipment (EVSE), this deficit is currently being addressed in an update of the standard ISO 15118-20. ISO 15118-20 is set to be published in summer 2022. This updated version includes the depositing of the charging certificate in the EV and additional functions of the charging management enabling V2G [21].

ISO 15118-20 represents a significant step towards bidirectional charging on the section between EV and EVSE. However, further standards need to be established in support of bidirectional and smart charging. Furthermore, standards need to be connectable to each other to ensure the total process of load control and billing. In consideration of the German framework described e.g. by the national platform electro mobility (NPM) [22], VDE FNN target picture controllability of EVSE [23] and the smart meter gateway-Roadmap-process [24] a range of projects funded within the funding program “Elektro-Mobil” agreed on a landscape of standards to process the communication for smart charging. These standards can be currently used nationally and, to some degree, internationally [2]. The work of the funded projects and the accompanying research support the process of standardization in that way that they made visible under which interaction of standards the communication for two exemplary use cases of smart charging come to reality in their pilot project and should be applied for further smart charging use cases. The core is a triad of ISO 15118, IEC 63110 with OCPP and VDE-AR-E 2829-6 (Equality to VDE-AR-E 2122-1000 in process) with among others EEBUS.

Fig. 1 and Fig. 2 present the actors /entities and the communication channels of smart charging systems for two specific use cases, which occur in the “Elektro-Mobil” pilot-projects. While Fig. 1 shows the communication channels for the price driven use cases, Fig. 2 presents the communication channels in case of emergency regulations via grid-measures.

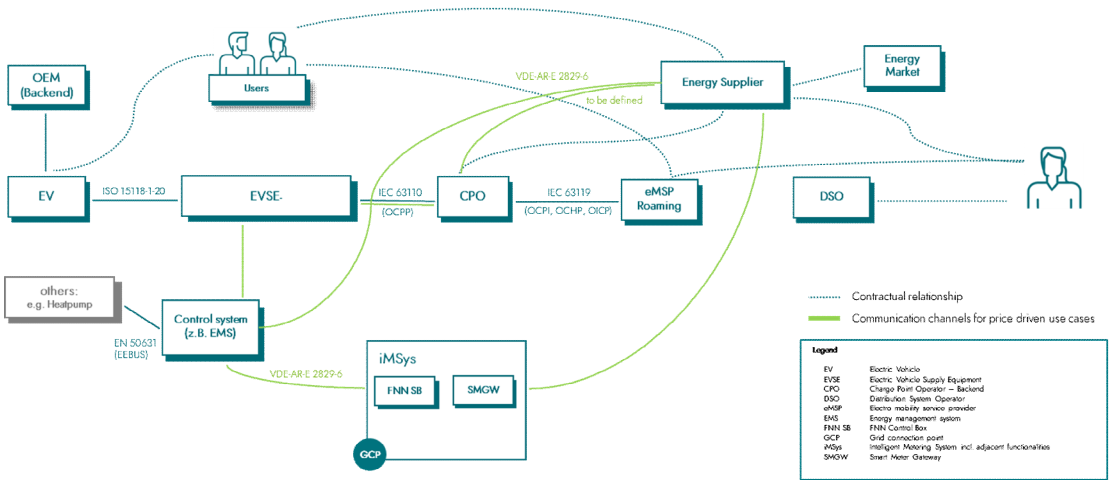


Figure 1: Smart charging system - Communication channels for price driven use cases (green coloured lines)

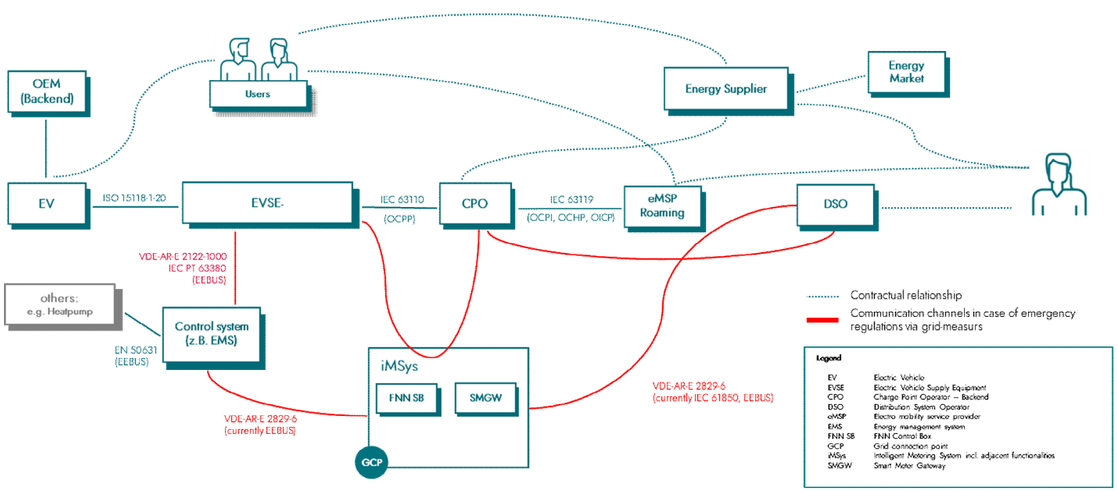


Figure 2: Smart charging system - Communication channels of emergency regulations via grid measures (red coloured lines)

In order to provide solutions for different use cases and situations, the projects are working on different approaches. Most projects are developing solutions with a local control at the grid connection point. The project ELBE is pursuing a cloud-based approach to implement smart charging and applies openADR for the connection to the DSO.

Both Figures show the complexity of smart charging and its standards on which most of the projects could find a consensus. The “Elektro-Mobil” projects have made it possible to agree on the standards, which addresses smart charging via price incentives and grid-measures. On this consensus, further developments as on compatibility could build up.

In order to achieve a standardized system, which functions on an international level, further work on the development of new standards and the update of existing standards is necessary.

In addition, the implementation of regulations is necessary to enable the stakeholders to fulfil the whole process from identifying market signals, grid challenges, processing and orchestrating different control signals as well as measuring and accounting the delivered electricity.

3 Conclusion

Smart charging can help break down the obstacles which currently hinder the expansion of electric mobility. It can potentially reduce costs for users, while improving the grid stability simultaneously. At the same time, a higher share of renewable energy can be fed into the grid and investments into grid infrastructure could be reduced. However, smart charging is currently not prevalent. Different projects in Germany, the USA and Europe are researching how to implement it optimally. In some countries it is partly already implementable. It was found that the most user-friendly smart charging tariff is TOU, which offers reduced electricity prices during off-peak hours and is already in use at several regions of the world. Nevertheless, it is possible that more efficient tariffs for the grid, such as dynamic RTP, could assert themselves if the charging process is conducted automatically. It is crucial for smart charging that relevant standards for the communication between all entities are compatible to process the whole chain from load control to billing. Most promising in Germany seems to be the core of ISO 15118, IEC 63110 with OCPP and VDE-AR-E 2829-6 (Equality to VDE-AR-E 2122-1000 in process) with among others EEBUS between EV and EVSE and grid. Internationally openADR is also a preferred standard for the connection to the grid. While their usage can depend on the use case, it is also possible that their functionalities and contents need to be converged. For this reason further observation is needed.

While smart charging already has many advantages, bidirectional charging offers even higher incentives for the users and to electro mobility, being more climate-friendly. With this system, it is not only possible to save money for the users when charging the EV at off-peak hours, but also to earn money by selling energy which had been previously stored during a period of oversupply. However, bidirectional charging does not only give incentives to the user, it also could play an important role for the grid stability. With pooled bidirectional charging supplied as system services, the usage of renewable energy can become even higher since the natural fluctuations can be compensated. Thus, smart charging can therefore pave the way to a more climate-friendly world and an efficient energy system. In order for the aggregated flow of electricity from the EVs into the energy system to take place via V2G and V2H, all the necessary processes must be clearly regulated by law.

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