[·] Philipp Danner, Wolfgang Duschl, Dominik Danner, Ammar Alyousef and Hermann de Meer. Flexibility reward scheme for grid-friendly electric vehicle charging in the distribution power grid. In *Proceedings of the 3th Workshop on Electric Vehicle Systems, Data, and Applications*, EV-Sys '18, New York, NY, USA, 2018. ACM.

Flexibility Reward Scheme for Grid-Friendly Electric Vehicle Charging in the Distribution Power Grid

Philipp Danner
Bayernwerk AG
Regensburg, Deutschland
philipp.danner@bayernwerk.de

Wolfgang Duschl
Bayernwerk AG
Regensburg, Deutschland
wolfgang.duschl@bayernwerk.de

Dominik Danner
University of Passau
Passau, Deutschland
dominik.danner@uni-passau.de

Ammar Alyousef
University of Passau
Passau, Deutschland
ammar.alyousef@uni-passau.de

Hermann de Meer
University of Passau
Passau, Deutschland
demeer@uni-passau.de

ABSTRACT

Due to the increasing number of *Electric Vehicles* (EV) entering the transportation sector, we need to take a closer look to the distribution power grid, which needs to support the increasing number of charging processes. Grid enhancement to peak load of EV charging processes is very expensive, hence an intelligent solution is preferred. This paper introduces a new concept, called the *Reward Scheme*, which main objective is to advertise grid-friendly charging processes in order to avoid power quality issues in the distribution grid. To achieve this, we distinguish between guaranteed and flexible power at a charging spot. Using the guaranteed power as a reference, we calculate the grid-friendliness factor of different flexible charging rates, which in turn are proposed to the grid user, e.g. the *Charging Service Providers* (CSP). This paper describes a simulation-driven approach to obtain the grid-friendliness factor, as well as the required communication between the CSP and the *Distribution System Operator* (DSO).

KEYWORDS

Power Flexibility, Grid-Friendliness, Reward Scheme

ACM Reference Format:
Philipp Danner, Wolfgang Duschl, Dominik Danner, Ammar Alyousef, and Hermann de Meer. 2018. Flexibility Reward Scheme for Grid-Friendly Electric Vehicle Charging in the Distribution Power Grid. In *e-Energy '18: The Ninth International Conference on Future Energy Systems, June 12–15, 2018, Karlsruhe, Germany*. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3208903.3213893

1 INTRODUCTION

Charging process optimization is one of the key concepts for seamless integration of electro mobility into our existing power grids. The reliable avoidance of peak loads and imbalance in supply and demand, caused by unfavorable or highly parallel charging processes, is essential to reduce the possibility of critical situations in the power grid. In the field of charging scheduling, there are various optimization goals. This includes economical objectives such as minimizing charging costs [12, 13] or maximizing revenues [14, 29]; charging related objectives such as minimizing battery degradation [10, 19] or minimizing charging time [1]; environmental objectives like maximizing regional renewable energy sources [28] or minimizing CO_2 emissions [15, 20], but also grid related objectives like considering power line losses [7], minimizing peak loads [17] and optimizing voltage profiles [11].

Especially grid related constraints play a role in terms of charging issues, since the permissible charging rate for a charging process always represents an important basis for scheduling. The principle usually refers to adhering to specified limits (asset overload, voltage or other power quality parameters). However, considering that there are different power grid topologies with different connection points (e.g. households, commercial enterprises, industry), weather conditions (e.g. volatile energy sources), grid expansion levels (e.g. cable cross-sections, cable length, transformer power rate), and system perturbations by a wide variety of electronic devices (e.g. voltage changes, flicker, harmonics, interference frequencies), it becomes clear that the information on the maximum permissible power consumption or compliance with uppermost limits can only be a partial indicator of grid-friendly charging.

Even if price-based incentives, e.g. by the *Electric Vehicle (EV)* fleet operator or the *Energy Supplier (ES)*, are common optimization strategies [4, 18, 30], only the *Distribution System Operator (DSO)* has information about whether a certain load behavior has an improving or worsening effect on the power grid. To control the *Power Quality (PQ)* on the customer grid side, there are various techniques such as on-load tap changing methods, voltage controls on the medium and low voltage side, string voltage regulators, active/passive PQ filters, controllable consumption devices or simple conventional grid enhancement. However, these solutions do not necessarily regulate a critical situation in the low voltage grid locally, but effect a bigger area of the grid. With the use of intelligent measuring systems (smart meters) and controllable devices in the grid, selective control might be possible [8, 21]. Increasing the power demand of a charging station, if required by the grid, is only possible if an EV is plugged and charging, so a reactive approach is not always possible. To circumvent this problem, a proactive and

---

e-Energy '18, June 12–15, 2018, Karlsruhe, Germany

ACM ISBN 978-1-4503-5767-8/18/06…$15.00
https://doi.org/10.1145/3208903.3213893

[·] Philipp Danner, Wolfgang Duschl, Dominik Danner, Ammar Alyousef and Hermann de Meer. Flexibility reward scheme for grid-friendly electric vehicle charging in the distribution power grid. In *Proceedings of the 3th Workshop on Electric Vehicle Systems, Data, and Applications*, EV-Sys '18, New York, NY, USA, 2018. ACM.
See `http://www.net.fim.uni-passau.de/papers/DannerP2018a` for full reference details (BibTeX, XML).

concrete method on when to charge at a certain charging station with a certain charging rate is required.

There are a large number of technical and environmental restrictions, which could inhibit the execution of the desired charging processes. These could, for example, be the restrictions or unforeseen controls of the charging rate by the connector or the charging station, the state of charge of the battery, the remaining driving range compared to the distance to the charging point or other driver-related reasons to not perform a charging process as planned. In order to face these countless variables, a certain scope for decisions (different charging performance options with different rewards per unit of time) should provide a starting point for incentives in order to charge more grid-friendly. A power grid operator can individually determine the type and level of incentives (e.g. by adjusting grid usage fees) for different grids without having to reveal the concrete cause of a grid situation that needs to be addressed. For these reasons, the concept of providing ancillary service to improve individual grid situations would be a sensible supplement to an incentive scheme based on rigid threshold values.

This paper presents a new concept, the so-called *Reward Scheme*, where individual incentives are created for the selective execution of future charging processes of different charging rates. The reward scheme thus provides a forecasted reward for planning of charging processes in a grid-friendly way. The *Reward Scheme* take into account various grid situations and the resulting compensation effects required through power adjustment (different charging rates). All of this is done while at the same time the business secrets of the grid operators like grid topology, concrete PQ issues or control strategies are not publicly revealed. The paper also suggest a calculation method for the *Reward Scheme* using a simulation driven model.

In the following Section, related work on grid-friendly algorithms, grid-consumer protocols and methodologies are given. Section 3 describes our proposed *Reward Scheme* to provide grid-friendly EV charging planning. In Section 4 the communication protocol is described and, finally, the *Reward Scheme* concept is concluded in Section 5.

2 RELATED WORK

Most research work [23–26] defines the flexibility in the power grid as the available energy in the grid in terms of imbalance between the supply and demand. The ES or the *Transmission System Operator* (TSO) sends such flexibility as a price signal to their customers. Especially big power consumers, like data centers [3, 16, 22], will react accordingly to the price signal with the goal of decreasing their overall energy costs. Demand response protocols, for example OpenADR[1], are used to establish such communication between the grid operators and the consumers. However, demand response does not consider the concerns of the DSO significantly since the DSO is working as the infrastructure provider and its main responsibility is to maintain the electricity supply to the consumers. In the grid of the DSO, electricity flow is limited by physical constraints from the used grid elements (e.g transformer and line limits) and other PQ parameters such as the voltage level. According to the standard EN50160, DSOs in Europe must operate their power grid within certain frequency, voltage level, waveform and voltage balance boundaries.

The Open Smart Charging Protocol[2] (OSCP) is the only open source protocol that describes the data flow between a DSO and a *Charging Service Provider* (CSP). Using this protocol the CSP can obtain forecasts about the available feeder line capacity of a charging station at its connection point to the distribution power grid. The DSO orchestrates the usage of the overall available cable capacity within its power grid. The model behind the OSCP is only based on upper power capacity limitations, hence the charging station is not allowed to exceed the assigned threshold. With increasing number of distributed renewable energy sources the necessity to have a lower power capacity limit to charging stations arises due to overvoltage. Additionally, apart from hard-cut limitations a stepwise categorization of different options is needed to guide EVs to different locations in the same or different grid sections, where the charging process is more grid-friendly.

Besides these protocols several algorithms are proposed in literature to enable EV charging on smart grids without overloading power supply assets [4, 5, 27], violating voltage level limitations [6, 9] or to find the equilibrium between power supply and demand [24]. Most of them propose reactive negotiation mechanisms between ongoing charging processes to stay below predefined thresholds. Furthermore, the locations of the EV charging processes are fixed. The *Reward Scheme*, proposed in this paper, focuses on the proactive part similar like OSCP, where the EV user can even be guided to different locations in order to support the distribution power grid.

3 GRID-FRIENDLY EV CHARGING REWARD

The basic idea of the concept is to reward grid-friendly EV charging behavior in order to avoid undesirable grid situations, like under-/overvoltage, asset overloading or other power quality and grid stability issues, in a proactive way. The *Reward Scheme*, therefore, is used to provide information about available charging rates (in kW) and their corresponding grid-friendliness factor forecasted over time at a specific charging spot (at the grid connection point). The grid-friendliness factor is used to derive potential penalty or reward according to an offer, which acts as an incentive for performing a certain charging process. In order to realize this kind of relationship, a contract must be concluded beforehand. A possible user of the *Reward Scheme* is the CSP. In this paper, the CSP is defined as an entity, which is responsible for operation, management, and maintenance of charging stations. The CSP negotiates a contract with the DSO, stating which rewards or penalties will be received or have to be paid in the event of non-fulfillment of certain promised actions. The CSP can then include the grid-friendly charging via reward and penalty in the offers to its customers. In order to grant a reward or penalty to the CSP, each CSP must report its future power consumption to the DSO. This booking information is further used for distributing the remaining flexible power between competing CSPs. The type of use, e.g. commercial or public, as well as the specific group of users (fleets, transport vehicles, private cars) are not restricted. The reaction on elasticity of demand of the EV user

---

[1] http://www.openadr.org/

[2] http://www.openchargealliance.org/

[·] Philipp Danner, Wolfgang Duschl, Dominik Danner, Ammar Alyousef and Hermann de Meer. Flexibility reward scheme for grid-friendly electric vehicle charging in the distribution power grid. In *Proceedings of the 3th Workshop on Electric Vehicle Systems, Data, and Applications*, EV-Sys '18, New York, NY, USA, 2018. ACM.

See `http://www.net.fim.uni-passau.de/papers/DannerP2018a` for full reference details (BibTeX, XML).

due to changed conditions like traffic, too less range to reach the charging station and thus penalty of non-execution of a booked charging process are part of the business model of the CSP and, therefore, not part of this paper.

With the fast developing electro mobility, a grid enhancement to peak load is no longer economical. At the same time, the CSP wants to provide its customers the fastest charging option that is possible. Due to this discrepancy, we use the concept of guaranteed and flexible charging power. Guaranteed power means that a certain charging rate (e.g. 15 kW at a 30 kW grid connection) is provided 24/7 by sufficient grid enhancement. The remaining 15 kW are considered as flexible power, which can be granted fully, partly or not at all, depending on the respective grid situation. With this concept, each CSP gets a certain basic service of the guaranteed power. The height of the guaranteed power can be increased by additional payments to the DSO for better grid enhancement. The service quality of the CSP remains at a high level using the guaranteed power and additional flexible power with the specific grid-friendliness reward, while at the same time the CSP can profit from rewards that are paid by the DSO due to providing grid-friendly charging of the flexible power. The *Reward Scheme* provides one input for optimizing the charging offers of the CSP. Other inputs could be the energy price, the renewable energy mix in the grid and the time-depending availability of charging stations.

3.1 Concept and Output of the Reward Scheme

The reward scheme is requested and only valid for a specific charging spot, which from grid perspective is the grid connection point of a set of charging stations, as can be seen in Figure 1. The operator of that charging spot, e.g. the CSP, is responsible for splitting the demand to the available charging stations/connectors at this charging spot.

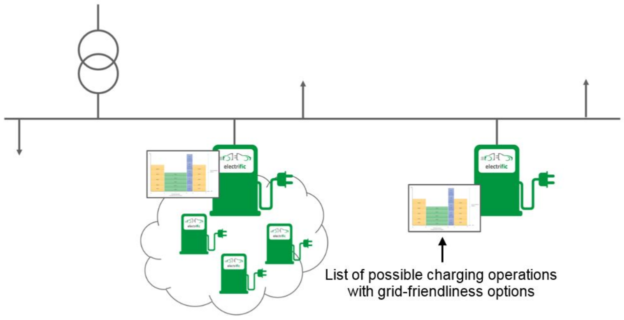

Figure 1: Charging spots with charging options and rewards in a low voltage network.

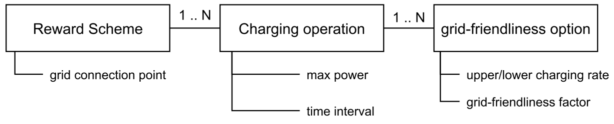

Figure 2: Structure of the Reward Scheme.

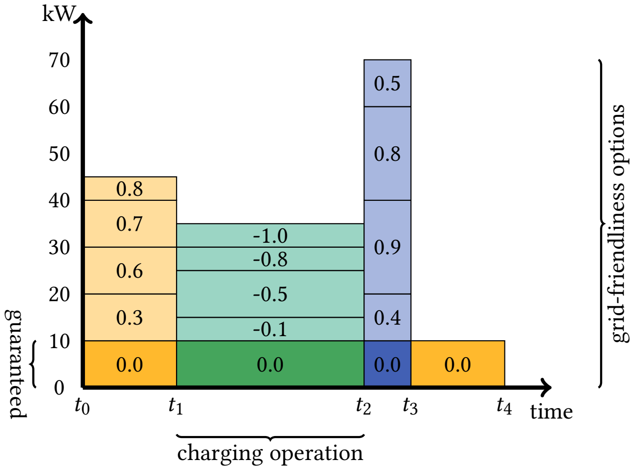

Figure 3: Reward schema output for each charging spot (fictitious values).

The output of the *Reward Scheme* request is a list of possible charging operations for the requested charging spot (grid connection point) over time. A charging operation is defined as time slot with a constant maximum charging rate and consists of multiple grid-friendliness options. Each grid-friendliness option defines an upper and a lower charging rate and the corresponding grid-friendliness factor, which is valid within that bounds. The structure of the *Reward Scheme* is given in Figure 2.

The whole charging process of an EV can combine multiple charging operations with different grid-friendliness options. The length of the offered charging operation time slots can differ and is depending on the resolution of the forecasted grid situation. In any case, the length will be bigger than a specific threshold, as we do not want to have high fluctuations of load in the grid and the forecasted grid situation will not be very precise in small time scale (e.g. all charging operations are slotted bigger than 1 minute). The allocation of the grid-friendliness options within a charging operation refers to the compliance with previously defined thresholds of the respective DSO. In any situation, at least one option, showing the guaranteed capacity with a neutral grid-friendliness factor, is available and serves as the reference value from which the remaining options are created. The DSO determines the tolerable differences of power grid situations in terms of power demand for its grid as intervals before a new grid-friendliness factor represents a new charging rate class. The number of different grid-friendliness options is limited with the constraint that each option has a minimum charging rate difference of e.g. 1 A per phase, thus 690 W on all phases. The reason for this is that small changes in power demand usually have only a slight change in the effect on the power grid situation. Furthermore, this limits the computational effort and reduces the output size of the *Reward Scheme*. The offered grid-friendliness options provide a certain flexibility to the CSP, as the CSP does not need to choose the most grid-friendly charging option, but can choose freely with the trade-off of e.g. a monetary penalty.

Visualized, a diagram like shown in Figure 3 with the following properties can be imagined as the output of the *Reward Scheme*: The

[·] Philipp Danner, Wolfgang Duschl, Dominik Danner, Ammar Alyousef and Hermann de Meer. Flexibility reward scheme for grid-friendly electric vehicle charging in the distribution power grid. In *Proceedings of the 3th Workshop on Electric Vehicle Systems, Data, and Applications*, EV-Sys '18, New York, NY, USA, 2018. ACM.
See `http://www.net.fim.uni-passau.de/papers/DannerP2018a` for full reference details (BibTeX, XML).

x-axis represents the time, and the y-axis shows the available maximum charging rate of single charging operations in kW (forecasted values). Each charging operation is divided into one or multiple grid-friendliness options, which include a specific grid-friendliness factor. The grid-friendliness factor is defined in the range of $[-1, 1]$, where -1 means worst and $+1$ best grid-friendliness. A neutral grid-friendliness factor of 0.0 is always assigned to the guaranteed option as it represents the reference value. Within a certain grid-friendliness option (charging power range), the reward stays the same. The maximum charging rate is limited by the remaining grid capacity (e.g. cable, line, transformer, and bus bar) and the power quality (e.g. voltage range, flicker or harmonics) in the grid.

In the example shown in Figure 3, specifically in the period between t_0 and t_1, it would be best for the grid to charge with 45 kW (grid-friendliness factor 0.8). More charging power, however, is not possible due to grid constraints (capacity or power quality limit). In the period between t_1 and t_2, in contrast, the highest charging power of 35 kW is offered but linked with a negative, hence worse, grid-friendliness factor. The grid-friendliness factors are based on the respective classification of the DSO and the underlying grid. If the remaining power at a specific grid connection is considered as too low (depending on the definition of the DSO), the grid-friendliness factor will be negative. In case of a highly overloaded grid, all grid-friendly options will have a negative factor except the guaranteed power (reference value). The factors are given as absolute values within the defined interval $[-1, +1]$, which makes grid-friendliness options of different charging operations comparable. To translate the respective rewards to financial incentives, a simple mapping could be used, in which certain grid-friendliness factors are defined with a concrete financial reward or penalty. An exemplary calculation of the *Rewards Scheme* using a simulation-driven model with grid data is shown in the following section.

3.2 Simulation-Driven Calculation

To calculate the *Reward Scheme* output of the simulation-driven model, some input parameters are required. These include the *Geo Information System* (GIS) information of the corresponding grid section (e.g. low/medium voltage grid), forecasted loads of connected households, agricultures and industries (e.g. using smart meters) and forecasted generations of distributed renewable energy source (e.g. wind plants, biogas plants or photo-voltaic), as well as the guaranteed power of every charging spot in this grid section. Using a power flow solver (e.g. Newton-Raphson method), it is then possible to calculate the utilization and the voltage levels of all grid components within the low voltage grid. From this calculation, the maximum acceptable charging rate at the requested charging spot, which does not harm the grid in terms of power quality and grid utilization, can be determined.

When calculating this maximum acceptable charging rate at one specific charging spot using *Optimal Power Flow* (OPF) calculation, all other charging spots in this grid section are assumed to consume their guaranteed power or, in case of already booked charging processes, the corresponding charging rate of the booking. In general, the calculation should use conservative limits concerning utilization (e.g. transformer at maximum 80% loading) and power quality (e.g. voltage band between ±5% instead of ±10% as described in EN 50160), as we also want to avoid near critical situation while planning charging processes. The latter also depends on the transmission ratio, since the 10% threshold of the EN 51060 counts for both, the medium-voltage and low-voltage networks. If no tap changer is installed in between (which is generally the case), both gird levels must be considered.

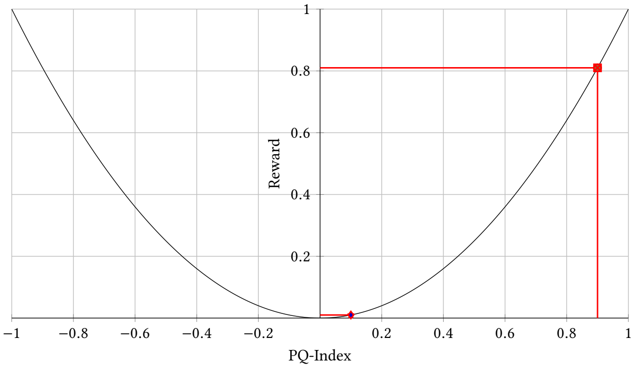

Figure 4: Reward weighting function x^{2n} where $n = 1$

After determining the maximum acceptable charging rate at the requested charging spot for each time slot, the single grid-friendliness options with its corresponding grid-friendliness factor needs to be identified. In doing so, the maximum charging rate is split into different grid-friendliness options of specific size (e.g. 690 W). The different charging rates are now fed into the grid simulation to measure the changes concerning the power quality (e.g. voltage range) and asset utilization (e.g. transformer loading) by comparing *"charging with the guaranteed charging rate"* as a reference scenario with *"charging at the specific charging rate of the grid-friendliness options"* at the requested charging spot.

To evaluate the power quality and the asset utilization we use a component, which is called *PQ Indicator*. The concept of the PQ Indicator is also used in the reactive smart charging approach described in [2]. The PQ Indicator receives different grid KPIs such as voltage level, voltage balance, flicker or harmonics from the relevant connection points in the grid (e.g. transformer, charging station or the worst point in the grid) and determines the respective power quality for our charging spot. The exact evaluation is depending on the DSOs configuration. The output of the PQ Indicator (in the following referred to as PQ-Index) is a positive number (up to +1), if higher load is required at our charging spot and a negative number (down to −1), if less load is beneficial for the grid.

```
foreach charging operation (=time slot) do
    $PQ\text{-}Index_0$ = PQ-Indicator($guaranteed\ charging\ rate$);
    foreach grid-friendliness options with charging rate $k$ do
        $PQ\text{-}Index_k$ = PQ-Indicator($k$);
        $R_k = w(PQ\text{-}Index_0) - w(PQ\text{-}Index_k)$;
    end
end
```

Algorithm 1: Pseudo code for reward calculation

[·] Philipp Danner, Wolfgang Duschl, Dominik Danner, Ammar Alyousef and Hermann de Meer. Flexibility reward scheme for grid-friendly electric vehicle charging in the distribution power grid. In *Proceedings of the 3th Workshop on Electric Vehicle Systems, Data, and Applications*, EV-Sys '18, New York, NY, USA, 2018. ACM.
See `http://www.net.fim.uni-passau.de/papers/DannerP2018a` for full reference details (BibTeX, XML).

In order to strengthen the reward for critical situation, a weighting function $w(x) = x^{2n}; n = 1$, plotted in Figure 4, is applied to the PQ-Index. Considering the example from Figure 3 between t_0 and t_1, the PQ-Index at 10 kW guaranteed charging rate is 0.9 and the PQ-Index at 45 kW (highest grid-friendliness option) is 0.1. After transformation with the weighting function shown in Figure 4, the weighted values are feed in the following reward calculation: $R = w(PQ\text{-}Index_{10kW}) - w(PQ\text{-}Index_{45kW})$. The output R is used as grid-friendliness factor of the 45 kW charging option.

The pseudo code in Algorithm 1 shows the calculation of the grid-friendliness factor R_k for each grid-friendliness option with charging rate k within each charging operation (=time slot). The differences of the charging rates k, as well as the length of the time slots could be set dynamically in order to cluster certain charging operations and grid-friendliness options.

4 COMMUNICATION AND SCALABILITY

In order to apply the *Reward Scheme* in the charging station domain, we need to define two communications between the CSP and the DSO. First, the CSP requests the reward for a certain time frame in the future, and second, the CSP informs the DSO about future power usage, hence, sends a booking request to the DSO. The later is mandatory for verification of the monetary reward or penalty. Furthermore, the booked power is necessary for calculating the *Reward Scheme* of future requests more precise.

The reward request from the CSP contains the ID of the targeted charging spot (grid connection point) and the time frame (start and end time) in which a charging process should be scheduled. Optional parameters, like a minimum accepted grid-friendliness factor and the target power capacity of the EV, might be sent along with the request for server-side performance optimization.

After obtaining the answer of available charging options and their grid-friendliness options, the CSP needs to send a booking request, which selects appropriate grid-friendliness options in each charging option, where an EV will be charged. Since charging options can span a wide time range and grid-friendliness options can span a wide charging rate range, the booking request should specify the actual power demand as good as possible. The booking of the power, therefore, should follow the so-called charging profile of the EV. After receiving the booking request, the DSO verifies whether the chosen grid-friendliness factors are still valid by recalculating the *Reward Scheme*. If not (in case another power booking changes the gird situation significantly), the booking request is rejected, otherwise the chosen charging profile (time series of booked charging power) is stored at the DSO for future calculations.

Figure 5 shows the sequence of messaging between the CSP, the DSO and the DSOs' internal *Reward Scheme Model*. In case the booking request is rejected, the CSP can start from the beginning and request a new *Reward Scheme*. Since a CSP manages many charging processes, sequentially booked charging profiles of the same CSP are treated individually. The flexible power booking mechanism implements a *First-Come-First-Serve* (FCFS) strategy. Consequentially, the question of scalability of this mechanism raises. We believe that this mechanism will scale very well with the number of participants because of the following two reasons: First, since the *Reward Scheme* is calculated using forecasted load and generation profiles plus the known booked flexible power usage, only the later changes with interleaving booking requests. The power quality of the low/medium voltage grid where a charging spot is installed is mainly influenced by local loads and generations in the same grid section. As a result, the impact of interfering booking requests is limited to the local area and, hence, the maximum number of competing users is limited as well. Second, depending on the power capacity range of the single grid-friendliness options, even with interleaving booking requests, a booking can still be accepted, if the chosen charging profile still translates to the same grid-friendliness factors at each charging operation.

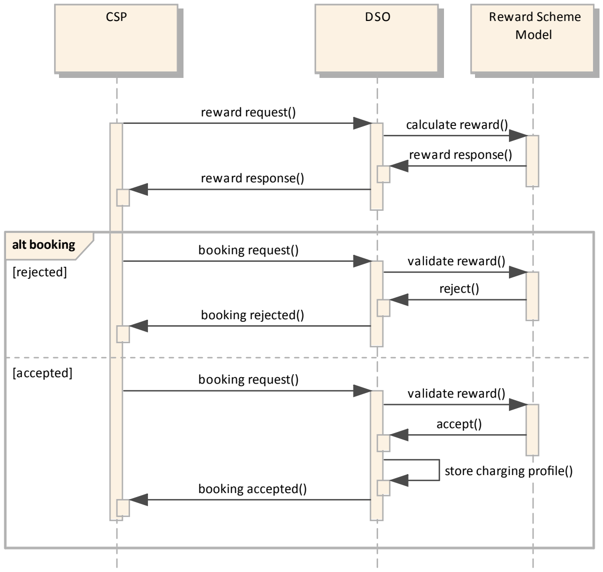

Figure 5: Sequence diagram for requesting the Reward Scheme and booking.

The *Reward Scheme* communication protocol uses a polling approach because electro mobility has a volatile power demand that is also limited by battery capacity and can even be shifted to another grid connection point (depending on the remaining driving range). Thus, the grid-friendliness of a charging process is only of interest, whenever it is planned by the EV user.

5 CONCLUSION AND FUTURE WORK

This work presents a communication and classification scheme to provide grid-friendly charging services. In contrast to currently existing protocols connecting the CSP with the DSO, our solution adds fine granular grid-friendly charging options. In this context, the *Reward Scheme* classifies the effect of different charging rates on the power grid, which could be linked to certain financial rewards or penalties.

Nevertheless, the evaluation of the grid situation and the corresponding charging rates needs to be identified by the DSO depending on the specific grid. In addition to the asset loading and the voltage levels used in this paper, the PQ-Indicator component may take further parameters into account such as system perturbation

[·] Philipp Danner, Wolfgang Duschl, Dominik Danner, Ammar Alyousef and Hermann de Meer. Flexibility reward scheme for grid-friendly electric vehicle charging in the distribution power grid. In *Proceedings of the 3th Workshop on Electric Vehicle Systems, Data, and Applications*, EV-Sys '18, New York, NY, USA, 2018. ACM.

See `http://www.net.fim.uni-passau.de/papers/DannerP2018a` for full reference details (BibTeX, XML).

of the EVs like harmonics or interference frequencies. With the help of the *Reward Scheme* and the booking of flexible power, e.g. day ahead, also the ES can benefit through better prediction within its balancing group.

Our future work includes the investigation towards a data-driven reward calculation model, which requires less information about the power grid. Furthermore, fine-tuning of the proposed *Reward Scheme* will be carried out during the simulative evaluation of our approach, which is the top item on our to-do list. We also think to integrate the grid-friendliness in a kind of local trading between DSOs and CSPs, so that private customers could participate in a local grid-friendliness market. In this context, the *Reward Scheme* could be extended for any controllable loads on household level or in a larger scale even for connected micro grids at their point of common coupling.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 713864 (ELECTRIFIC).

REFERENCES

[1] Elham Akhavan-Rezai, Mostafa F Shaaban, Ehab F El-Saadany, and Fakhri Karray. 2016. Online Intelligent Demand Management of Plug-In Electric Vehicles in Future Smart Parking Lots. IEEE System Journal 10, 2 (June 2016), 483–494. https://doi.org/10.1109/JSYST.2014.2349357

[2] Ammar Alyousef, Dominik Danner, Friederich Kupzog, and Hermann de Meer. 2018. Design and Validation of a Smart Charging Algorithm for Power Quality Control in Electrical Distribution Systems. In Proceedings of the ninth International Conference on Future Energy Systems (e-Energy '18). ACM, New York, NY, USA. https://doi.org/10.1145/3208903.3212031 accepted.

[3] Ammar Alyousef, Florian Niedermeier, and Hermann de Meer. 2016. DC4Cities Power Planning: Sensitivity to Renewable Energy Forecasting Errors. In Proceedings of the 5th International Workshop on Energy Efficient Data Centres (E2DC '16). ACM, New York, NY, USA, Article 7, 6 pages. https://doi.org/10.1145/2940679.2940686

[4] Omid Ardakanian, Srinivasan Keshav, and Catherine Rosenberg. 2014. Real-Time Distributed Control for Smart Electric Vehicle Chargers: From a Static to a Dynamic Study. IEEE Transactions on Smart Grid 5, 5 (2014), 2295–2305. https://doi.org/10.1109/TSG.2014.2327203

[5] Omid Ardakanian, Catherine Rosenberg, and Srinivasan Keshav. 2013. Distributed Control of Electric Vehicle Charging. In Proceedings of the Fourth International Conference on Future Energy Systems (e-Energy '13). ACM, New York, NY, USA, 101–112. https://doi.org/10.1145/2487166.2487178

[6] Niangjun Chen, Chee Wei Tan, and Tony Q. S. Quek. 2014. Electric Vehicle Charging in Smart Grid: Optimality and Valley-Filling Algorithms. IEEE Journal on Selected Topics in Signal Processing 8, 6 (Dec. 2014), 1073–1083. https://doi.org/10.1109/JSTSP.2014.2334275

[7] Kristien Clement-Nyns, Edwin Haesen, and Johan Driesen. 2010. The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid. IEEE Transactions on Power Systems 25, 1 (Feb. 2010), 371–380. https://doi.org/10.1109/TPWRS.2009.2036481

[8] Filipe J. Soares David Rua, Diego Issicaba. 2010. Advanced Metering Inrastructure functionalities for electric mobility. In 2010 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe). IEEE, 1–7. https://doi.org/10.1109/ISGTEUROPE.2010.5638854

[9] Sara Deilami, Amir S. Masoum, Paul S. Moses, Mohammad A. S. Masoum, Amir S. Masoum, Paul S. Moses, and Mohammad A. S. Masoum. 2011. Real-Time Coordination of Plug-In Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile. IEEE Transactions on Smart Grid 2, 3 (Sept. 2011), 456–467. https://doi.org/10.1109/TSG.2011.2159816

[10] Yifeng He, Bala Venkatesh, and Ling Guan. 2012. Optimal Scheduling for Charging and Discharging of Electric Vehicles. IEEE Transactions on Smart Grid 3, 3 (Sept. 2012), 1095–1105. https://doi.org/10.1109/TSG.2011.2173507

[11] Junjie Hu, Guangya Yang, and Henrik W Bindner. 2015. Network constrained transactive control for electric vehicles integration. In 2015 IEEE Power Energy Society General Meeting. IEEE, 1–5. https://doi.org/10.1109/PESGM.2015.7286174

[12] Junjie Hu, Shi You, Jacob Østergaard, Morton Lind, and QiuWei Wu. 2011. Optimal Charging Schedule of an Electric Vehicle Fleet. In Universities' Power Engineering Conference (UPEC), Proceedings of 2011 46th International, Vol. 46. VDE, 1–6. http://ieeexplore.ieee.org/document/6125547/

[13] Lucia Igualada, Cristina Corchero, Miguel Cruz-Zambrano, and F.-Javier Heredia. 2014. Optimal Energy Management for Residential Microgrid Including a Vehicle-to-Grid System. IEEE Transactions on Smart Grid 5, 4 (July 2014), 2163–2172. https://doi.org/10.1109/TSG.2014.2318836

[14] Chenrui Jina, Jian Tang, and Prasanta Ghosh. 2013. Optimizing Electric Vehicle Charging With Energy Storage in the Electricity Market. IEEE Transactions on Smart Grid 4, 1 (March 2013), 311–320. https://doi.org/10.1109/TSG.2012.2218834

[15] Michiel Koot, John TBA Kessels, Bram De Jager, WPMH Heemels, PPJ Van den Bosch, and Maarten Steinbuch. 2005. Energy management strategies for Vehicular Electric Power Systems. IEEE Transactions on Vehicular Technology 54, 3 (May 2005), 771–782. https://doi.org/10.1109/TVT.2005.847211

[16] Zhenhua Liu, Iris Liu, Steven Low, and Adam Wierman. 2014. Pricing Data Center Demand Response. In The 2014 ACM International Conference on Measurement and Modeling of Computer Systems (SIGMETRICS '14). ACM, New York, NY, USA, 111–123. https://doi.org/10.1145/2591971.2592004

[17] Zhuowei Luo, Zechun Hu, Yonghua Song, Zhiwei Xu, , and Haiyan Lu. 2013. Optimal Coordination of Plug-In Electric Vehicles in Power Grids With Cost-Benefit Analysis - Part I: Enabling Techniques. IEEE Transactions on Power Systems 28, 4 (Nov. 2013), 3546–3555. https://doi.org/10.1109/TPWRS.2013.2262318

[18] Zhongjing Ma, Duncan S. Callaway, and Ivan A. Hiskens. 2013. Decentralized Charging Control of Large Populations of Plug-in Electric Vehicles. IEEE Transactions on Control Systems Technology 21, 1 (Jan. 2013), 67–78. https://doi.org/10.1109/TCST.2011.2174059

[19] Maigha and Mariesa L. Crow. 2018. Electric Vehicle Scheduling Considering Co-optimized Customer and System Objectives. IEEE Transactions on Sustainable Energy 9, 1 (Jan. 2018), 410–419. https://doi.org/10.1109/TSTE.2017.2737146

[20] Ramin Mehri and Mohsen Kalantar. 2015. Multi-objective scheduling of electric vehicles considering wind and demand uncertainties. In 2015 Smart Grid Conference (SGC). IEEE, 122–129. https://doi.org/10.1109/SGC.2015.7857421

[21] Myriam Neaimeh, Robin Wardle, Andrew M. Jenkins, Jialiang Yi, Graeme Hill, Padraig F. Lyons, Yvonne Hübner, Phil T. Blythe, and Phil C. Taylor. 2015. A probabilistic approach to combining smart meter and electric vehicle charging data to investigate distribution network impacts. Applied Energy 157 (2015), 2295–2305. https://doi.org/10.1016/j.apenergy.2015.01.144

[22] Florian Niedermeier, Wolfgang Duschl, Torben Möller, and Hermann de Meer. 2015. Increasing Data Centre Renewable Power Share Via Intelligent Smart City Power Control. In Proceedings of the 2015 ACM Sixth International Conference on Future Energy Systems (e-Energy '15). ACM, New York, NY, USA, 241–246. https://doi.org/10.1145/2768510.2768527

[23] Sarah O'Connell and Stefano Riverso. 2017. Flexibility Analysis for Smart Grid Demand Response. CoRR abs/1704.01308 (2017). arXiv:1704.01308 http://arxiv.org/abs/1704.01308

[24] Yasutomo Ota, Hideo Taniguchi, Hidenori Suzuki, Takeshi Nakajima, Jumpei Baba, and Akihiko Yokoyama. 2012. Implementation of grid-friendly charging scheme to electric vehicle off-board charger for V2G. In 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe). 1–6.

[25] Peter Palensky and Dietmar Dietrich. 2011. Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. IEEE Transactions on Industrial Informatics 7, 3 (Aug. 2011), 381–388. https://doi.org/10.1109/TII.2011.2158841

[26] Farrokh Rahimi and Ali Ipakchi. 2010. Demand Response as a Market Resource Under the Smart Grid Paradigm. IEEE Transactions on Smart Grid 1, 1 (June 2010), 82–88. https://doi.org/10.1109/TSG.2010.2045906

[27] Jose Rivera, Christoph Goebel, and Hans-Arno Jacobsen. 2015. A Distributed Anytime Algorithm for Real-Time EV Charging Congestion Control. In Proceedings of the 2015 ACM Sixth International Conference on Future Energy Systems (e-Energy '15). ACM, New York, NY, USA, 67–76. https://doi.org/10.1145/2768510.2768544

[28] Sandip Sharma, Shun-Hsien Huang, and NDR Sarma. 2011. System Inertial Frequency Response Estimation and Impact of Renewable Resources in ERCOT Interconnection. In 2011 IEEE Power and Energy Society General Meeting. IEEE, 1–6. https://doi.org/10.1109/PES.2011.6038993

[29] Eric Sortomme and Mohamed A El-Sharkawi. 2011. Optimal Charging Strategies for Unidirectional Vehicle-to-Grid. IEEE Transactions on Smart Grid 2, 1 (March 2011), 131–138. https://doi.org/10.1109/TSG.2010.2090910

[30] Ganesh K. Venayagamoorthy, Pinaki Mitra, Keith Corzine, and Chris Huston. 2009. Real-time modeling of distributed plug-in vehicles for V2G transactions. In 2009 IEEE Energy Conversion Congress and Exposition. IEEE, 3937–3941. https://doi.org/10.1109/ECCE.2009.5316210