Field test of charging management system for electric vehicle

State of the art charging management using ISO 61851 with EV from different OEMs

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***Abstract*—In this publication the project ePlanB is presented. It deals with an intelligent Charging Management System (CMS) of Electric Vehicle Supply Equipment (EVSE) conglomeration in a field test with Electric Vehicles (EVs) from six different Original Equipment Manufacturers (OEMs). Furthermore, technical characteristics are shown and benefits for stakeholders discussed.**

Keywords—Electric mobility, Charging Management System, Smart-Grid, Energy management, Energy supply and power grid operation

I. Introduction

In order to reduce global warming the emission of Greenhouse Gas (GHG) emissions must be reduced [1]. In combination, EVs and renewable energy sources offer the potential to substantially decrease GHG emissions [2]. Powered by energy from renewable sources EVs can significantly decrease GHG-footprint of road transportation. Governments all over the world are driven by this fact and take measures to increase the market penetration of EVs [3] [4]. Additionally, EVs can provide many applications to support integration of volatile renewable energy to the electric grid [5] [6] [7] [8] [9] [10].

The EV market is emerging with an increasing number of EV model and a growth in the sale numbers of EV units [11] [12]. However, the integration of this increasing amount of EVs into the electric grid also imposes challenges and can lead to additional investments in power supply systems [13] [14]. Through intelligent CMS additional investments can be reduced and the integration of renewables can be supported [15].

A. Field test project ePlanb

The aim of the project is to develop an intelligent CMS for electric vehicles, which takes several input data from participants, the distribution system operator (DSO), renewable power production forecasts and energy prices into account, in order to generate optimized charging plans.

The system is tested at a Park and Ride (P+R) station in Buchloe, Germany. It comprises fourteen EVs from six different OEMs which are given to commuters. The project lasts over 3 years until June 2017. It is funded by the Bavarian Ministry of Economic Affairs and Media, Energy and Technology whilst being executed by the Lechwerke AG, LEW Verteilnetz GmbH, Research Center for Energy Economics, the city of Buchloe and the county of Ostallgäu.

B. State of the Art for EV-Charging

The International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO) have published several norms in which standards for EV-charging are defined. These norms have been widely adopted by industry and national norming institutes. Norm IEC 62196 [16] defines different plug types for EV and EVSE for AC and DC charging as shown in the TABLE I.

TABLE I. Connector Types based on IEC 62196

Connector Type	Based on:	Distribution
Type 1	SAE J1772-2009	Northern America, Asia
Type 2	IEC 62196 Type 2 –	Europe
Type 3	EV Plug Alliance	

In IEC 61851 general requirements for charging electric vehicles are specified [17]. For example, they comprise charging modes (TABLE II.) and unidirectional communication (TABLE III.).

TABLE II. Charging Modes according to IEC 61851-1

Charging Mode	Description
Mode 1	Slow charging from a household-type socket-outlet.
Mode 2	Slow charging from a household-type socket-outlet with an in-cable protection device
Mode 3	Slow or fast charging using a specific EV socket-outlet with control and protection function installed.
Mode 4	Fast charging using an external charger.

This communication is realized with a 1 kHz pulse-width-modulation (PWM) signal. The duty cycle of the PWM signal is linked to the predefined current consumption which must not be exceeded.

TABLE III. CURRENT CONSUMPTION IN AS FUNCTION OF PWM-DUTY CYCLE ACCORDING TO IEC 61851-1

Duty Cycle	Maximum Current Consumption of EV
<3 %	Charging not allowed (0 A)
3 % < Duty Cycle < 7 %	High Level Communication is required
7 % < Duty Cycle < 8 %	Charging not allowed
8 % < Duty Cycle < 10 %	6 A
10 % < Duty Cycle < 85 %	Available current = duty Cycle * 0,6 A
85 % < Duty Cycle < 96 %	Available current = (duty Cycle -64) * 2,5
96 % < Duty Cycle < 97 %	80 A
Duty Cycle > 97 %	Charging not allowed

With the modulation of the PWM-signal, the maximum current consumption of the EV can be restricted. With knowledge of the amount of used phases, the maximum allowed power can be calculated. Therefore control of the charging power is already possible through usage of the PWM-signal.

In ISO 15118 [18], a more advanced bidirectional high-level-communication (HLC) with the support of Efficient XML-Messages is specified. The first part of this standard was released in the year of 2013, the second part in 2014 and further parts have not reached the status of international standards yet.

C. Applications for Charging Management Systems

CMS can offer several grid-related energy storage applications (similar to other energy storage systems), which are characterized by [19] and shown in TABLE IV.

TABLE IV. FIVE CATEGORIES OF ENERGY STORAGE APPLICATIONS ACCORDING TO [19]

Category 1 — Electric Supply Electric Supply
1. Electric Energy Time-shift
2. Electric Supply Capacity
Category 2 — Ancillary Services
3. Load Following End User/Utility Customer
4. Frequency Regulation
5. Electric Supply Reserve Capacity
6. Voltage Support
Category 3 — Grid System
7. Transmission Support Integration of Renewable Energies
8. Transmission Congestion Relief
9. Transmission & Distribution Upgrade
10. Substation On-site Power
Category 4 — End User/Utility Customer
11. Time-of-Use Energy Cost
12. Demand Charge Management
13. Electric Service Reliability
14. Electric Power Quality
Category 5 — Renewables Integration
15. Time-shift
16. Capacity Firming
17. Grid Integration

Different applications demand different technical requirements. As a commonality, the EVs power consumption is controlled in most of them. This includes reducing the power consumption from positive values to zero and may go further into reaching negative values (feeding power into the grid - Vehicle2Grid). The requirements of power adaption for some applications are of high dynamic (e.g. for frequency control). Moreover, applications requiring reactive power generation (e.g. voltage support) are technically possible.

Current state of the art technology already allows all forms of applications. However, the integration of such technologies into EVs and the necessary integration into futures smart grids take time. Today’s CMS are therefore limited by the capabilities of the current EV models on the market, by non-proprietary standards and by slow transition of the electricity system to a smart grid. Nevertheless, several stakeholders could already make use of the available technology in order to obtain benefits.

D. Stakeholders and Benefits

A charging management system alters the charging of the EV by enforcing an intelligent charging schedule instead of letting the EV immediately charge as soon as it is plugged into the EVSE. The vehicle is not anymore charged as fast as possible (i.e. with full power). Instead the CMS is used to provide value added services depending on the stakeholders, which might have positive influences on EVSE-lifecycle costs. As a result, the overall costs for electric mobility can be reduced.

In the project ePlanB a CMS for EVSE-conglomeration is being developed and tested. A conglomeration of EVSE is defined by multiple EVSE at the same location. This can be for example a fleet of charging points in close vicinity from each other or a car park with many charging points for EVs. The crucial point is that multiple EVSE are concentrated at one location. Nevertheless, the CMS may be used for single EVSE as well. Then the cost for communication-, control- and measurement devices has a bigger impact on the economic efficiency of the system. TABLE V shows involved stakeholders, their interests and the possible benefits of the ePlanB charging management system for them.

TABLE V. STAKEHOLDER ANALYSIS

Stake--holder	Interests	Benefits of CMS
DSO	Power transmission to EVSE-location	CMS can give additional flexibility in grid operations and therefore increases grid efficiency and decrease necessary grid expansion
Electricity Provider	Provide energy as business model to EVSE-Operator	CMS allows the utilization of lower cost energy and/or lower CO2-Emissions
EVSE-Operator	Sell charging energy as business model	Cost reduction for EVSE operations through value added services, e.g. load reduction on demand of the DSO in order to get the benefit of lower grid fees or power saving to decrease billable power peaks
EVSE-Service-Provider	Provide EVSE-related services to EVSE-Operator as business model	Additional service to offer

EV-user	Charging vehicles until departure	Decrease costs for charging, usage of energy with lower CO2-emissions
National Economy	Cost reduction for reducing GHG-emissions	Allow charging with energy with lower CO2-emissions, possible support for integration of renewable energies
Service Provider	Use of CMS for additional applications that create extra value	Initial requirement for offering additional applications

The EV user's acceptance is crucial for the successful introduction of CMS. The mobility of users must not be limited by the CMS, otherwise acceptance will be difficult to reach. Therefore, it is necessary to obtain knowledge about the user's planned time of departure and the expected state of charge (SOC) at that time. Based on this information and by combining it with EV-specific charging parameters, like the minimum and maximum charging power that the EV supports, the minimum duration ΔT_{min} required for charging that amount of energy at maximal power can be identified. Furthermore, the potential time interval ΔT_{avail} in which the power shifting can take place can be calculated as well (the time interval between arrival and departure minus a security time buffer). Since in most cases ΔT_{avail} is greater than ΔT_{min}[1], extra value for the stakeholders can be created by shifting charging power inside the resulting time buffer in an intelligent way.

A two-year long field test takes place between March 2015 and February 2017 in order to get further insight into that potential, to support the development of the CMS, and to validate and evaluate the implemented CMS.

II. Field Test

During the field test, fourteen EVs are given to commuters of a Park and Ride (P+R)-station in Buchloe, Germany. Commuters are drivers with a very regular driving behavior and long parking times, which makes them an ideal target group for testing the CMS.

The EVSE-conglomeration consists of a total of sixteen charging points. Type 2 connectors in Mode 3 are used with the IEC 61851 PWM-signal to control the power reduction for each charging point. ISO 15118 is not supported by all EVs within the field test and for that reason it is not yet utilized. As a requirement, the CMS should be capable to work with any existing EV which supports IEC 61851 without the utilization of any proprietary interfaces. This setup enables the usage of low dynamic[2] CMS applications, which should be easily achievable in theory. However, practice has shown that the EVs behave differently than expected and the CMS needs to take EV-model specific considerations into account in order to work properly. Fig. 1 shows the modular structure of the CMS.

[1] Commuters usually park for durations between 5 and 10 hours whereas – depending on the EV's charging characteristics and SOC at arrival – the needed charging time ranges from 1 to 8 hours.

[2] The total reaction time ranges from approximately 30 seconds to 1 minute between a triggering event and the effective enforcement of an updated charging plan. Roughly half of the delay is due to incompressible latency in wireless connections (GPRS). The rest comes from the time needed to solve the optimization problem.

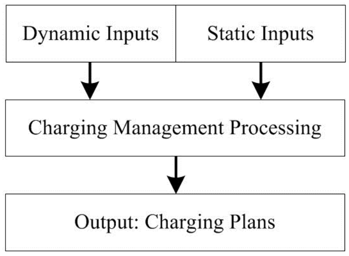

Fig. 1. Overview on Structure of the developed CMS

Immediately after the EV is plugged, optimized charging plans are generated depending on dynamic and static inputs.

A. Dynamic Inputs

All input data whose value changes over time are treated as dynamic inputs.

The participant's data (arrival time, departure time and battery state of charge (SOC) at the time of arrival) spans a timeframe in which the charging of the EV can be controlled. Moreover the DSO has the ability to limit the maximum allowed power consumption on demand. This data defines the boundaries of the optimization space.

The optimization's goal is to maximize usage of local power generation from renewable energies and to minimize the cost of energy while respecting the user's and DSO's expectations. Therefore forecasts for the local renewable power production and for the energy prices are taken into account in the cost function of the optimization problem.

Finally the actual arrival and departure time of each EV is received from the E-Mobility-Operator. Fig. 2 summarizes these dynamic inputs. Any change in the data from these dynamic inputs triggers a new event which starts a new optimization of the charging plans based on the updated data.

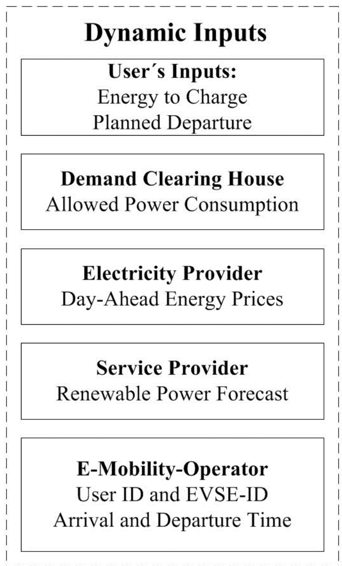

Fig. 2. Dymamic Inputs for CMS

B. Static Inputs

Static inputs are inputs that change rarely like the EV's charging behavior. For example some of the vehicles are not able to interrupt the charging completely and resume it a few minutes or hours later. These vehicles require a minimum charging current in order to avoid the so called "sleep mode". TABLE VI. shows the used EVs in the field test, technical parameters and their sleep-mode behavior.

TABLE VI. EVS IN THE FIELD TEST AND TECHNICAL PARAMETERS[3]

Quantity	OEM / Type	Usable Battery Capacity	Number of Phases	Max. Current	Falls in "sleep-mode"
2	BMW i3	18.8 kWh	1	30,7 A	No
2	Mitsubishi i-Miev	16 kWh	1	13,7 A	No
3	Nissan Leaf	24 kWh	1	16,0 A	No
2	Renault Zoe	25.9 kWh	3	31,5 A	Yes
2	Smart fortwo ed	17.6 kWh	3	32,0 A	No
3	Volkswagen e-Golf	24.3 kWh	1	15,6 A	Yes

The sleep mode of EVs constitutes a real challenge because it decreases the degree of freedom regarding the CMS. The EVs susceptible to falling into sleep-mode have to be charged with a minimum current of 6 A which corresponds to 1.4 kW up to 4.1 kW depending on the number of charging phases. To identify these EVs and to get additional insights, the charging behavior for each EV-type has been tested with several test-routines prior to the deployment of the CMS in the field test. The sleep mode behavior for example has been tested with the charging plan shown in the Fig. 3. Within this test the charging breaks last between 1 minute and 8 hours. If the EV does not resume charging after the given break this means that the EV fell into sleep-mode and the test has not been passed. In that case, charging cannot remotely be started again. The plug has to be physically disconnected from the EV and then reconnected again to awaken the vehicle and resume charging.

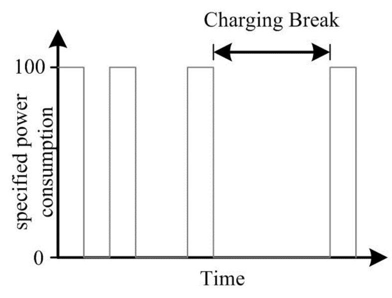

Fig. 3. TEST PROCEDURE FOR SLEEP-MODE BEHAVIOR DETECTION

Another assessment is a full-charge test which is shown in figure Fig. 4. The measurements begin with vehicles discharged up to a SOC of less than 5 % and are then charged with maximum power until the charging process is terminated by the EV when the battery is full.

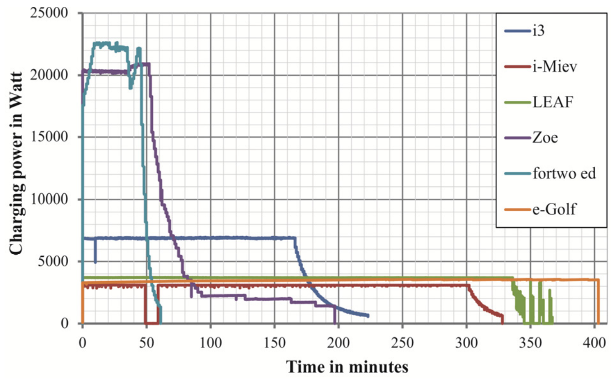

Fig. 4. FULL-CHARGE TEST WITH MAXIMUM POWER

The results indicate that the charging power is not constant over time (exception: e-Golf). The constant power phase makes about 80-90 percent of the charging time. During this period, the charging power is limited by the rated power of the EV's charger. Afterwards, the charging power is limited by the exponential power drop (grey dotted line) during the constant voltage phase of constant-current-constant-voltage (CCCV) charging (Fig. 5).

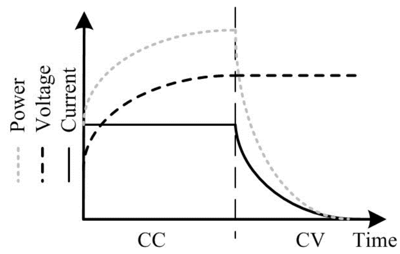

Fig. 5. SCHEME OF CCCV-CHARGING OF BATTERIES

Therefore the charging power is a function of the EV's battery SOC which is in turn influenced by the chosen SOC-window for battery operation by the OEM. Since the e-Golf does not show an exponential power drop, the vehicle's charger terminates charging before the CV-phase is reached. All other vehicles do reach phases of CV.

The varying EV charging characteristics and the lack of high level communication between EV and EVSE (e.g. for sharing the exact SOC-value of the EV's battery) represent challenges for the practical implementation of the CMS. Due to that, defining charging power as a function of SOC cannot be implemented. The reduction of the charging power in the CV-phase is taken into account in the CMS with an additional charging time.

[3] The data is a snapshot of state of the art EVs used in ePlanB-project. The charging behavior can differ with other vehicle's configurations and revisions

C. *Charging Management Processing*

The charging management in project ePlanB takes into account input data from different actors. Planned departure times and the necessary amount of energy to charge are received from EV-users. The Demand Clearing House, in this case the DSO, communicates the allowed power consumptions of EVSE conglomerations. The time-variant energy price is obtained through an interface to EPEX Day Ahead Spot Market. A forecast of local renewable energy production is delivered by a third party service provider. Additionally, the E-Mobility Provider delivers real-time input about User IDs, arrival and departure times of EVs at the EVSE-conglomeration. These inputs are stored in the database of the CMS, which in turn triggers an event to a coordinator process as shown in Fig. 6.

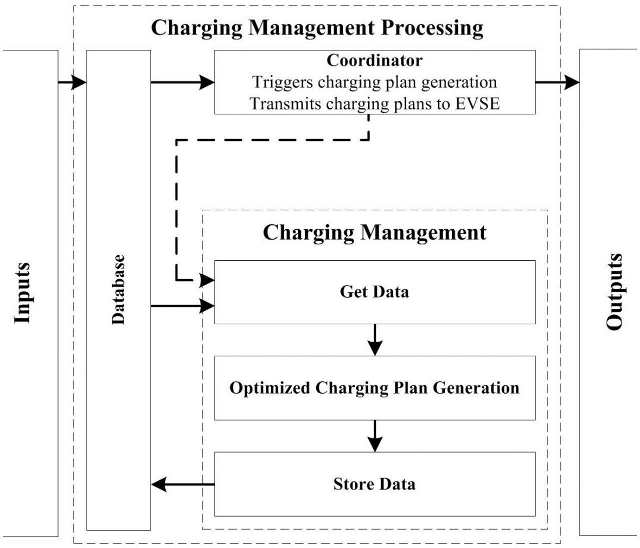

Fig. 6. SCHEME OF CCCV-CHARGING OF BATTERIES

Upon reception of a new event, the coordinator triggers the charging management which gathers the latest data, creates optimized charging plans for each connected vehicle and stores them in the database. After the storage of the updated charging plans, they are sent as to the EVSE.

D. *Charging Plan Generation*

When a charging plan generation is triggered the latest data is gathered from the database (Get Data) by the charging plan generator. In this process, the generator combines static inputs like vehicle specific charging characteristics (interruptible capacity, charging power), dynamic inputs like the amount of energy to charge and the available timeframe until the EVs departure. It then puts it into correlation with the maximum allowed power consumption of the EVSE-conglomeration. In the project, the upper limit is set statically by the physical grid connection and can be reduced further dynamically by the DSO. This allows the DSO to limit the peak power consumption of the EVSE-conglomeration at the P+R-station dependent on grid stress which results in lower grid fees for the EVSE-operator. Since the DSO is integrated and grants lower grid fees, its limit must not be exceeded. The dynamic and static inputs are then combined into a linear equation system with the target to minimize energy costs and maximize the usage of local and renewable energy. The result of the optimization is a set of optimized charging plans for each connected EV.

E. *Charging Plans*

A charging plan is a schedule for the current consumption as shown in Fig. 7.

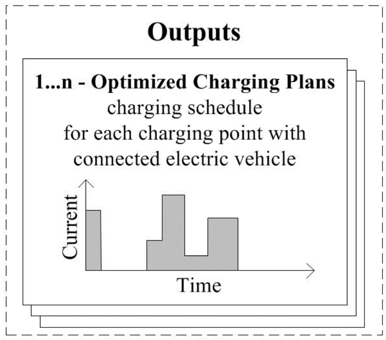

Fig. 7. EXAMPLE OF A CHARGING PLAN

The charging plan for a given charging point consists of a schedule where the maximum allowed current consumption for each time interval is specified. After being generated, the charging plans are transmitted to the EVSE which will then follow that schedule and adapt the duty cycle of the PWM signal according to the maximum allowed current defined in the charging plan. As per the IEC 61851, the charging current that the EV draws from the EVSE must not exceed the limit indicated by the PWM-signal and as a result the EV's maximum charging power can be dynamically controlled according to the generated charging plan.

In case of a CMS for EVSE-conglomerations, the charging plan for each EV is individually optimized, but a higher aim to also optimize the overall power consumption of the EVSE-conglomeration is factored in by the optimization problem. This means, that each new data input triggers a charging plan generation for the whole EVSE-conglomeration. In the field test this is results in more than 100 charging plan generations per day.

F. *Charging Management Interfaces*

The CMS in the field test has different interfaces for several actors. Fig. 8 shows the most important interfaces in the field test.

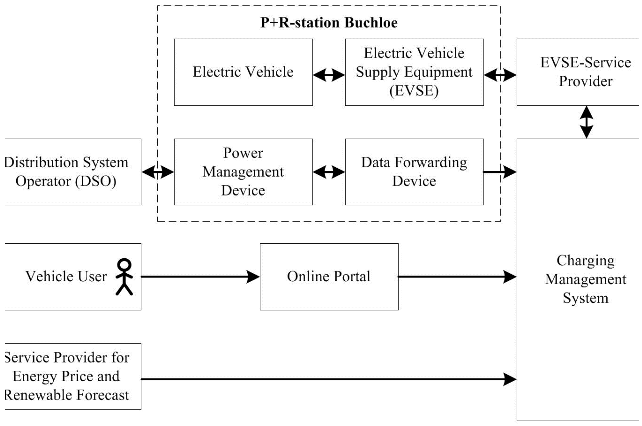

Fig. 8. INTERFACES BETWEEN ACTORS IN EPLANB

The EVSE-service provider is responsible for identification, authentication and support of billing and providing a Simple Object Access Protocol (SOAP) interface for bidirectional data exchange to the CMS. Through this interface, the CMS receives in real-time a timestamp regarding the plugging in/out to the EVSE, alongside with a user ID and EVSE-ID. In the other direction, the CMS sends back the generated charging plans for each EVSE.

Since the SOC of the EV is not available through the interface with the EVSE-provider, it is required to get that information from the user, alongside with the his planned departure time. This information has to be provided for each arrival on the P+R -station. The user enters this information in an online portal and can be changed anytime. If no data is entered for a particular day, fallback data are assumed in form of a weekly standard schedule. In the future, this sort of information may be transmitted by HLC from EV to EVSE according to ISO 15118 and the online portal becomes redundant. But even in this case, the planned departure time has to be communicated by the user to the EV or to some other input methods.

Since there is no standardized communication interface between switchable loads – as which electric vehicle supply equipment (EVSE) is regarded – and the DSO the standard interface for renewable energy power plants (feed-in management) is used. It is a hardwired communication interface. On the DSO-side, it is a programmable logic controller (PLC) with wireless communication to its IT backend; on the EVSE-operator-side it has four binary outputs and a one input. The outputs are used for transmission of power reduction signals from the DSO. The input is used for actual power consumption feedback to the DSO. This way of design allows a safe communication between DSO and CMS without major changes at the DSO's backend.

Information from third party service providers like EPEX-day-ahead Spot Market-prices and renewable energy production forecasts are received once a day via File Transfer Protocol (FTP) and imported into the CMS-Database.

III. RESULTS

A. *Comparison of uncontrolled charging with controlled charging*

The commuters at the P+R-station are mainly typical commuters who start working from early in the morning until late afternoon. Therefore, uncontrolled way of charging results in high power peaks during the morning (after arrival). These early power peaks take place before the peak production from renewable power forecasts is reached. Fig. 9 shows this pattern observed in uncontrolled charging on 15-Jun-2016. By contrast Fig. 10 shows controlled charging for the 18-Jan-2016.

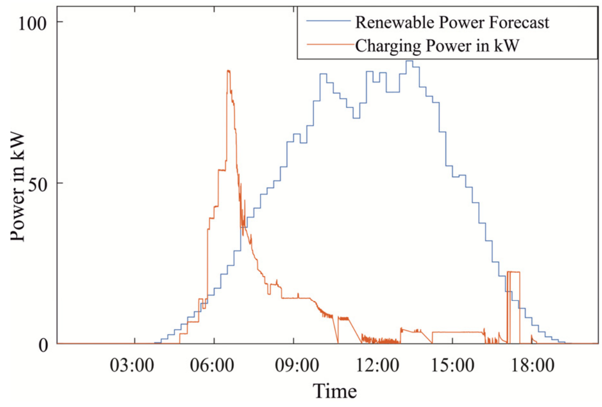

Fig. 9. UNCONTROLLED CHARGING ON P+R STATION ON 15-JAN-2016

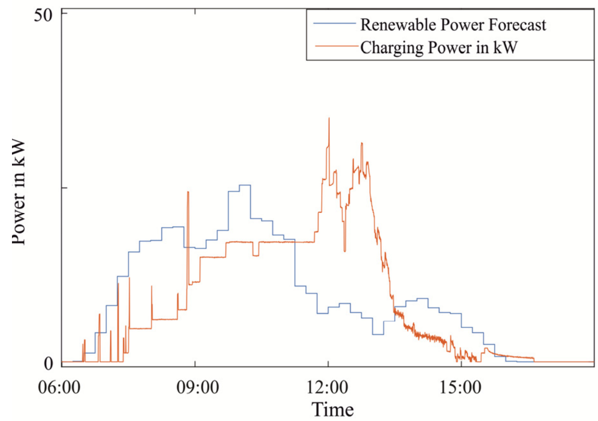

Fig. 10. CONTROLLED CHARGING ON P+R STATION ON 18-JAN-2016

Since the CMS is still in development, at this point of time the effect can be only described qualitatively. Quantitative data analysis is planned for the next project phase. Comparing these exemplary days of uncontrolled and controlled charging, it is obvious, that the CMS shifted charging from early times to later times and therefore reduced power peak (notice the scale difference for the power axis). As a result, the charging power peaks are smaller but wider. But a CMS can even so have the effect of concentrating charging and therefore maximizing power peaks. For this exemplary day the maximum power consumption limit, which was set by DSO was 69 kW and therefore not reached. This is caused by the different charging capabilities of the EVs (e.g minimum charging power).

Fig. 11 shows the input data for this exemplary controlled charging day. Subplot 1 is referring to the day inputs for energy price and renewable production forecast. Subplot 2 shows the resulting charging plans for the 9 EVs which parked at the P+R-station during that day. Since charging plans are created dynamically the resulting charging plan for the day is a combination of 349 single EV charging plans generated from 56 triggering events. Processing the optimization problem from a single event takes between 15 to 40 seconds depending on the complexity (e.g. number of cars currently connected).

The discrepancy between planned charging power and resulting charging power can be explained by inaccurate knowledge of EV's SOC and therefore the impossibility of implementing the charging power as a function of SOC.

The CMS tends to assume that EVs are capable of charging at their maximum power at any time. But in fact, EVs may already be in their CV-charging phase with reduced charging power or even be full. The impact of this inaccuracy increases with planned charging power and the amount of energy that has already been charged. That is why the charging power correlates very well to the planned charging power before 10:00 AM. Afterwards the correlation decreases until after 01:00 PM there is no charging measurable anymore but the CMS still expects charging. The EVs are in fact fully charged at that point of time. This behavior of the CMS comes from the added extra "security" charging time to compensate for the lack of knowledge of the real-time actual SOC and also for the eventuality that the test persons may enter inaccurate SOC-data.

In subplot 3 the EVs status is apparent. EV's presence (in blue) ranges from 03:30 AM to 06:00 PM. Charging intervals are marked in green and the planned departure time in yellow. It is of tremendous importance for user acceptance to ensure that the expected amount of energy has been charged before departure. However, if the user does not deliver accurate inputs for planned departure there is a risk that the EV couldn't be charged according to the expectations of the user.

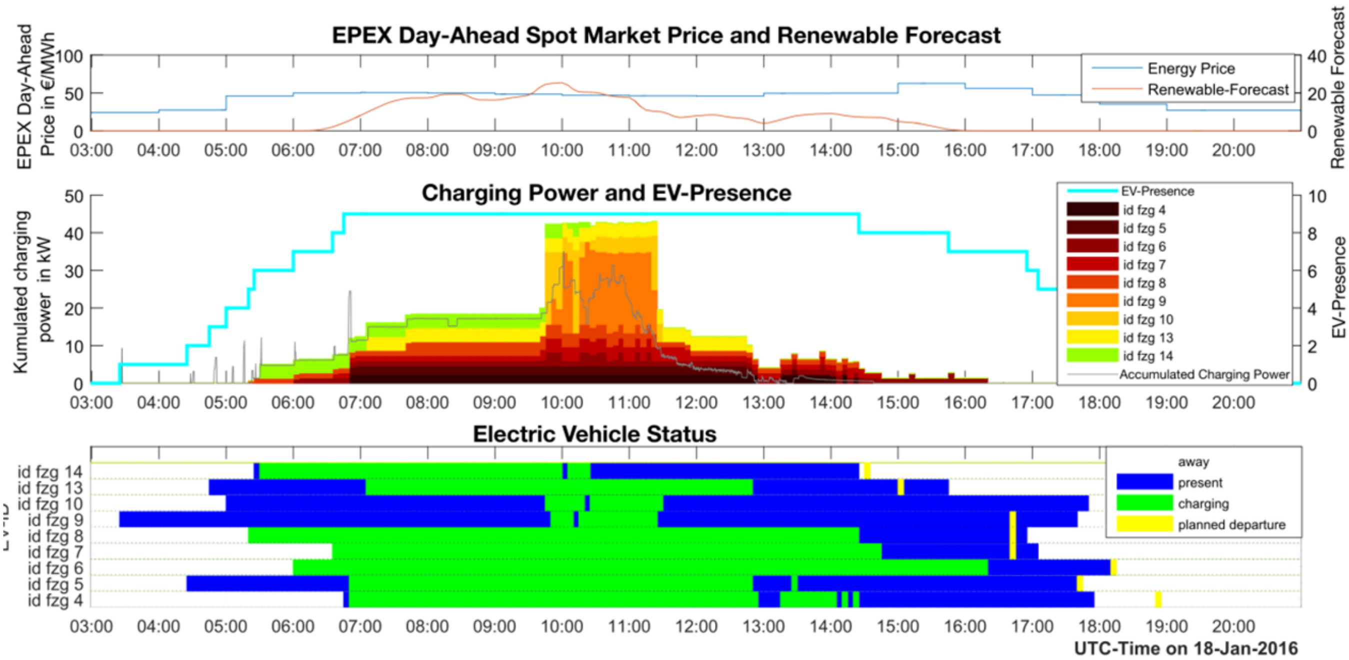

Fig. 11. CMS-INPUTS AND COMBINATION OF 349 CHARGING PLANS OF THE DAY

B. *Challenges:*

Due to the usage of ISO61851 the EV batteries state (SOC) is only received once after the user entered the information manually. There is no real-time feedback from the EV available. Due to that fact the actual SOC can only be estimated by the charging management system and thus an inaccuracy is inevitable. To ensure that the EVs are charged before the user departs, certain tolerances for charging efficiency and a buffer for the SOC-estimation are taken into account in order to compensate for inaccurate user's inputs.

Due to technology development the interfaces between actors will change in the future. It is expected, that HLC communication according to ISO norms between EV and EVSE will lead to better predictions of SOC and thus contribute to simplify the usage of CMS for EV-users and to improve the quality of charging plans generation.

IV. CONCLUSION AND FIELDS OF APPLICATION

In the future this technology can be used in energy and power management systems of EVSE-conglomeration (e.g. in car parks) to reduce costs by reducing power peaks (lower cost for power peaks in case of registered power measurement), reducing grid fees and thus, reduces overall costs for EVSE. Furthermore it could be used to charge EVs at times of higher availability of renewable energy to reduce the effective carbon dioxide emission footprint and support integration of renewables into electrical grid. An assessment of the effectiveness of the CMS in spite of the aforementioned limitations will be conducted based on the data collected during the two-year long field test.

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