Analysis of the technical and economic potential of current charging solutions for high-power charging (HPC) parks for battery electric vehicles (xEVs)

Roman Scholdan (M.Sc.)
eMobility department
P3 group
Aachen, Germany
Roman.Scholdan@p3-group.com

Sören Schrader (M.Sc.)
Leader eMobility department
P3 group
Aachen, Germany
Soeren.Schrader@p3-group.com

***Abstract*— The comprehensive expansion of the charging infrastructure as well as increasing charging power of electric vehicles present a technical and an economical challenge to charging park operators. The use of battery storage systems and decentralized generation plants can reduce the overall costs of a charging park by partially covering the load. Moreover, additional revenues can be generated through alternative marketing strategies for the components of the charging park. For this purpose, the technical and economic potential of current integrated charging solutions for high-power charging (HPC) parks is analyzed.**

Keywords—battery electric vehicles (xEV), charging infrastructure, high-power charging (HPC), energy management system

I. Introduction

The rapidly growing market for battery electric vehicles (xEVs) enters a new stage in 2019 when for the first-time cars with a charging power of over 300 kW are made available. Although this will be primarily limited to high-end vehicles, other automotive OEMs are on the same path with increasing announcements of xEVs with over 100 kW of DC charging power [1]. For the users to benefit from High Power Charging (HPC) on the vehicle side, the same power is required on the charging park side. Therefore, a comprehensive HPC charging infrastructure is necessary which poses challenges to the operators of charging parks. In order to provide HPC to customers, high grid connection capacities are required which are connected to high investment and operational costs. To avoid that, battery storage systems (BSS) as well as decentralized generation plants such as photovoltaic (PV) plants can be used to relieve the grid connection by partially covering the load of the charging park [2]. OEMs of charging hardware reacted to that demand by offering charging stations that are combined with integrated battery storage systems [3] [4] or with PV systems as a roofing to generate energy at low costs [5]. To what extent those solutions can help to reduce the overall costs of a charging park needs to be examined.

Beyond the primary purpose of charging electric vehicles the installed battery capacities could moreover be used to provide system services to the grid so that additional revenues could be realized for the charging park operator. In Germany the only system service that is currently approved to be supplied by batteries and the only system service that has a compensation model for the provider is reserve power [6]. The economic potential of the provision of reserve power with the stationary batteries of a charging park has to be investigated.

II. Model Description

A. Background

The topic of xEV charging stations and related problems has been subject of various scientific papers over the last decades. While some works focus on the reduction of the required grid capacity by sizing the grid connection to the average load and installing an additional BSS [7], others aim at mitigating the impact of charging xEVs using additional decentralized generation plants [2] [8]. Moreover, the optimization potential of charging park power management was analyzed [9] as well as the optimal number of xEV charging points for specific use-cases under consideration of investment costs [10]. However, all of these aspects have to be considered in one approach in order to comprehensively answer the questions outlined in the introduction of this paper.

Therefore, two mathematical models were developed with the objective to first determine the overall load of a charging park for any charging park configuration and subsequently cost-optimizing the dimensions and operation strategy of all charging park components (including alternative marketing options for the BSS and PV plant). A scheme of both models including their interaction and important inputs is depicted in Figure 1. The developed models are applied for this paper in a use-case of a medium-sized HPC charging park with focus on two different charging solutions and connection to the low voltage grid. The used data is described in chapter III. Subsequently the results are reviewed in chapter IV, before summarizing and discussing the main findings in the final chapter.

B. Load Simulation

The load simulation is realized in a probabilistic model based on the provided input to the model:

- Configuration of the charging park (number, electrical power and load sharing abilities of the charging points)
- Measured charging curves of real electric vehicles (3,7 kW to 320 kW of charging power)
- Arrival frequency of the electric vehicles
- Probability distribution of the vehicles' charging power, BSS capacities and state of charge (SoC)

The model chronologically simulates the arriving vehicles and distributes them to free charging points if available. Since the focus in this step of the simulation is on the load, the power supply is no restrictive condition yet, so that all vehicles can charge with maximum power. The only exception to this rule is the simulation of chargers with two or more charging points,

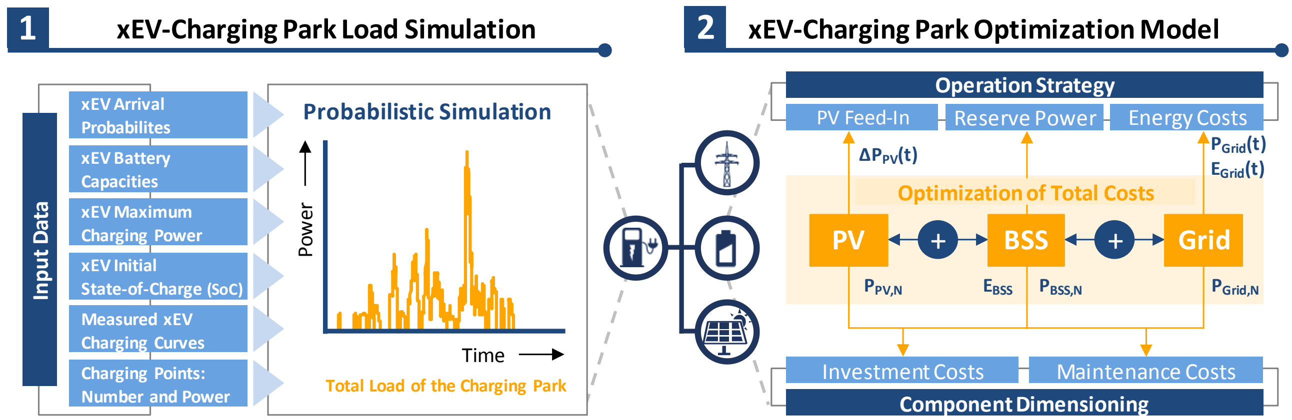

Figure 1: Overview of the developed models: Load simulation and charging park optimization model

at which the maximum charging power can be dynamically distributed between the vehicles.

As much of the input is of a stochastic nature, the load simulation is realized as a probabilistic model. That means, that one day of charging park operation is simulated with multiple repetitions, each with an own sample from the randomly distributed input data, to ensure that the whole range of possibilities deriving from the stochastic input, is appropriately represented in the output and that the output is reproducible. The number of repetitions needed to generate reproducible results depends on various factors (charging park configuration, number of arriving cars, number of chargers etc.) and must be determined for every use-case individually. Subsequently from the resulting quantity of load curves the 99th-quantile regarding the peak power is processed to exclude those extreme scenarios, which would only occur in very rare occasions, so that they should not be considered when configuring an economically viable charging park. The output of the model is the cumulated yearly load curve of the charging park with a temporal resolution of 10 s. The load curve serves as an input for the following optimization model.

In addition to the described features, the model offers further options, such as departure times (resulting in maximum charging durations) or load shifting. However, for the given public HPC scenario those options are chosen to be irrelevant, since all arriving cars should be charged with the maximum charging rate until a certain target SoC is reached.

C. *Optimization Model*

The cost-optimized dimensioning of the charging park's components is realized in the optimization model, which receives the following input:

- Charging park load curve generated by the load simulation model
- Component costs: Grid connection, PV plant and BSS
- Operating costs, including energy costs as well as maintenance costs
- Revenues realized by the PV plant or by the provision of reserve power
- Normalized PV generation curve

Not considered are the costs of the charging hardware itself and the constructional costs because those costs are often fixed and not optimizable, as well as the revenues made by charging the customers. Instead the model focuses on the cost-optimized power supply of the given charging load.

The developed model is a mixed-integer linear optimization. The target function aims at providing the required charging power while minimizing all caused costs and maximizing possible revenues. To ensure that the technical limitations of the charging park's components are met the model contains a large number of constraints: The BSS SoC has to be held in an approved SoC-range as well as the input/output power of the BSS must not be exceeded. The generation of the PV plant has to comply to the given PV generation curve and the rated grid connection capacity must not be surpassed. In case of the provision of reserve power, the BSS has to be held within a certain SoC-range to be able to provide enough buffer storage in case of longer frequency deviations. Additionally, the BSS has to be charged or discharged with the required reserve power at every moment of offering. The final result of the optimization model includes the dimensions of the components grid connection capacity, PV plant and BSS, as well as the overall capital value including the costs and revenues of the charging park.

The described optimization model simulates the charging park for yearly time periods and a temporal resolution of 10 s. The high temporal resolution is needed to accurately simulate peak loads and the provision of power reserve. As a result of the high temporal resolution, solving the model as a whole proved to be impossible even when using large quantities of cores and memory on computer clusters. In order to make the model solvable, the optimization problem is decompensated into multiple sub-problems by using the Benders Algorithm. The complicated variables, which are the dimensioning of the components, are solved within a master problem, while one week of charging park operation is solved in each sub-problem. The optimum is approached by iteratively adapting the components' dimensions and subsequently solving the sub-problems. With the help of the Benders decompensation the model is solvable within hours on an average computer.

III. Data Description

As more and more charging hardware OEMs announce chargers with combined BSS and PV system, this paper aims at analyzing the technical and economic potential of such integrated products in an appropriate environment. Examples for charging solutions that combine power electronics with BSS can be found in [3] and in [4]. An example for solar roofing for charging parks can be found in [5]. While HPC is generally associated with larger sized charging parks on highways or main traffic routes, the recent past has shown that also non-highway scenarios are relevant in combination with HPC. For this paper a use-case is selected that represents a small HPC charging park located in the catchment area of a German city. Two charging solutions are analyzed:

(A) A 320 kW charger with the possibility to either operate one charging point at 320 kW or two charging points at 160 kW each

(B) Two separate charging points of 160 kW each with no load sharing abilities

Each charging solution is combined with a 150 kWh BSS (power to energy ratio of 3/2 resulting in 225 kW of BSS power) and a small sized PV system of 4.2 kWp, which serves as a realistic assumption for carport-mounted PV plants. Another reason for the predefinition of the PV plant to 4.2 kWp is that previous results have shown, that without limitation the optimization model maximizes the size of the PV plant in almost all use-cases [11]. This result was explained by the fact that PV generation represents the cheapest option of energy provision for the charging park if building space (available land/roof area) is not taken into consideration or unknown. Therefore, the limitation to 4.2 kWp should serve as a more realistic assessment on the PV situation. In the following abstracts the data used for the load simulation and the optimization model is described.

A. *Input Data for Load Simulation.*

To define the frequency of arriving xEVs to a charging park, the assumption was made, that the traffic on the road next to the charging park is correlated with the possibility of arriving charging vehicles. The German Federal Highway Institute carries out automated vehicle counting on German highways and main roads [12] which can be used to derive an arrival probability on nearby charging stations (see right diagram of Figure 2 for example). To estimate the charging power of the arriving vehicles, the current xEV market distribution was assessed, as well as OEM announcements and technical considerations concerning the maximum viable charging power. The derived distribution for charging power of arriving vehicles is depicted in Figure 2. Note that this represents an assumption on the average distribution of xEVs for the examination's observation period of 20 years.

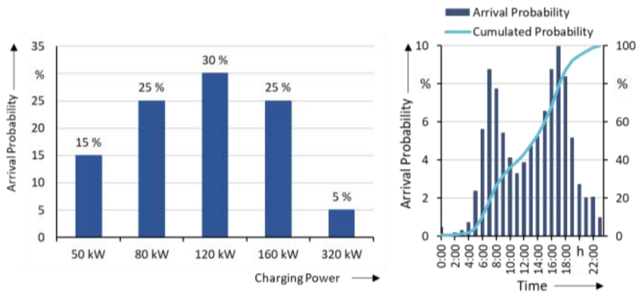

Figure 2: Arrival probability of xEVs divided into charging power classes and example for arrival probability per day

B. *Input Data for Optimization Model*

As input data for the optimization model the costs of the regarded components have to be considered, as well as the energy costs and the revenues generated by the components.

For a new grid connection on low voltage level in Germany the customer usually pays a fixed flat rate for the construction works plus variable costs that depend on the distance to the next grid connection point plus a so-called building cost subsidy (BCS) that depends on the grid connection capacity. P3 studies have shown that the mentioned costs vary greatly between the 888 currently in Germany registered distribution grid operators (DSOs) [13]. The BCS can range from 15 €/kW to 165 €/kW. The influence of the height of the BCS on the economic efficiency of the regarded charging solution will be analyzed. Further component costs are the costs for the PV plant, which are oriented towards current studies [14], as well as costs for the BSS which are derived from P3 studies and are presumed to be 470 €/kWh for the simulations (except for those simulations, in which the BSS costs are analyzed and varied).

Regarding the energy costs used in the optimization model, studies published regularly by the Federal Association of the German Energy and Water Industries [15] are used. Moreover various studies concerning the development of energy costs in Germany over the next 20 years are taken into account [16] [17] [18]. An integral part of the energy costs are the grid connection fees that consist of the capacity charge and the energy rate. Similar to the BCS both costs depend greatly on the local DSO and can vary on low voltage level for under 2.500 full load hours (2.500 full load hours of grid usage were not exceeded in any of this paper's simulations) from 1 €/kW to 110 €/kW (capacity charge) and from 1,5 ct/kWh to 13,5 ct/kWh (energy rate) as P3 studies have shown. The customer is charged with the grid connection fees every year. The capacity charge is calculated with the highest average load over a period of 15min obtained from the grid connection. In contrast to that the energy rate is calculated with the total amount of energy obtained from the grid connection over one year. The influence of the height of the grid connection fees on the economic efficiency of the regarded charging solution will be examined.

The generation of PV plants is compensated in Germany with fixed fees that are guaranteed for a period of 20 years and that depend upon the date of plant construction. Plants with installed powers of under 100 kWp are usually compensated with the feed-in tariff "Einspeisevergütung" whereas plants above 100 kWp are compensated with the direct marketing tariff ("Direktvermarktung"). For the chosen use-case of a roof-mounted PV system of 4.2 kWp only the feed-in tariff "Einspeisevergütung" is economically viable, because direct marketing is usually coupled with fixed monthly or yearly payments for a service provider, which makes the model unattractive for relatively small PV plants (< 100 kWp). A pessimistic assumption was made for the feed-in tariff used for the PV plant in the simulations, referring to the tariffs for current plant construction [19].

The provision of reserve power with batteries was approved by the German TCOs in 2015 [20]. Reserve power is needed to balance the generation and load of the grid so that the grid frequency is kept close to 50 Hz. Reserve power is traded on the electricity balancing market as different products, one of them being the Frequency Containment Reserve (FCR) which is needed for short-term stabilization after a frequency deviation. Currently batteries are only authorized to provide FCR which is traded as a symmetrical product in contracts of weekly lengths. That means that a provider of FCR has to guarantee the capability to provide positive and negative reserve power for the duration of one week. Due to ongoing discussions to shorten the length of the FCR product to 4 h [21] the profitability of this option will be analyzed in this paper as well. Another reserve power product is Frequency Restoration Reserve (FRR) which is needed to restore the grid frequency to its nominal value. Since the 12th of July 2018 FRR is traded as asymmetrical products of 4 h, which means that the provider only has to guarantee the ability to provide FRR for a duration of 4 h and the provider can choose to offer positive or negative reserve power. Although in Germany the provision of FRR by BSS is currently not authorized, an analysis of the economic potential is conducted in this paper.

The costs and revenues for the provision of reserve power are oriented towards compensation models offered by service providers [22]. The customer is charged a one-time payment for the installation of the required hardware and moreover the service provider keeps a third of the generated revenues. Controversially the providers of revenue power still have to pay the grid connection fee for the energy that is charged into the BSS when providing negative reserve power although they are contributing to the stability of the grid. How those costs influence the economic efficiency of this marketing option will be analyzed. Revenues are generated by offering capacity on the Germany electricity balancing market. For the described model the historical revenues generated in 2018 are used.

IV. RESULTS

In the following the results of the developed load simulation and optimization model are presented.

A. Load Simulation Results

One of the biggest challenges for charging park operators is the question of how many xEVs will be charged regularly over the next decades. A comprehensive analysis of this question that factors in the location of the park, as well as socioeconomical and political factors can be found in [23]. In order to manage the complexity of the models, a different approach was chosen for this paper: First the maximum number of xEVs that can charge per day at the regarded charging park was calculated using the load simulation model. In this paper the maximum number of xEVs per day is defined as the maximum number of vehicles that can be charged without having to reject further xEVs that could not be served. Subsequently three different scenarios were derived from this number: Maximum utilization (100 % of the calculated maximum xEVs per day), medium utilization (50 %) and low utilization (20 %). This approach allows to compare the two chosen charging solutions in terms of maximum charging capacity. Subsequently for the optimization model analysis, the medium utilization scenario was chosen in order to answer the question of how the cost-optimized power supply should look like for an average utilization scenario. Figure 3 displays the maximum xEVs and the peak loads for both described charging solutions (see chapter III) in differing utilization scenarios:

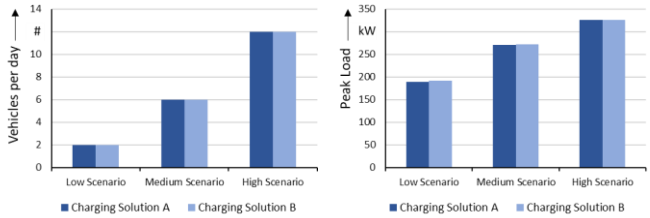

Figure 3: Comparison of maximum number of xEVs per day (left diagram) and peak load (right diagram) per charging solution

It can be clearly seen that the additional charging power of charging solution A doesn't yield any advantage in terms of maximum number of xEVs that can be charged at the charging park under the assumptions made in this analysis. This result can be explained with the low arrival probability of xEVs with over 160 kWp charging power (see Figure 2): Charging solution A could only provide an advantage over charging solution B in terms of maximum servable xEVs, if an xEV of over 160 kW arrives at the charging park and due to the shorter charging time another xEV could charge while with charging solution B the charging point would still be blocked. But since the arrival probability of such xEVs is relatively rare (5 %), this case doesn't occur in the simulation.

Due to the high similarity of the load simulation results of both analyzed charging solutions, the optimization model results will focus on the results for charging solution B.

B. Optimization Model Results

To analyze the economic efficiency of the chosen charging solution B (2 charging points with 160 kW each), multiple charging park configurations were cost-optimized under variation of decisive parameters. The following results show the capital value for an observation period of 20 years for the overall costs (positive values) reduced by the generated revenues (negative values). For the calculation of the capital values an interest rate of 1 % was presumed. Moreover, the required grid connection capacities are depicted in the right diagrams for each examination.

In Figure 4 the results for the derived utilization scenarios are shown under consideration of different charging park components and under the assumption of average values for costs and revenues discussed in chapter III.B. For this analysis the capacity of the BSS was set to a fixed value of 150 kWh and the installed power of the PV plant was set to a fixed value of 4.2 kWp (see scenario description in chapter III). The grid connection capacity was cost-optimized in each simulation.

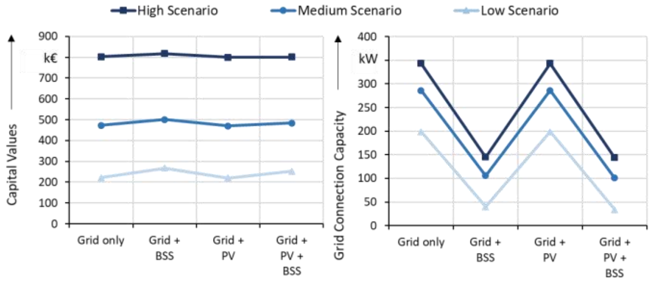

Figure 4: Optimization results for all utilization scenarios with differing charging park configurations

The results show, that by assuming average costs the charging solution with integrated 150 kWh BSS yields no economic advantage over the conventional grid only solution. Even though the grid connection capacity can be reduced by around 67 % on average (comparison of “Grid only” to “Grid + BSS”), those cost savings cannot compensate for the additional BSS costs. Even in combination with the PV plant (“Grid + PV + BSS”) the additional BSS cannot generate an economic advantage compared to the scenario without BSS (“Grid + PV”) and just helps to reduce the needed grid connection capacity even further (69 % on average). Compared to previous results with this model [11] the assumption can be made that the simulated PV plant is too small to have a major impact on the economic efficiency of the BSS.

In order to determine, if a smaller sized BSS would be a better economic fit for the chosen scenario, the optimization model was used to simulate various BSS sizes between 50 kWh and 250 kWh. To manage the complexity of the results the medium utilization scenario was chosen for all upcoming examinations. Figure 5 shows the results for the BSS size analysis, whereby the configurations with BSS (“Grid + BSS” & “Grid + PV + BSS”) are compared to the configurations without BSS (“Grid only” & “Grid + PV”):

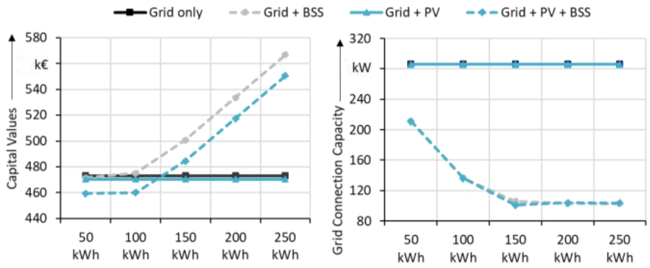

Figure 5: Results for varying BSS capacities (medium scenario)

The depicted results show that from an economic perspective a smaller sized BSS of 50 kWh could generate a minor advantage compared to the scenarios without BSS (reductions in capital values of about 1.3 % on average). In combination with the PV plant even a 100 kWh BSS still lowers the capital value by 2.2 %. From a technical point of view however the 150 kWh BSS appears to be the optimum size for maximum grid connection capacity reduction, since larger BSS of over 150 kWh cannot reduce the grid connection capacity any further.

Obviously, the analyses conducted so far are largely impacted by the assumptions for BSS costs of 470 €/kWh on average. Regarding combined solutions of a BSS in addition to the charger, those costs would be reflected in the higher price that the manufacturer charges for the integrated solution compared to the standalone charger solution (without BSS). For the chosen charging solutions (see chapter III) for example, this would result in around 70 k€ of extra costs for the BSS. In order to examine which effect the BSS costs have on the optimum BSS dimension for the chosen charging park scenario, further simulations were carried in which the BSS was not predetermined to a certain dimension while the BSS costs were varied from 330 €/kWh to 610 €/kWh. In addition to previous results Figure 6 also includes the optimized BSS capacities in the diagram on the right-hand side:

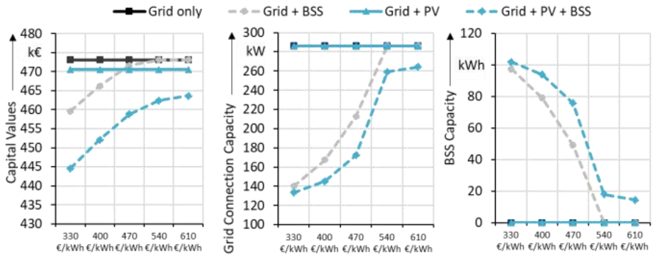

Figure 6: Results for varying BSS costs and completely adjustable BSS capacity (medium scenario)

The focus of the results lies on the comparison of the configurations “Grid only” to “Grid + BSS” and “Grid + PV” to “Grid + PV + BSS”. For the configurations without PV plant it can be clearly seen that larger sized BSS of capacities from 80 to 100 kWh are only economically viable if the extra costs for the BSS don’t exceed 400 €/kWh. Even then the reductions in capital value are relatively small with 2.1 % on average. With the initially assumed average costs of 470 €/kWh the cost-optimized BSS dimension is reduced to a third of the size of the initially chosen charging solution (about 50 kWh) for a negligible cost reduction (about 0.3 %). From BSS costs of 540 €/kWh onwards no BSS is installed which means at this point the power supply via only the grid connection is the cheapest option. In contrast to that the configurations that include a PV plant always offer enough cost saving potential so that a BSS can be installed even with high BSS costs (about 15 kWh BSS at 610 €/kWh). At low BSS costs (330 €/kWh) a capital cost reduction of 5.5 % can be realized with the installation of a 102 kWh BSS.

After the conclusion that the 150 kWh BSS of the chosen charging solution doesn’t yield an economic advantage under the assumption of average costs for Germany, the question arises under which circumstances it does. Therefore, the parameter building cost subsidy (BCS) was analyzed in the range of 15 €/kW to 165 €/kW (average in Germany: 65 €/kW). Figure 7 shows the results for the BCS-analysis:

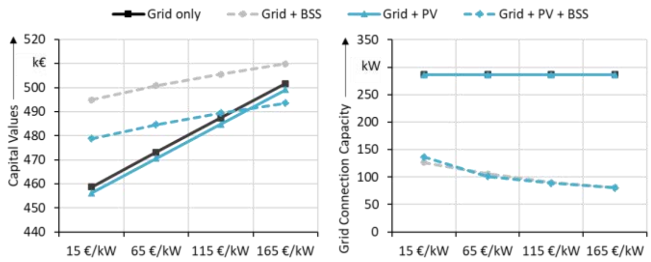

Figure 7: Results for varying BCS (medium scenario)

The results show that only under high BCS of 165 €/kW the 150 kWh BSS provides an economic advantage when combined with the 4.2 kWp PV plant. Without a PV plant there is no BCS-scenario in which the BSS provides any advantage, besides for the grid connection capacity which can be steadily decreased down to 80 kW.

The relatively small effect of a high BCS on the economic profitability of the BSS is explained through the limited effect of the BCS on the overall costs of the charging park: It only comes into effect once for the installation costs for the grid connection. In contrast to that there is a cost parameter connected to the grid connection which comes into effect every year: The capacity charge has to be paid yearly for the peak load of the charging park as part of the grid connection fees (see chapter III.B). Since the BSS has a direct effect on the required grid connection capacity, its economic potential should be directly affected by the capacity charge. The energy rate on the other hand, which is also part of the grid connection fees, has no direct effect on the economic profitability of the BSS, because the BSS doesn't help to reduce the energy consumption of the charging park, as previous analyses have shown [11]. Figure 8 depicts the results of the analysis, in which the capacity chargers were varied between 5 €/kW and 110 €/kW (average in Germany: about 20 €/kW):

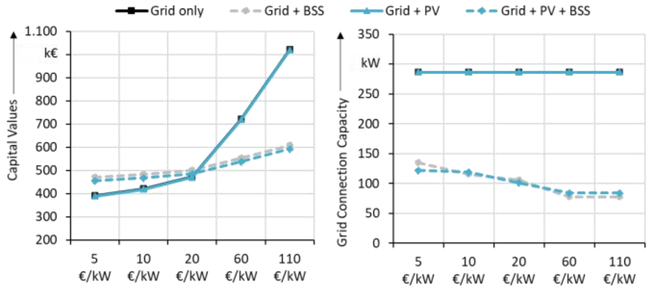

Figure 8: Results for varying capacity charges (medium scenario)

The previously mentioned presumption is confirmed by the results: With slightly higher than average capacity charges the additional BSS unfolds high economic potential: At 60 €/kW cost reductions of 23.2 % (without PV) and 25.2 % (with PV) can be achieved. At very high capacity charges of 110 €/kW the cost reductions are even more significant: 40.3 % (without PV) and 41.8 % (with PV). This is directly caused by a reduction in grid connection capacity of about 72 % on average (with and without PV). The reduction of grid connection capacity is directly connected to the decrease of the peak demand of the charging park from the grid, because the optimization model determines the grid connection capacity only as large as necessary.

The analyses conducted so far have demonstrated under which circumstances the regarded charging solution can yield economic efficiency when using the integrated BSS solely for charging purposes. As xEVs mainly arrive at the charging park during the day, the installed BSS could be unused during long stretches. Especially in those times the provision of reserve power could generate additional revenues for the charging park operator. Therefore, simulations were carried out that include the option to offer FCR and FRR on the electricity balancing market. Figure 9 depicts the results of those simulations for the two relevant configurations that include a BSS. As pointed out in chapter III.B, the energy charged into the BSS during the provision of reserve power is currently charged with grid connection fees, so that those extra costs must be considered. However, to examine the effect of the grid connection fees on the profitability of reserve power provision, additional simulations were carried out under the assumption that providers would be freed from those extra costs. Those simulations are labelled with "No GCF" in Figure 9. The results of the reserve power simulations are compared to the results without reserve power provision (compare to Figure 4), which are labelled "No Reserve Power" (first column):

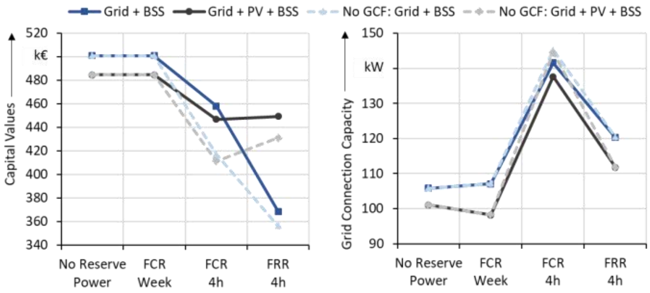

Figure 9: Results for the provision of reserve power with and without grid connection fees (GCF) for the provided reserve energy (medium scenario)

It is evident that the provision of FCR as a weekly product yields no further economic value to the charging park operator, because the weekly product is too inflexible to combine it with the volatile daily load and operation of the charging park. However, the results also show, that with the upcoming change to 4h-products, the provision of FCR becomes profitable for the regarded use-case (see column "FCR 4h"). Surprisingly the configuration without PV plant ("Grid + BSS") benefits even more (overall cost reductions of 8.5 %) than in combination with the PV plant (7.8 %). The reason for that is that in combination with a PV plant the BSS is primarily used to store the PV generation and increase the self-consumption of the charging park. As a result, there is less margin for the provision of FCR in the BSS which reduces the economic efficiency of that option. The profitability is enhanced, when the assumption is made that in the future there won't be any GCF for reserve power provision anymore (see dashed lines): In that case FCR-provision as 4h-products reduces overall costs for the charging park operator by 16.7 % (without PV) or by 15.1 % (with PV). For the results of FRR-provision, the above-mentioned observation that the PV plant hinders the full economic potential of the BSS can be confirmed: Without the PV plant, the FRR-provision generates revenues that lower the overall costs for the charging park operator by 26.4 % (with GCF) or 40.5 % (without GCF). In combination with the PV plant those cost reductions decrease to 7.3 % (with GCF) or 12.4 % (without GCF). Regarding the effect of GCF on the provision of reserve power overall it can be noticed that especially FCR-provision (the only reserve provision currently allowed for BSS in Germany) would benefit from a removal of GCF. The reason for that is that FCR is offered as a symmetrical product (see chapter III.B) which means that the provider cannot prevent paying GCF (specifically the energy rate) by only offering positive FCR. In contrast to that FRR can be offered as a positive or negative product (see chapter III.B), so that extra costs caused by GCF could be avoided which reduces the economic impact of GCF on the provision of FRR.

V. Conclusion and Discussion

The purpose of this paper was to analyze two specific, close to the market HPC charging park solutions: The first option consisted of two 160 kW charging points with a 150 kWh integrated BSS and a 4.2 kWp PV-roof. The second option added the feature to combine both 160 kW charging points to a single 320 kW charging points in case of only one xEV charging. The virtual HPC charging park was located in the catchment area of a German city where the arrival probability of xEVs could be derived from vehicle counting on the connected highway. With both charging park solutions, the maximum number of xEVs that could be charged per day without having to reject serving further vehicles was calculated to 12 xEVs. The reason for the equal result for both configurations was found in the assumption that only 5 % of the charging xEVs would be able to charge with over 160 kW, which limits the effect of the 320 kW charger. It was shown that under the assumption of average German energy and component costs the integrated BSS yields no economic advantage because the added costs for the BSS cannot be compensated by the reduction of grid connection capacity (see Figure 4). With the assumed extra costs of 470 €/kWh for the BSS only a combination of a smaller sized BSS of 50 to 100 kWh and the PV plant could slightly reduce the overall costs by 2.2 % (see Figure 5). Even under the assumption of low extra costs for the BSS (330 €/kWh), the optimum BSS size never exceeded 100 kWp (with and without PV plant, see Figure 6). Overall the results show that from a technical point of view (or from the grid operator's perspective) the BSS proved great potential to reduce the required grid connection capacity. However, this can only lead to increased economic profitability in areas where the capacity charges exceed 20 €/kW (see Figure 8). In contrast to that the effect of high building cost subsidies (BCS) on the economic potential of the BSS is too low, because BCS come into effect only once and not every year compared to costs for capacity charge (see Figure 7). The analysis for reserve power provision proved that FCR as a weekly product is too inflexible to generate any profitability for charging park operators. With the foreseen change to 4h-products however, FCR-provision could lead to overall cost reductions of up to 8.5 % in the chosen use-case. In case that FRR-provision would be allowed for BSS, overall costs could be reduced by up to 26.4 % for this charging park scenario. The PV plant proved to be detrimental to the economic profitability of reserve power provision, because the BSS would be used to primarily store the PV generation in order to increase the self-consumption of the charging park, which means less margin for the provision of reserve power in the BSS. Furthermore, the results showed that the obligatory grid connection fees (GCF) have a higher impact on the profitability of FCR, because of the symmetry of FCR products which makes grid connection fees currently unavoidable for the providers. Without GCF overall cost reductions of up to 16.7 % with FCR and of up to 40.5 % with FRR were calculated for the chosen use-case.

As the eMobility world is constantly changing and evolving, the described models of this paper do too. Currently one of the most interesting and anticipated topics is vehicle-to-grid (V2G). Not only does it promise grid operators a new source for providing system services such as reserve power, it also has the potential to generate new income for charging park operators and charging customers as well. In terms of the described models a V2G simulation means disrupting the fixed load curve of the charging park and simulating bidirectional charging. The aim and challenge for further examinations will be to examine an in-depth analysis of the revenue potential of V2G while keeping the optimization model solvable.

REFERENCES

[1] electrive.net, "Unser Blick voraus: Diese Elektroautos kommen 2019," 31 December 2018. [Online]. Available: https://www.electrive.net/2018/12/31/unser-blick-voraus-diese-elektroautos-kommen-2019/. [Accessed March 2019].

[2] S. Schrader, R. Scholdan, C. Bussen and R. Küsters, "Capabilities to reduce the grid connection power of high power charging (HPC) parks for battery electric vehicles (EVs) with connection to the medium voltage grid," EVS31, 2018.

[3] Kreisel Electric, "Kreisel Chimero Charger," [Online]. Available: http://www.kreiselelectric.com/chimero/. [Accessed March 2019].

[4] Porsche Newsroom, "Electric pit stop," November 2018. [Online]. Available: https://newsroom.porsche.com/en/technology/porsche-e-mobility-fast-charging-modular-building-blocks-system-electricity-grid-visitor-frequency-space-constraints-power-electronics-cooling-unit-pit-stop-missione-taycan-engineering-2018-1-15796.html. [Accessed March 2019].

[5] Fastned, "Everything you've always wanted to know about fast charging," 2018.

[6] 50hertz, Amprion, Tennet, Transnet BW, "Anforderungen an die Speicherkapazität bei Batterien für die Primärregelleistung," 2015.

[7] S. Bai et al., "Optimum design of an EV/PHEV charging station with DC bus and storage system," 2010.

[8] A. Mohamed et al., "Real-Time Energy Management Algorithm for Plug-In Hybrid Electric Vehicle Charging Parks Involving Sustainable Energy," 2014.

[9] U. Abronzini et al., "Optimal energy control for smart charging infrastructures with ESS and REG," 2016.

[10] B. Ferguson et al., "Optimal Planning of Workplace Electric Vehicle Charging Infrastructure with Smart Charging Opportunities," 2018.

[11] R. Scholdan, S. Schrader, C. Bussen and A. Brinster, "Analysis of the potential of stationary batteries to reduce the grid connection power and costs of high power charging (HPC) parks for battery electric vehicles (xEVs)," 2019.

[12] Federal Highway Research Institute, "Traffic surveys," 2018. [Online]. Available: https://www.bast.de/BASt_2017/EN/Traffic_Engineering/Subjetcs/traffic-surveys.html. [Accessed March 2019].

[13] Bundesnetzagentur, "Übersicht Strom- und Gasnetzbetreiber - Stand: 09.05.2018," 2018.

[14] Fraunhofer ISE, "Aktuelle Fakten zur Photovoltaik in Deutschland," 2018.

[15] Federal Association of the German Energy and Water Industries - BDEW, "BDEW-Strompreisanalyse Januar 2019," 2019.

[16] Agora Energiewende, "Die Entwicklung der EEG-Kosten bis 2035," 2015.

[17] BMWi, "Entwicklung der Energiemärkte - Energiereferenzprognose," 2014.

[18] TU Dresden, "Abschätzung der Entwicklung der Netznutzungsentgelte in Deutschland," 2014.

[19] IBC Solar, "EEG Stand 17.Juli 2017 - Einspeisevergütungen im Überblick & Erlösobergrenzen im Sinne des Marktprämienmodells," 2018.

[20] 50hertz, Amprion, Tennet, Transnet BW, "Anforderungen an die Speicherkapazität bei Batterien für die Primärregelleistung," 2015.

[21] 50hertz, Amprion, Tennet, Transnet BW, "Antragsentwurf für die Festlegung der Modalitäten für die Frequenzhaltungsreserven (FCR) und Frequenzwiederherstellungsreserven (FRR)," 2018.

[22] Next Kraftwerke, "Sonnige Aussichten - Höhere Erlöse und mehr Service in der Direktvermarktung," 2017.

[23] D. Bracht, T. Montag and T. Schürer, "Analysis of Intelligent Charging Strategies to Reduce the Need of Grid Reinforcement Measures Caused by the Market Ramp-Up of Electric Vehicles," 2019.