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Potential and Limitation of Controlled Charging of Electric Vehicle for PV Self-Consumption Maximisation in Private Households

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Abstract

This work presents a smart charging infrastructure for private households with the objective of maximising the self-consumption by controlled charging of the battery electric vehicles. Core of the system is a forecast based optimisation algorithm for calculating charging schedules. The whole system was successfully tested in a two-year field test under realistic conditions. The algorithm led to excellent results and self-consumption could be increased by controlled charging compared to uncontrolled charging. Nonetheless, limitations of controlled charging were identified. This work gives a detailed insight into the field test, discusses the results and points out solutions for the identified limitations.
Keywords: smart charging, optimisation, photovoltaic, BEV, ICT

1 Introduction

Apart from fast charging stations on motorways and major roads, charging stations at home or work will build the foundation of the charging infrastructure. From an ecological point of view charging of BEV is only reasonable when using renewable energy sources. Thus a combination of private PV system and charging infrastructure is an expediently approach. Furthermore, its more cost efficient to charge a BEV with self-generated energy since generation costs are lower than markets electricity prices.
Due to decreasing feed-in remuneration the feed-in becomes less important from financial point of view. Instead, self-consumption of PV energy generated on-site has become a profitable business model for private households. The generation of one kilowatt hour by PV system costs currently around 10 ct/kWh [6] in contrast to an average electricity price of 29,32 ct/kWh [2]. The self-consumed energy of one kWh is therefore around 19 ct cheaper. For a typical PV system and private household the self-consumption rate is approximately 30 %. This means 30 % of the PV generated energy can be consumed on-site. The self-consumption rate highly depends on the dimensioning of the pv system as well as on user behaviour and resulting load profiles. Battery storages and BEV can help to increase the self-consumption rate. In order to do so, an intelligent home energy management system (HEMS) and controlled charging strategies are necessary. The HEMS is aware of current PV generation, load profiles and user needs. It can shift charging processes into times of high local generation.

This use case was implemented and demonstrated in the Fellbach ZEROplus project [7], which was part of the national showcase program for electro mobility. The Fraunhofer ISE developed a HEMS and a charging infrastructure which is capable of generating forecast based charging schedules. The optimisation goal was hereby to maximise the share of PV energy charged by the BEV. This work gives a detailed insight into the field test, discusses the results and points out solutions for the identified limitations. The article is structured in five sections. Section 2 provides a brief overview of current communication protocols as well as available charging systems for private households. The optimisation algorithm is presented in Section 3. The field test and results are presented in section 4. The article concludes with section 5 which discusses results and points out possible improvements and future research topics.

2 Related work

This section describes current developments on communication protocols for BEV charging. Furthermore a differentiation of existing systems and the system presented in this work is given.

2.1 Communication Protocols

The vast majority of charging infrastructure in private domain is AC based. According to IEC 61851-1 [5] they can be grouped by three different charging modes. Mode 1 specifies single-phase charging over normal household socket or three-phase CEE socket. It has neither special safety nor communication features. Mode 2 extends Mode 1 by using an In-Cable-Control-Box (ICCB) which adds rudimentary communication and electrical safety features. It is mostly used as adapter when no Mode 3 infrastructure is available. Mode 3 defines a dedicated infrastructure for charging EVs such as charging stations or wall boxes. They include electric safety features and enable controlled charging. To control the charging process the charging current can be dynamically adjusted via puls width modulation. A mode 3 infrastructure is therefore a prerequisite for the aforementioned PV self-consumption maximisation.
On top of the low-level IEC 61851-1 communication a high-level communication called ISO 15118 [4] has been specified. ISO 15118 will provide a sophisticated communication and allows authentication, billing and charging schedule negotiation. While some parts of the ISO 15118 have been already published others are still under construction and hence it is rarely supported by current charging infrastructures and EVs. First production BEV supporting ISO 15118 are expected in 2018. Since ISO 15118 covers only the communication between charging infrastructure and EV a back-end communication is necessary for contract and certificate management as well as smart charging. Here, the Open Charge Point Protocol (OCPP) is the de facto standard [8]. It was originally developed from charge point operator view thus featuring authentication, metering, status reports and firmware management. In its current version 1.6 basic smart charging features were added. Version 2.0 is announced for the end of 2017 and it will support more advanced smart charging features as well as an ISO 15118 interface for interoperability.

2.2 Smart Home E-Mobility Systems

There have been several smart home e-mobility solutions emerged on the marked in the past few years. Such systems often feature controlled charging of the BEV to maximise PV self-consumption. They normally consists of a control box connected to PV inverter and charging station [9, 10]. Thus the system is aware of current PV generation. A common approach is to charge the BEV with the surplus PV energy which is not needed by the household. These systems often advertise a use case with typical PV systems of around 5 kWp and and single-phase charging BEV. However, the trend is toward higher battery capacities and thus also to higher charging powers to charge the BEV in acceptable time. Against this background, the system presented in this work features a three-phase 22 kW charging system. This work evaluates the interplay between three-phase based BEV charging and PV system in terms of self-consumption maximisation. Moreover, a forecast based optimisation is used instead of an surplus PV power control.

3 Optimisation approach

In order to maximise the share of PV in the charging processes, the algorithm presented in [1] was used and adopted to single charging stations. The algorithm solves a mixed-integer optimisation problem and returns a power-based charging schedule. The input needed for computation is the amount of energy to be charged and the available time period for charging until the electric vehicle is used again. Furthermore, the state of charge (SOC) at arrival time is needed. Since the IEC 61851-1 does not support SOC transmission, the user has to enter it manually. At the connection of the electric vehicle, the HEMS computes an optimized charging schedule based on the forecasted residual PV power profile and the household load.

3.1 Formulation of the optimisation problem

By the time the user connects the vehicle to the charging station, an optimized charging schedule is calculated. This is done using a mixed integer linear program approach, that is described here.

For the optimisation the time period until the planned disconnection of the car from the charging station is discretized in a set of timesteps $\mathbb{T}$, each corresponding to a 15 minute time interval. Then the optimisation is done by minimizing a cost function, that depends on the charging powers in each time step and a specific cost per energy unit.

$$\underset{P_{p,t}}{\text{minimize}} \sum_{p,t} P_{p,t} \times \chi_{p,t} \Delta t, \tag{1}$$

where P and χ denote the charging powers and the energy costs respectively where the index t refers to the respective timestep. The index p links the power to a power band. This is used to distinguish power from different sources, namely the supply from the electricity grid and the PV generation. Different power bands can be assigned different prices which helps prioritise charging from photovoltaic generation.

The connection from the predefined power bands to the optimisation problem is done via a boundary condition.

$$P_{p,t} \leq P_{p,t}^{max} \quad \forall p, t\,. \tag{2}$$

Furthermore the vehicle must be fully charged by the time of disconnection, which can be expressed as

$$\Delta t \sum_{p,t} P_{p,t} \geq E_{dem}\,, \tag{3}$$

where the inequality takes into account, that the minimal charging power together with the finite discretization timestep might render an exact satisfaction infeasible.

Additionally the vehicle poses constraints on the minimum and maximum charge power that have to be considered in the optimisation in order to generate applicable charging schedules. Both limits require the introduction of binary variables to the optimisation problem. The upper bound on the charging power decreases at high state of charges (SoC). To include this behaviour in a linear way, the SoC dependence is described as a piecewise constant function. This function maps a value of the SoC to a maximum charge powerP_s^{max}. A set of S binary variables $X_{s,t}^{SOC}$ is neccesary for each timestep to determine which maximum power is active at the respective SoC. The condition for the upper limit then reads

$$\sum_{p} P_{p,t} \leq \sum_{s=0}^{S} P_s^{max} X_{s,t}^{SOC} \quad \forall t\,. \tag{4}$$

For a in-depth discussion of the further expressions needed to constrain $X_{s,t}^{SOC}$ see [1].

For the lower bound the variables

$$X_t^{on} = \begin{cases} 1 & \text{vehicle } c \text{ is charging at time } t \\ 0 & \text{vehicle } c \text{ is not charging at time } t \end{cases}\,. \tag{5}$$

are introduced, so the corresponding boundary condition that the charging power is either larger than the minimum charging power or zero, reads

$$P^{min} X_t^{on} \leq \sum_{p} P_{p,t} \leq \max_{s}(P_s^{max}) X_t^{on} \quad \forall t\,. \tag{6}$$

3.2 Input Data

For the optimisation of PV self-consumption a reliant forecast of the residual PV generation is needed. For this purpose, a forecast for the PV generaton from an external service provider is used. A forecast for the household load is done on site from historical data using a persistance approach. Both forecasted timeseries are used to generate a powerband for the optimisation

$$P_{p=0,t}^{max} = P_t^{PV} - P_t^{Load} \tag{7}$$

In order to prioritize charging from the generated PV power, the power band is assigned a zero prize $\chi_{0,t}$ for all timesteps. A second power band is generated with the grid power up to the household connection rate

$$P_{p=1,t}^{max} = P^{max} - P_{p=0,t}^{max} \tag{8}$$

that is assigned a cost of $\chi_{1,t} > 0$. The value for $P^{max} \sim 40$kW is irrelevant, as the maximum cahrge power of the used vehicle is lower.

The parameters neccessary for the vehicle description are taken from manufacturers data and summarized in table 1. The departure time as well as the initial SoC of the vehicle is retrieved via a user input in a web UI at the charging station.

Table 1: Parameters specific to the electric vehicle used

E^{tot}	Total battery capacity	22 kWh
P^{min}	Minimal charging power	6 kW
P^{max}	Maximal charging power	22 kW

4 Field Test

To evaluate the optimisation approach a two-year field test (2014-2016) was performed in the town of Fellbach close to Stuttgart in Germany. Five families participated in the field test and experienced electric mobility in everyday life. The five buildings meet the energy-plus standard and each of them is equipped with a 10 kWp PV system. Despite the large dimension of the PV generator no stationary battery storage was installed. As vehicles three Renault ZOE and one Mitsubishi i-MiEV were used, where one Renault ZOE was used for car sharing by two families.

4.1 Test Setup

To perform the field test the households were equipped with a HEMS and a charging station both developed and installed by Fraunhofer ISE. The system overview is given in Figure 1. The HEMS consists of an energy management gateway (EMG), smart meters and a tablet as user interface (HEMS UI). The smart meters were read out every five seconds via m-bus communication protocol to get detailed power profiles of: grid supply and feed in, electrical load, PV generation, heat pump consumption and BEV charging. Current power flows, daily energy statistic and historical data were visualized on the tablet as an android application. The charging stations support a charging power of 22 kW (AC), have a type 2 socket and an android based user interface (EVSE UI). The IEC 61851-1 protocol was used for the communication since ISO 15118 was neither finalized nor were suitable EVs available at the beginning of the field test. The physical layer of IEC 61851-1 is realised by the Mode 3 Board (M3B) which is connected to the supply equipment communication controller (SECC).

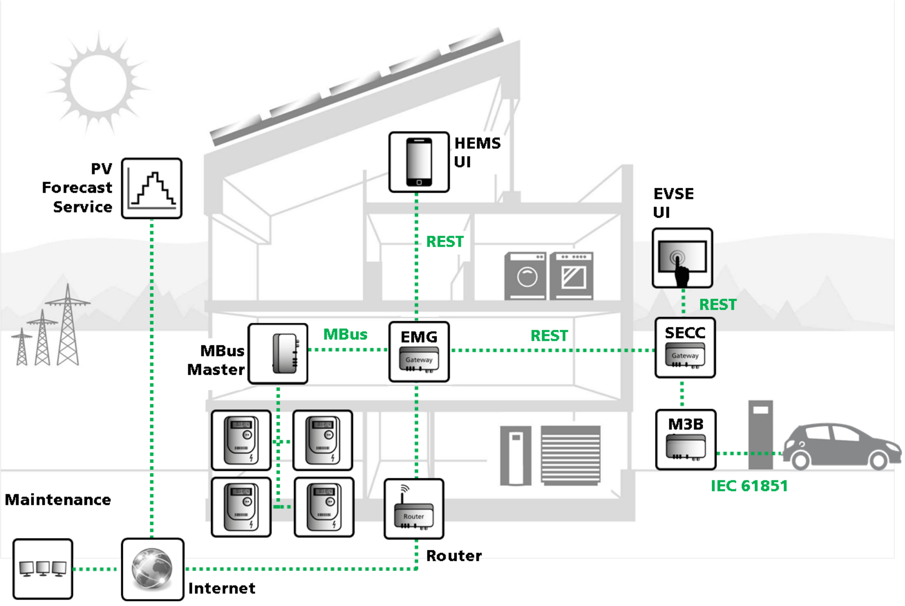


Figure 1: Communication concept and system overview.

4.2 OpenMUC Software Framework

The EMG and SECC were realised as OpenMUC applications running on linux based single board computers. OpenMUC [3] is an generic software framework for monitoring and control applications. The architecture of OpenMUC is depicted in figure 2. It is based on Java/OSGi and supports several communication protocols from the energy domain. Furthermore it provides an integrated data logging and features a Web UI for configuration and visualisation. Logged data as well as the configuration can be accessed by an RESTful interface from external systems. In this project the HEMS UI and EVSE

UI made use of this interface. Due to the lack of a communication standard between charging station (SECC) and smart home (EMG) a simple RESTful approach has been chosen to exchange user needs and charging schedules.

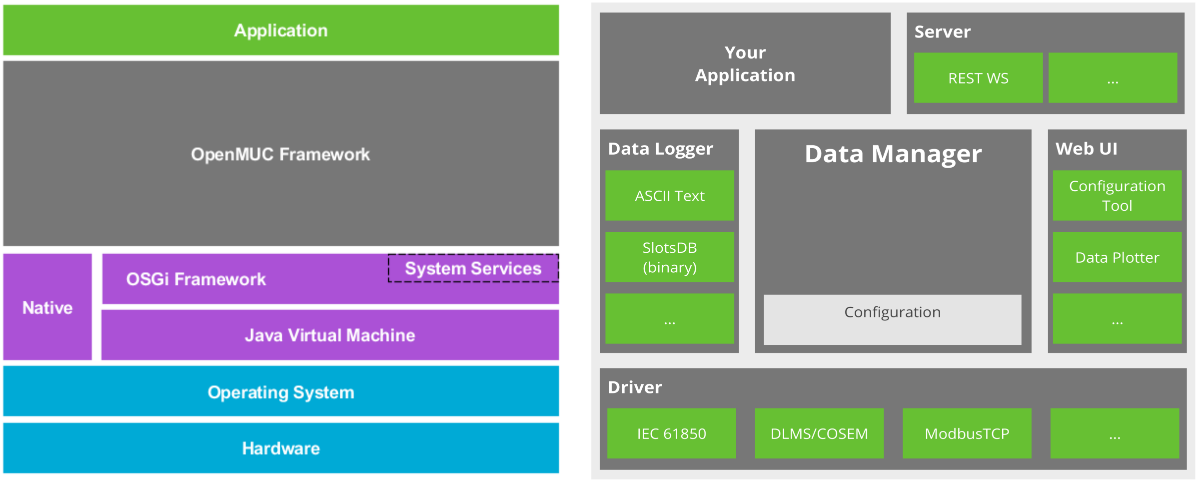


Figure 2: Architecture of the OpenMUC software framework.

4.3 Procedure of a Charging Process

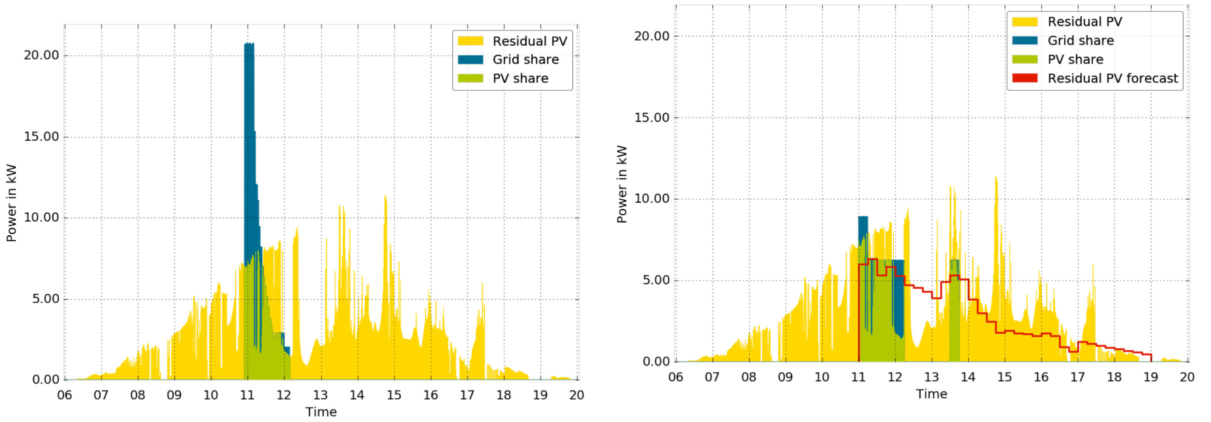
Prior to a charging process, the battery electric vehicle is connected to the charging station and the SOC is entered at the EVSE UI. This is necessary to calculate the energy demand for the charging process since IEC 61851-1 does not support this measurement. In this field test only full charging to reach 100 % SOC is considered. Afterwards the user can choose between two charging modes: controlled charging or immediate uncontrolled charging. In case of controlled charging the user needs to enter the expected departure time. This information is sent to the EMG which calculates the charging schedule by the algorithm presented in Section 3. The complete schedule is then sent back to the SECC that is responsible for the execution. As soon as the time corresponding to a changed scheduled power value is reached, the SECC triggers a command to the M3B to change the pulse width signal corresponding to the new power value. If the controlled charging is not possible for some reason the immediate uncontrolled charging is used as backup operation to ensure charging of the BEV. In this case the BEV is directly charged with maximum charging power. The immediate can also be chosen manually for example when the user is not sure about the next usage of the BEV.

4.4 Results

The controlled charging processes recorded in the field test were analysed in detail, in order to evaluate the performance of the proposed optimisation approach. For evaluation the PV share of controlled and uncontrolled chargings was compared. In order to do so, the setup of the real-world controlled charging processes was used to simulate equivalent uncontrolled charging processes. These simulations were based on the arrival and expected departure time as well as the SOC at the time of connection of the vehicle.

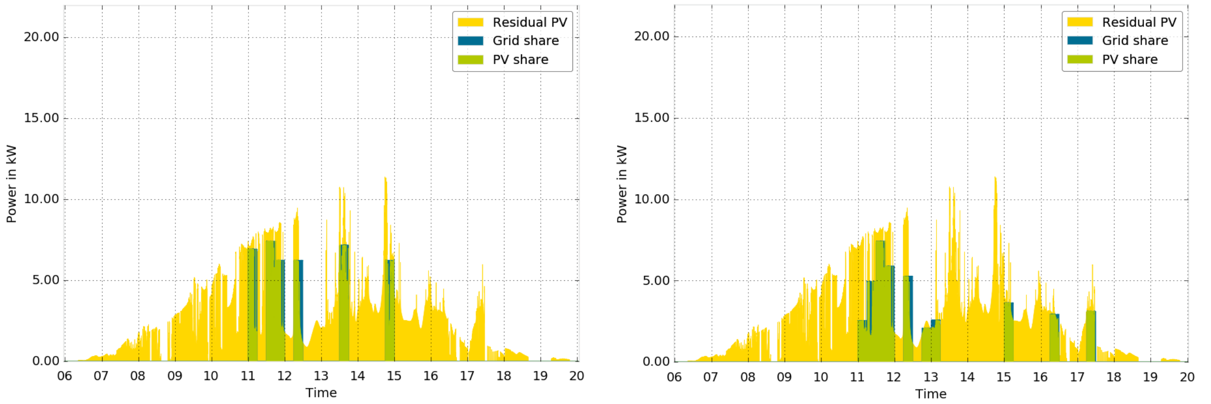
The controlled charging mode feature was rolled out in the second year of the field test. Since then 288 charging processes were recorded. In 132 cases the vehicles were charged in immediate uncontrolled mode, which was mainly used by the car sharing users to ensure high availability for the next usage of the car. The i-MiEV was mainly charged over night thus its charging processes have no relevance for further evaluation. From the 93 remaining controlled charging processes of the Renault ZOE, 48 could be used for further evaluation. In the other cases, the vehicle was disconnected prior to the expected departure time which left the schedule executed incompletely. Therefore these charging processes were excluded from further analysis.

The recorded 48 charging processes were performed in various conditions. These include sunny and cloudy days and connection periods in various times of both the year and the day. In total, 482 kWh were charged to the vehicles. In the uncontrolled case 92 kWh of the 482 kWh could be covered by PV. In the controlled case the share of PV was increased by 33 % to 123 kWh. Thus the proposed optimisation approach lead to a considerable improvement of PV share and proved its practicality. In figure 3a and 3b the two main effects of the controlled charging can be observed. The charging power was lowered substantially, and blocks of charging periods were shifted to times with a high residual PV generation. In this case the PV share could be improved by 22.43 %. Figure 3b also illustrates the issue of forecast accuracy. From 12:00 till 12:15 a higher PV generation was predicted. Since the residual PV forecast serves as input data for the optimisation, the algorithm calculated a schedule according to that data. This inaccuracy finally led to an schedule which caused avoidable energy import from grid. To evaluate the influence of the accuracy of the forecast, a simulation with recorded data from field test was performed. Instead of the PV forecast data the recorded PV and load profiles were used as a hypothetical perfect forecast as input data for optimisation. This led to higher PV share which can be seen in figure 3c.



(a) uncontrolled, PV share = 46.82 %

(b) controlled, forecast based, $P_{min} = 6.2\,kW$, PV share = 69.25 %

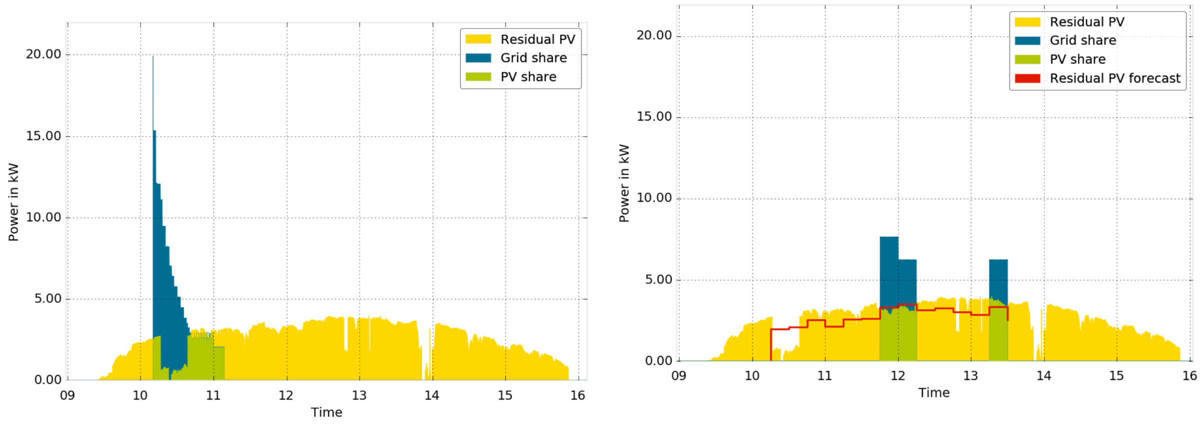


(c) controlled, real residual PV, $P_{min} = 6.2\,kW$, PV share = 80.22 %

(d) controlled, real residual PV, $P_{min} = 2\,kW$, PV share = 84.13 %

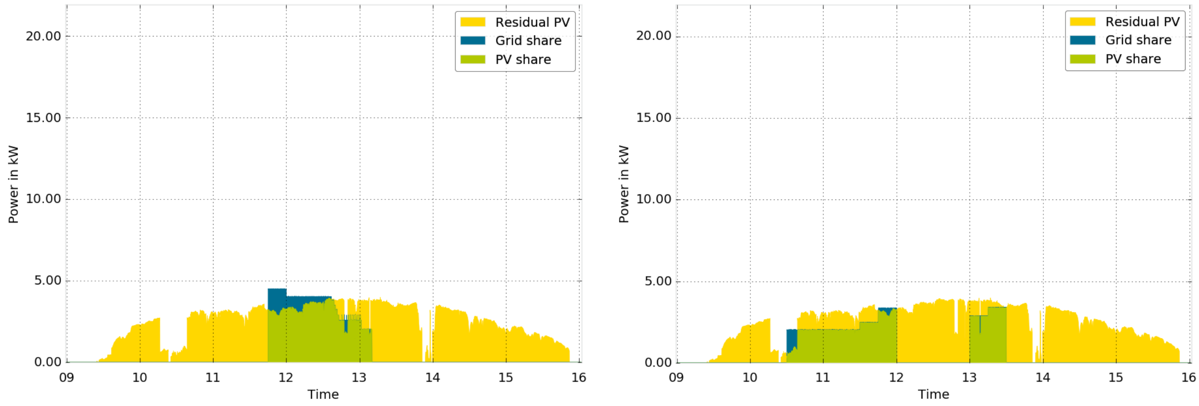
Figure 3: Charging process on a partly clouded sommer day around noon.

Additionally to the forecast accuracy a second restriction has been discovered during the field test. It turned out that the minimal charging power of BEV limits the maximisation of self-consumption. The IEC 61851-1 [5] defines a minimal charging current of 6 A. This corresponds to a minimal charging power of 4.14 kW for 3-phase charging. In case of the ZOE the minimum charging power is 6.2 kW, which is even higher. If the ZOE receives a power command below 6.2 kW it will stop the charging process. The PV generator in the field test had a peak generation of 10 kW, which is quite high for residential PV generators. However, in the second year of the field test, when controlled charging was probed, generation above 6.2 kW was measured only for 287.5 hours, that were distributed between march and october. Apart from rare charging processes on sunny summer days around noon the restriction of the minimal charging power automatically leads to energy import from grid for the charging process. The issue of the minimal charging power is shown in figure 4. In this case the charging process took place on a sunny winter day. Although the vehicle was connected during the day and the available energy amounts to more than the demand, energy supply from the grid was needed due to the restriction posed by the minimal charging power (figure 4b). To examine the effect of the minimal charging power, simulations with lower theoretical charging powers were performed. The results are shown in figure 4c and 4d for $P_{min} = 4$ kW and $P_{min} = 2$ kW as well as in figure 3d for the previous scenario. Since the generated PV power only reached 4 kW at maximum the PV share could have been improved if minimal charging powers were possible by the BEV.



(a) uncontrolled, PV share = 33.47 %

(b) controlled, forecast based, $P_{min} = 6.2\,kW$, PV share = 50.02 %



(c) controlled, forecast based, $P_{min} = 4\,kW$, PV share = 86.36 %

(d) controlled, forecast based, $P_{min} = 2\,kW$, PV share = 94.61 %

Figure 4: Charging process on a sunny winter day.

In order to retrieve a better a understanding of the achieved results a theoretical optimum of the PV share was calculated. For this it is assumed that there are no technical restrictions and the charging power could follow the residual PV power in real time. The sum of all residual PV energy generated, when a vehicle was connected amounts to 279 kWh. However situations are included in which, the available PV energy exceeds the demanded energy of the respective charging process. Accounting for this effect brings the theoretically available PV energy to 195 kWh, which can serve as a reference value. This means that even in theoretical conditions, the available PV energy could only cover 40 % out of the overall demanded energy of 482 kWh. The main reason is, that the vehicles were simply not connected during times of high PV production. Other reasons are charging on cloudy days or in wintertime where the PV system cannot generate the maximum energy. In table 2 the total PV share of all 48 charging processes are listed for different scenarios. In the field test 123 kWh could be covered by PV energy. This corresponds to 63 % of the theoretical optimum. As stated above, the uncontrolled charging would have led to only 90 kWh. If lower minimal charging powers for the BEV are assumed the coverage could be increased to 146 kWh in the forecast based case. If the forecast is replaced by the hypothetical perfect forecast as explained above, then even higher coverages are possible. In case of minimal charging power of 6.2 kW the forecast inaccuracy is responsible for 13 kWh lower PV coverage in the field test. If the minimal charging power is reduced to 2 kW a coverage of 164 kWh would be possible, corresponding to 84.1 % of the theoretical optimum. The remaining 15.9 % to the optimum have different reasons. In some cases even 2 kW were not low enough to avoid energy import from grid. Another reason are the fixed schedule intervals of 15 minutes. In the current implementation the PV energy between connection time of the BEV to the next 15 minute interval is not considered. Further future improvements are discussed in the next section.

Table 2: Charged energy covered by PV for different scenarios.

P_{min}	6.2 kW	4 kW	2 kW
Energy covered by PV (forecast)	123 kWh	146 kWh	146 kWh
Energy covered by PV (recorded)	136 kWh	160 kWh	164 kWh

5 Conclusion

The presented overall system worked stable during the field test and it proved its practicality in real world environment. The PV share could be considerably increased with the controlled approach compared to the uncontrolled charging mode.
Nonetheless statements about annual financial benefits for a single household can not be given at this point. On one hand the evaluated charging processes do not cover a whole year and come from different households. On the other hand the benefits of self-consumption highly depend on the individual usage profile of the EV like charging times and frequency. The best case scenario for the presented system regarding to financial benefits would be charging a car with a high annual mileage with charging processes during day time. This typically corresponds to second cars in private field. Furthermore, the system could be used by small and mid-sized companies with PV system and a charge point at company car park. In this case the BEV could be charged during the day shift at work.

The field test also revealed different limitations of the controlled charging according for maximisation of self-consumption. Beneath usage profiles of the BEV another limitation is the minimal charging power of BEV. From self-consumption perspective low charging powers would be desirable. Although the test was only performed with a single model of BEV (Renault ZOE with 6.2 kW minimal charging power) and quite big 10 kWp PV system it allows conclusions for other BEV models. Typical PV systems of single-family houses are in the range of 4-7 kWp, where the peak power is only reached on sunny summer days. If other BEV models implement the minimal charging power of 4.14 kW (3-phase) according to IEC 61851-1 standard then similar results compared to this field test can be assumed. Thus the BEV can not be fully charged with on-site generated PV energy since minimal charging power restriction automatically leads to energy import from grid. Information about minimum charging power are rare to find in technical data sheets of BEV or common overviews. In order to evaluate the minimal charging power of other BEV further tests are needed.

5.1 Future System Improvements

The minimal charging power can not be influenced by controlled charging because it is fixed by the BEV. An aspect which could be improved is the accuracy of the forecasts or the processing of the forecast. In this field test, the charging schedule was created only once right after connecting the BEV. In the next step rescheduling should be performed as soon as new forecast data is available. Additionally real time comparison between charging schedule, actual charging power and PV generation should be applied to determine inaccurate forecast and deviations from schedule. Detected deviations could then trigger a rescheduling. The real time check is also recommendable for another reason. The pulse width signal sent to the BEV via IEC 61851-1 refers to the maximum current and therefore to the maximum charging power. However, the final decision of the current charging power lies by the charge controller of the BEV. The maximum value serves only as upper limit and the BEV can charge with a charging power below that limit. This leads to deviations from calculated schedule since it contains maximum power values for each interval. This problem also arises with newer communication protocols like ISO 15118 since it also features schedules with maximum power values.
In this work the interval size of the schedule was set to 15 minutes since the available PV forecast provided this resolution. In terms of real time charging feature, smaller intervals could be applied for better synchronisation of charging power and available PV power. At least from communication protocol point of view (ISO 15118 or OCPP) small intervals are possible.
A further improvement could be machine learning methods to avoid or minimize BEV model specific schedule deviations. This refers to the maximum charging power as well as to charging power reduction at the end of the charging process when reaching 100 % SOC. This power reduction results from technical reasons when charging batteries and is individual for the used technologies. In the field test the Renault ZOE stared reducing the power when reaching around a SOC of 90 % of its 22 kWh battery. In this case the last 2.2 kWh are charged with less then 22 kW. At some point the charging power drops below the minimal charging power thus the controlled charging has no influence any more. Machine learning methods could therefore help to learn that specific charging profile between 90 % and 100 % SOC. This could then be considered for schedule calculation to minimize deviations between schedule and actual charging. In this field test static profiles were applied because the BEV were known and reference charging profiles were recorded during the first phase of the field test. Another improvement would be a flexible energy demand for charging. In this field test the BEV was always charged to 100 % SOC. The system could provide feedback to the user on how much PV energy could be charged until the planed

departure time. In some scenario it might be sufficient to recharge only a view kWh per charging. This could lead to a higher PV share but would also cause more charging processes since only a few kWh are recharged.

5.2 Future Research in the Scope of Smart Grid and BEV Integration

This work was focused on controlled charging in terms of self-consumption maximisation of private households. But this is only one aspect of controlled charging. For a successful large scale grid integration of BEV their charging processes have to be controlled according to current grid state and user needs. Uncontrolled simultaneous charging processes could strain the distribution grid in residential areas. The next step in a follow-up project is therefore to take controlled charging to the level of residential area and coordinate multiple charging stations at once. This gives much better opportunities to consider grid state and user needs together. The algorithm presented in [1] is already designed for this scenario and the Fellbach ZEROplus project revealed key findings on single system behaviour and technical implementation.

Another important aspect for successful and cost efficient large scale grid integration of BEV is the interoperability between various systems of the smart grid. This can be achieved by using standardized communication protocols and uniform interfaces. The ISO 15118 is already set as communication standard between charging infrastructure and BEV. OCPP serves as de facto standard between charging infrastructure and charge point operator back-end. Version 2.0 will provide features for ISO 15118 integration thus leading to a more consistent communication infrastructure. However, there are more actors like the distribution system operator (DSO) and user of the BEV which need to be involved in the controlled charging process. On grid automation site IEC 61850 standard is used and the current IEC TR 61850-90-8 proposes a object model for E-Mobility support according to ISO 15118 and IEC 61851. On user site the communication interface between charging infrastructure and HEMS is still open. OCPP 2.0 could be used for this interface since it will provide support for external local smart charging signals. Also IEC 61850 becomes interesting for smart homes in terms of the planed smart meter gateway (SMGW) roll-out with BSI protection profiles. It could be used to send coordinated charging schedules to charging stations of single-family houses using the controllable local system interface (CLS) of the SMGW. Another communication standard could be the Smart Home IP (SHIP) and the SPINE data models developed by the EEBUS initiative. However, proprietary systems, gateways and protocol proxies dominating the current charging infrastructure in the private area. Therefore standardisation and interoperable system design are still important areas of research for BEV integration into the smart grid.

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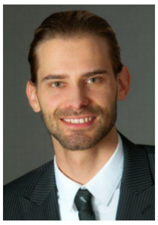

Marco Mittelsdorf (M.Sc.) works as software developer in the group *Smart Grid ICT* at the Fraunhofer Institute for Solare Energy Systems (ISE) in Freiburg since 2013. He is one of the main developer of the *OpenMUC* software framework and his research fields are energy management systems, communication protocols and electric vehicle charging. He was technical project manager of the *Fellbach ZeroPlus* project and is a member of the German ISO 15118 standards committee. He currently works on an inductive bidirectional charging system, which uses wireless ISO 15118 communication between EV and charging station.

Arne Groß studied physics at the Technical University of Dresden, Germany (Undergraduate), and at the Albert-Ludwigs-University of Freiburg, where he received his Masters degree for his work on experimental particle physics. In 2014 he joined the Smart Grids department of the Fraunhofer ISE and is now working as a PHD student. His main fields of work are algorithms for energy management systems with a focus on probabilistic model predictive control and optimisation.

Jörn Schumann studies computer science at the Furtwangen University of Applied Sciences. He currently writes his bachelor thesis at the Fraunhofer ISE in Freiburg. His topics cover smart charging schedules of BEV, back-end communication of charging infrastructure and data analysis. He is implementing an OCPP Java library as well as back-end server for coordinated charging schedule calculation.

Dr. Robert Kohrs is head of the research group Smart Grid ICT at the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg. He studied physics at the University of Bonn, where he also received his PhD for his work on semiconductor detectors. He joined Fraunhofer ISE in 2009, where he started as project manager with a focus on Energy Management Systems, Smart Metering and Electric Mobility. His work focuses on the development of software frameworks and communication protocols for energy management systems, distributed generation, storage systems and controllable loads.