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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)

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Summary

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 potential of stationary batteries to lower the charging park costs by reducing the required grid connection power is analysed within multiple parameter frames, as well as the potential to generate additional revenues by providing reserve power.

Keywords: BEV, fast charge, battery charge, BMS, simulation

1 Introduction

The rapidly growing market for electric vehicles (xEVs) will enter a new stage in 2019 when for the first-time cars with a charging power of over 300 kW will be 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] [2]. 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 PV plants can be used to relieve the grid connection by partially covering the load of the charging park [3]. OEMs of charging hardware reacted to that demand by offering charging solutions that combine the charging hardware with an integrated battery storage [4] [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.

To answer the outlined questions, a mathematical model is described in the next chapter that simulates the operation of a charging park considering the use of a stationary battery and the provision of reserve power. The developed model is applied for this paper in a use-case of a medium-sized HPC charging park with connection to the low voltage grid. The used data is described in chapter 3. Subsequently the results are reviewed in chapter 4, before summarizing and discussing the main findings in the final chapter.

2 Model description

The developed model can be divided up into two sub models, as seen in Figure 1: A load simulation model and an optimization model. The first model is simulating the load of a charging park for specific charging park configurations, arriving vehicles and time periods. The optimization model then optimizes the dimensioning of the charging park's components, which can include the grid connection capacity, a PV plant and a BSS, to provide the required power and energy at minimal costs. Both models are described in detail in the following sections.

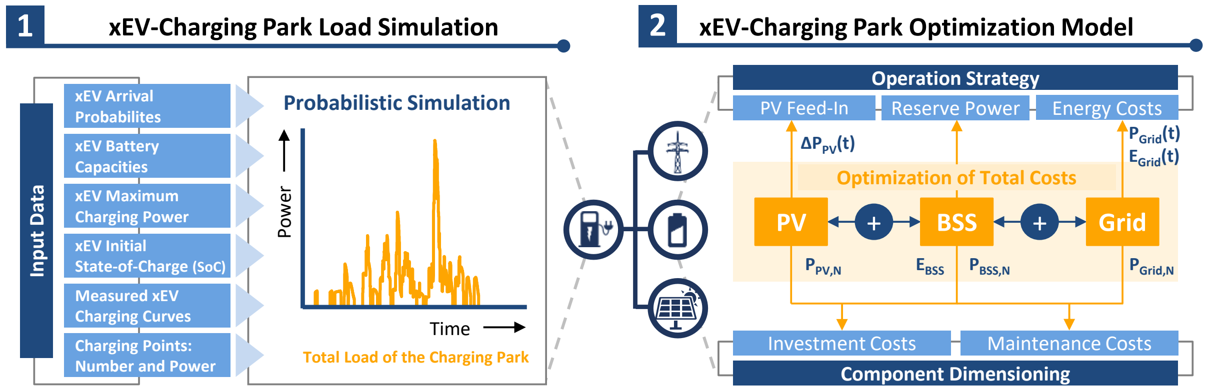

Figure 1: Overview of developed models: Load simulation and charging park optimization model

2.1 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 and electrical power of the charging points)
- Measured charging curves of real electric vehicles (3,7 kW to 350 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. 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.

2.2 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.

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 not exceeded 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 simulate peak loads and the power reserve accurately. 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 ram 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.

3 Data description

As more and more charging hardware OEMs announce chargers with combined BSS this paper aims at analyzing the use of the integrated BSS in an appropriate environment. Examples for such integrated charging solutions are the Kreisel Chimero [4] or the Porsche ChargeBox [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 with two 150 kW charging points and a combined 150 kWh BSS installed. The power to energy ratio is assumed to be 3/2 resulting in 225 kW of BSS power. In the following the data used for the load simulation and the optimization model is described.

3.1 Input data for the 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 [7] which can be used to derive an arrival probability on nearby charging stations. 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.

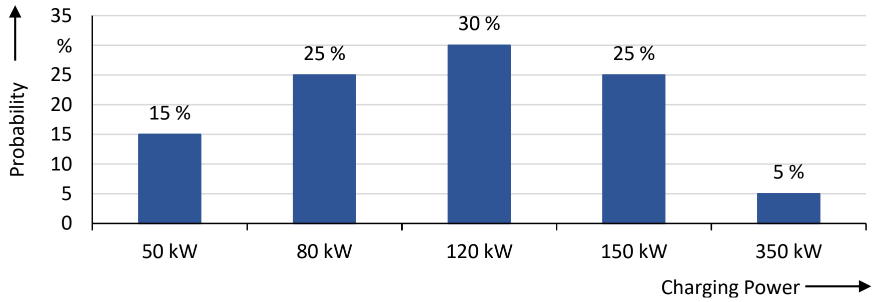

Figure 2: Arriving probability of xEVs divided into classes of maximum charging powers

3.2 Input data for the 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) [8]. 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 analysed. Further component costs are the costs for the PV plant, which are oriented towards current studies [9], as well as costs for the BSS which are derived from P3 studies and are presumed to be 470 €/kWh for the simulations.

Regarding the energy costs used in the optimization model, studies published regularly by the Federal Association of the German Energy and Water Industries [10] are used. Moreover various studies concerning the development of energy costs in Germany over the next 20 years are taken into account [11] [12] [13]. 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 both alternatives a pessimistic assumption was made for the simulations in this paper that refer to the tariffs for current plant construction [14].

The provision of reserve power with batteries was approved by the German TCOs in 2015 [6]. 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 [15] the profitability of this option will be analysed 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 [16]. 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 analysed. Revenues are generated by offering capacity on the Germany electricity balancing market. For the described model the historical revenues generated in 2018 are used.

4 Results

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

4.1 Load simulation results

One of the biggest challenges for the charging park operator is how the number of xEVs charged per day will change over the next decades. To assess that question, 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 amount 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 %). The results of the load simulation in form of xEVs charged per day for the three different scenarios are depicted in the left diagram of Figure 3:

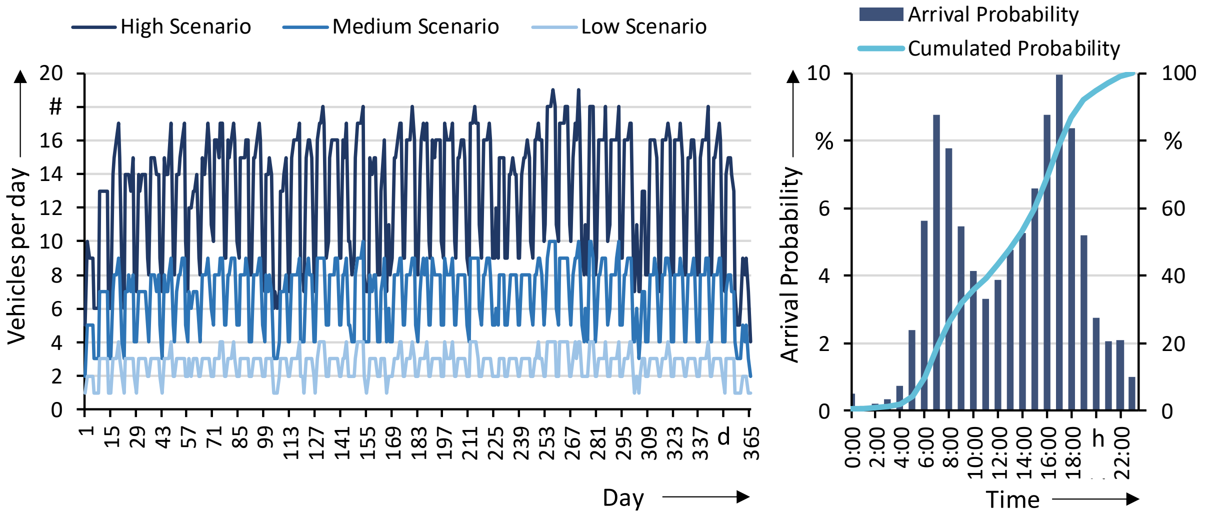

Figure 3: Charged xEVs per day for the three scenarios (left diagram) and probability of arriving vehicles of Day 257 (day with highest overall number of arriving vehicles) (right diagram)

The maximum amount of xEVs that can be charged per day regarding the chosen charging park configuration of two HPC chargers with 150 kW each is 19 xEVs, represented by the high scenario. Although 9,5 xEVs per charging station per day initially seem very small, a look at the arrival probabilities of the day with the highest overall number of arriving vehicles (depicted in the right diagram of Figure 3) provides an explanation: Major peaks occur in the morning and in the afternoon which limit the number of maximum xEVs per day. Following the above-mentioned procedure, the medium and low scenario represent a maximum amount of

10 and 4 xEVs charged per day. The calculated peak load for the high and medium scenario is 312,8 kW, which means that in both scenarios at least on one occasion both HPC chargers are fully used to capacity including efficiency losses from the grid connection point to the vehicles. In contrast to that the peak load for the low scenario is 292,7 kW, meaning that both HPC chargers are never simultaneously used to full capacity.

4.2 Optimization model results

To analyse the economic efficiency of the chosen charging solution, different charging park configurations were cost-optimized under variation of decisive parameters for the derived utilisation scenarios. The following results focus on the capital values over the observation period of 20 years which represent the sum of 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 utilisation scenarios are shown under consideration of different charging park configurations and under the assumption of average values for costs and revenues discussed in 3.2. For this analysis the capacity of the BSS was set to a fixed value of 150 kWh (see 3), while the grid connection capacity as well as the installed power of the PV plant were cost-optimized in each simulation. Simulations that consider the standard feed-in tariff for PV plants under 100 kWp are labelled "PV", while the simulations that considered direct marketing for PV plants over 100 kWp are labelled "PV(DM")".

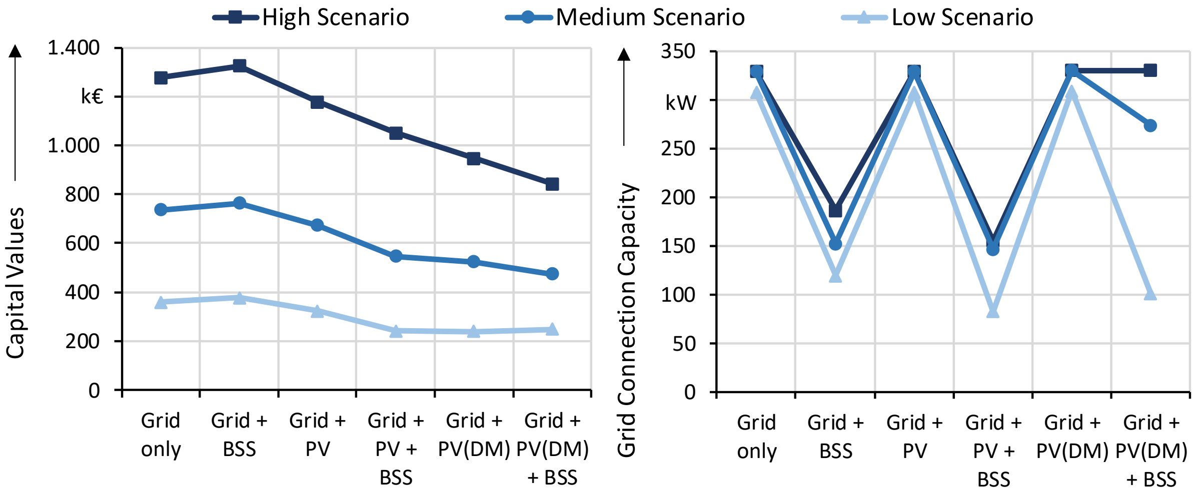

Figure 4: Optimization results for all utilisation scenarios with differing charging park configurations

The results show that by assuming average costs the charging solution with integrated BSS yields no economic advantage without an additional PV plant over the conventional grid only solution. Although the required grid connection capacities in all scenarios can be reduced by 43,3 % to 61,3 %, the added costs of the 150 kWh BSS cannot be compensated by that. With the addition of a PV plant however the integrated BSS leads to reduced costs in all scenarios. In all configurations with the standard feed-in tariff the PV plant is maximized to 100 kWp. Taking the option of direct marketing for the PV plant into account the installed PV plants are increased up to 610 kWp (high scenario), 485 kWp (medium) and 430 kWp (low). As the energy generated by the PV plant is the most cost-effective way to power the charging park, adding a BSS always helps to increase the amount of energy used for internal consumption. For the selected use-case of a small HPC-charging park an installed PV power of more than 100 kWp would be relatively unlikely considering the place needed for such a plant. For that reason, subsequent simulations were focussed on the standard feed-in tariff for plants under 100 kWp. In that configuration the regarded charging solution can reduce the capital value by 17,6 % (high scenario), 25,9 % (medium) and 32,8 % (low) compared to the conventional grid only solution. Compared to the configuration of grid connection and a 100 kWp PV plant, the reductions amount to 10,6 % (high scenario), 18,9 % (medium) and 25,3 % (low).

To analyse the influence of decisive parameters on the overall economic efficiency of the regarded charging solution, the focus in the upcoming examinations was placed on the medium utilisation scenario. As a next step the capacity of the integrated BSS was varied between 50 kWh and 250 kWh to determine whether the chosen dimension of 150 kWh by comparable real systems is economically viable. Figure 5 depicts the results for the configurations grid plus BSS and grid plus BSS plus PV. In order to compare those results, the same configurations without the additional BSS are shown as well.

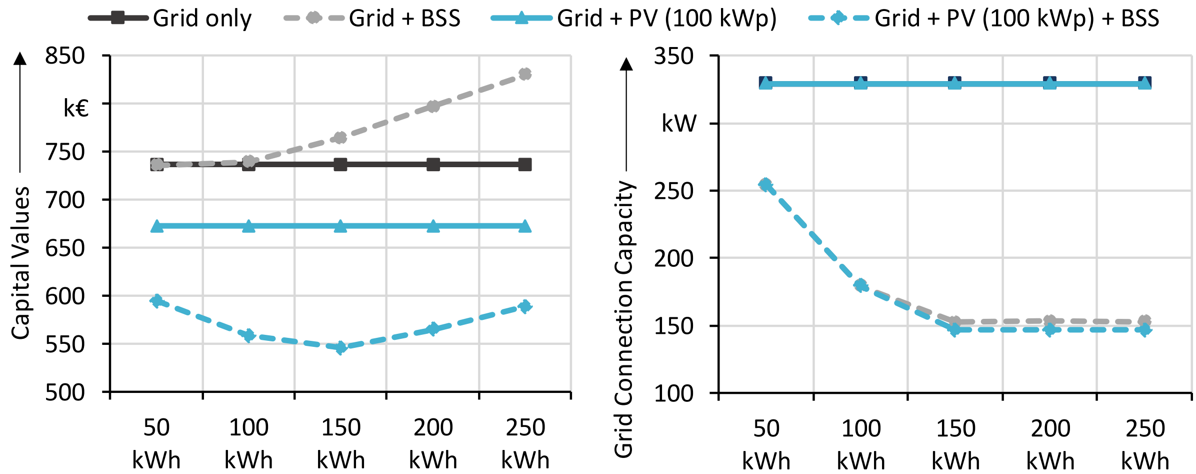

Figure 5: Results for varying BSS capacities (medium scenario)

Regarding the configuration of grid plus BSS, a small sized BSS of 50 kWh can help to slightly reduce the overall capital value. Larger sized BSS cannot compensate the higher component costs although the grid connection capacity can be further reduced by almost 40 %. In combination with a 100 kWp PV plant, the 150 kWh BSS appears to be the optimal solution according to both the capital value, as well as the grid connection capacity (42,4 % reduction), which cannot be further reduced by increasing the BSS capacity.

It becomes clear, that in any configuration without a PV plant, the only cost advantage of an additional BSS lies in the reduced grid connection capacity which means less installation costs and capacity charge payed per year. Apart from that, the overall energy obtained by the grid to power the charging park increases slightly with a BSS due to efficiency losses. Therefore Figure 6 shows the examination results of the effect of differing building cost subsidies (BCS), that account for a great part of the grid connection costs, on the profitability of the regarded system. The BSS capacity is reset to 150 kWh to stick further to the chosen charging solution.

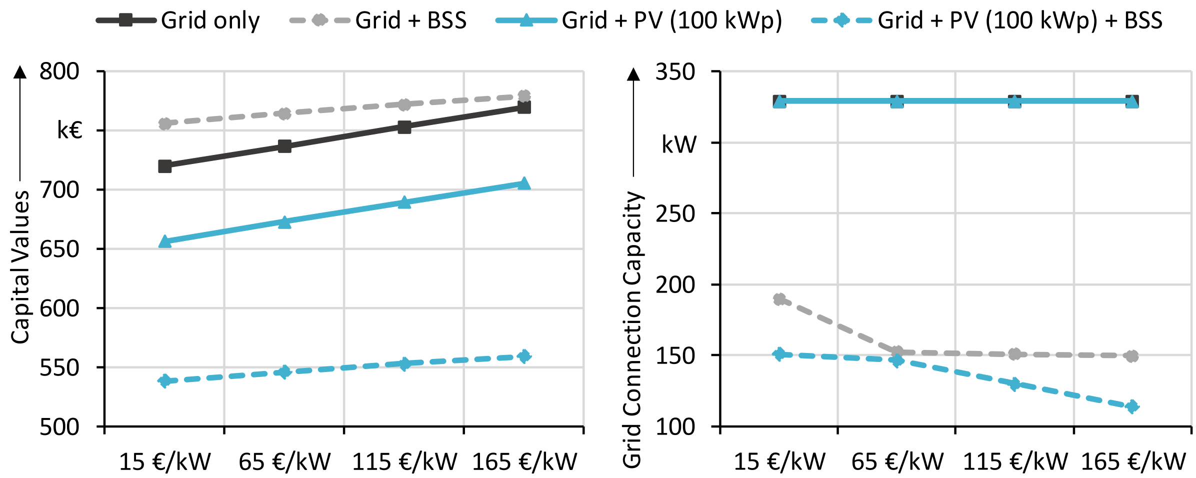

Figure 6: Results for varying BCS (medium scenario)

It can be seen, that in configurations including a BSS, the increase in BCS can be compensated by decreasing the required grid connection capacity, thus increasing the utilisation of the BSS. Nevertheless, even with maximum BCS the configuration of grid plus BSS doesn't yield any economical advantage compared to the grid only configuration. In the configurations with BSS the increase in capital value caused by an increase in

BCS from 15 €/kW to 165 €/kW can be limited to 3,5 % on average while the increase in capital value without BSS is 7,2 % on average.

As the BCS only affects the installation costs of the grid connection, the economic impact of a BSS is limited to this one-time investment cost. However, changes in the capacity charge should have a bigger impact on the profitability of the regarded charging solution, because the BSS can help to reduce the grid peak load which means yearly cost savings. Figure 7 depicts the results for varying capacity charges:

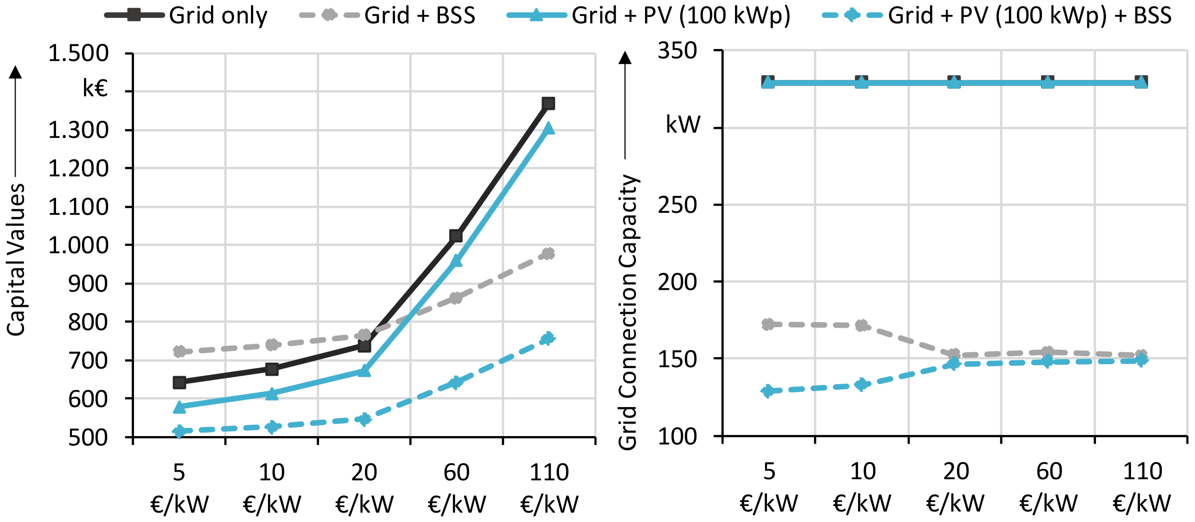

Figure 7: Results for varying capacity charges (medium scenario)

As mentioned in 3.2, the capacity charge is calculated with the yearly 15min-peak load from the grid connection. An additional BSS can help to reduce that peak load, so that the yearly operational costs for the grid connection are reduced. This presumption is confirmed by the depicted results, as a rise in capacity charge greatly increases the economic efficiency of the regarded BSS and in all configurations with BSS the 15min-peak load from the grid connection can be reduced. Even the configuration grid connection plus BSS becomes profitable compared to the grid only solution if the capacity charge amounts to over 20 €/kW. As the grid connection capacity on low voltage level is not directly connected to the capacity charge, the results don't show a correlation between those two factors. In the depicted configurations with BSS the rise in capital value, caused by an increase in capacity charge from 5 €/kW to 110 €/kW, can be limited to 41,3 % on average. In comparison the capital value of the configurations without BSS increase by 119,6 % on average.

To complete the analysis of the grid connection fees, Figure 8 shows the results for varying energy rates:

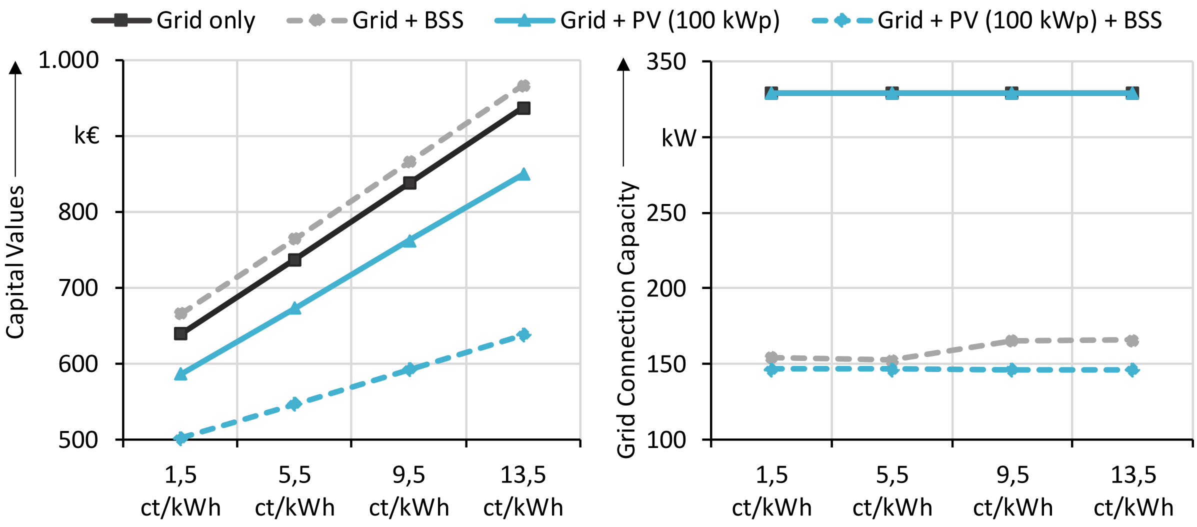

Figure 8: Results for varying energy rates (medium scenario)

In contrast to the capacity charge, the energy rate is calculated yearly with the total amount of energy obtained from the grid connection. As the results show, the effect of the energy rate on the profitability of the BSS is not distinctive because the BSS by itself does not decrease the amount of energy needed from the grid connection. Only in combination with a PV plant, the BSS can help to increase the internal consumption of the PV generation so that less energy needs to be obtained from the grid connection. With a rising energy rate from 1,5 ct/kWh to 13,5 ct/kWh, the increase of capital value in this configuration can be limited to 27,1 % whereas in the other three configurations the capital value uniformly increases by 45,6 %.

The previous results were generated under the assumption of BSS costs of 470 €/kWh (see 3.2). In the use-case of an integrated charging solution, decreasing or increasing BSS costs would either result in decreasing or increasing purchase prices or adjusted BSS capacities. To examine the effect of varying BSS costs on the optimal dimension of the BSS, simulations were carried out, in which the BSS capacity was not predetermined to a certain value. The results are depicted in Figure 9:

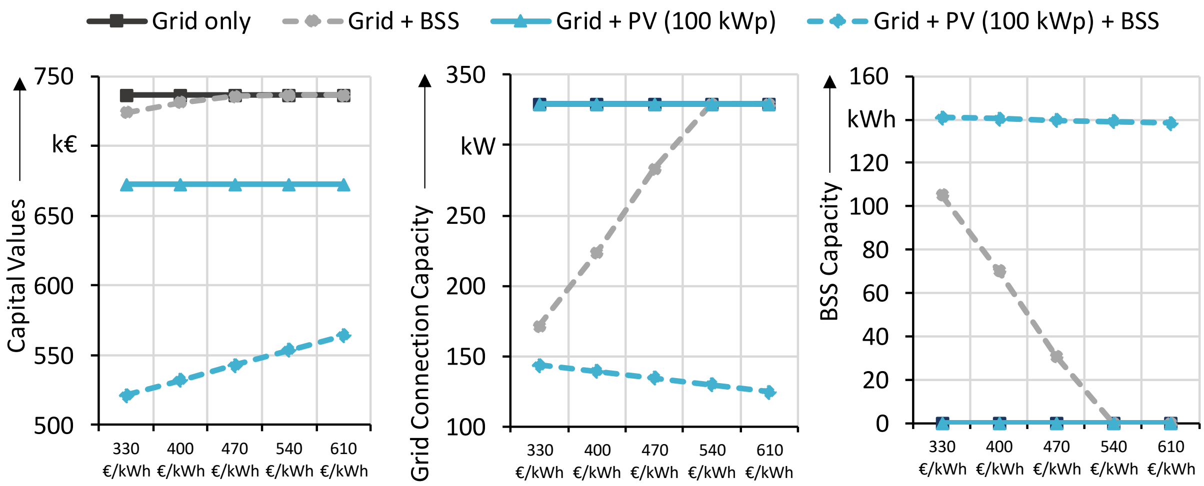

Figure 9: Results for varying BSS costs with completely adjustable BSS capacity (medium scenario)

The results show very clearly, that without a PV plant, larger sized BSS of 70 kWh to 105 kWh are only profitable when the BSS costs amount to 400 €/kWh or below. At slightly higher costs only a small BSS of about 30 kWh can be profitable and above 540 €/kWh the additional BSS is economically non-rewarding without a PV plant. With the addition of a PV plant however, the economic use of a BSS is so big that the BSS costs have no impact on the optimized BSS capacity, which is constantly staying at about 140 kWh. This proves again, as the results in Figure 5 already indicated, that the regarded charging solution with the integrated 150 kWh BSS is relatively well dimensioned when used in combination with a PV plant.

The results 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 10 depicts the results of those simulations for the two relevant configurations that include a BSS. As pointed out in 3.2, the energy charged into the BSS during the provision of reserve power is currently charged with grid connection fees, so that those extra costs have to be taken into account. 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 marked in Figure 10 with the label “No GCF”. The generated results are compared to the results without reserve power provision (compare to Figure 4), labelled “No Reserve Power”.

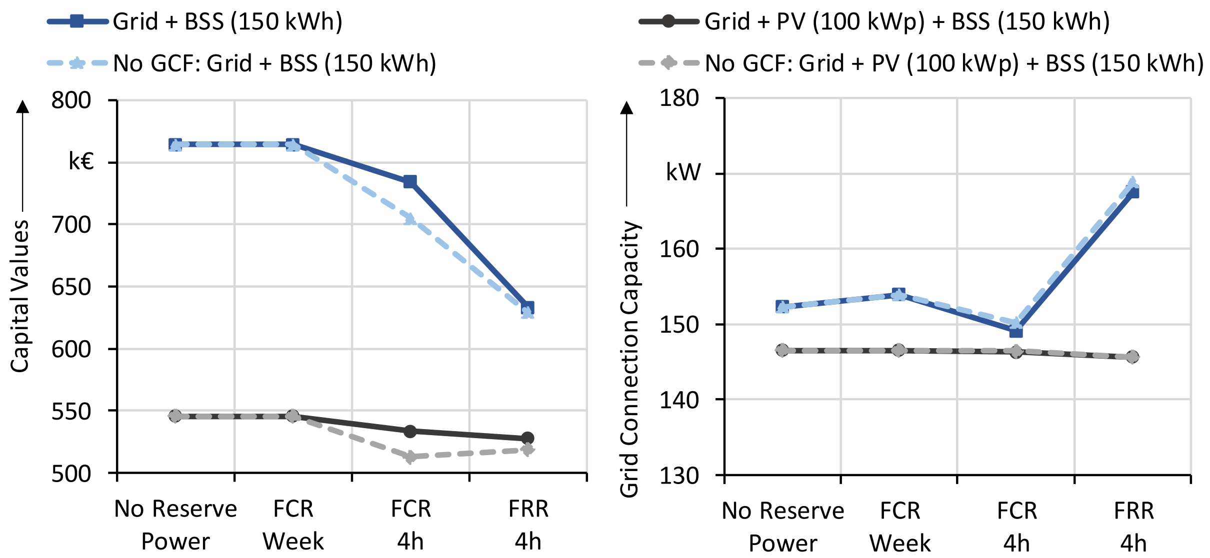

Figure 10: Results for the provision of reserve power with and without grid connection fees (GCF) on the reserve energy (medium scenario)

Initially it can be determined 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 daily operation of the charging park. With the upcoming change of FCR to 4h-products, the provision of FCR becomes profitable in the regarded use-case. Especially in the configuration without a PV plant the BSS can be used primarily to offer reserve power in times of no use, which reduces the capital value by 3,9 %. 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. Nevertheless, even in that configuration the capital value can be reduced by 2,2 %. If the provision of FRR would be authorized for BSS, this would present a highly profitable option for charging park operators as the results show. Particularly the configuration without PV plant again yields high potential, resulting in a reduction of capital value by 17,1 %. In combination with a PV plant the capital value can be decreased by 3,3 % by offering FRR. The obligatory grid connection fees especially have an impact on the economic efficiency of the provision of FCR as the simulations without GCF show. The reason for that is that FCR is offered as a symmetrical product (see 3.2) 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 3.2), so that extra costs caused by GCF can be avoided which reduces the economic impact of GCF on the provision of FRR. Without the obligatory GCF the capital value can be reduced by providing FCR by 7,7 % (without PV plant) and by 6 % (with PV plant).

5 Conclusion and discussion

The goal of this paper was to analyze a specific, close to the market HPC charging solution with an integrated BSS on its overall economic efficiency in consideration of the provision of reserve power as well as the variation of decisive parameters. As a use case a charging park with two 150 kW HPC chargers and a 150 kWh BSS, located in the catchment area of a German city was selected. With this charging park configuration, the maximum number of xEVs that could be charged per day without having to reject serving further vehicles was calculated to 19 xEVs. 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. However, in combination with a PV plant of a maximum size of 100 kWp, the integrated BSS can help to increase the self-consumption of PV generation by the charging park, reducing the overall capital value by up to 25 % (see Figure *4*). For further investigations a scenario of medium utilization for the charging park was chosen. It was calculated that in combination with a PV plant of 100 kWp the capacity of the integrated BSS is relatively close to an optimum of 140 kWh. Without consideration of a PV plant and under the assumption of average BSS costs of 470 €/kWh only smaller sized BSS of up to 50 kWh can be economically efficient (see Figure *5*). Only when assuming BSS costs of 400 €/kWh or below, bigger sized BSS of up to 105 kWh become economically viable without additional PV plant (see Figure *9*). Further results show that the effects of a high BCS (up to 165 €/kW) can be mitigated with an additional BSS by decreasing the required grid connection capacity, but even under that circumstances the regarded 150 kWh BSS could not present an economic advantage over the grid only configuration (see Figure *6*). The effect of both grid connection fees (capacity charge and energy rate) was analyzed but only the capacity charge proved to have a decisive impact on the profitability of the integrated BSS: Under the assumption of high capacity charges of up to 110 €/kW, the capital value could be decreased with the integrated BSS by 29 % for configurations without PV plant and by 42 % for configurations with PV plant (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. However, with the foreseeable introduction of 4 h products for FCR, capital value reductions of 4 % (without PV plant) and 2 % (with PV plant) could be realized. If the provision of FRR would be authorized for BSS, it would present a highly profitable option with capital value reductions of 17 % (without PV plant) and 3 % (with PV plant) (see Figure *10*). The provision of reserve power proved to always yield a higher economic efficiency for configurations without a PV plant, because in those the BSS is not primarily used to store the PV generation and the margin for reserve power provision is higher. Furthermore, the results showed that the obligatory grid connection fees have a higher impact on the profitability of FCR, because of the symmetry of FCR products which makes grid connection fees currently unavoidable for providers of reserve power by BSS.

Future examinations should include the analysis of further charging solutions, as for example charging stations with integrated power management systems that dynamically distribute the power between two or more charging points depending on the amount of vehicles charging simultaneously. Furthermore, charging solutions with integrated PV systems as a roofing could be a research object to create a use-case with a more realistic assessment on the PV topic in terms of actual building space available.

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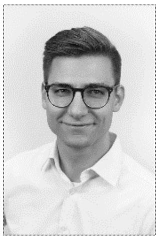

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