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Utilizing Local Flexibility Resources to Mitigate Grid Challenges at Electric Vehicle Charging Stations

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Abstract: Charging of electric vehicles (EVs) on a large scale can cause problems for the grid. Utilizing local flexibility resources, such as smart charging, stationary battery, vehicle-to-grid applications, and local generation can be an efficient way to contain the grid challenges and mitigate the need for grid reinforcement. Focusing on the INSPIRIA charging station located in Norway, this paper investigates the possibility of coping with imminent grid challenges by means of local flexibility. First, the potential grid challenges are estimated with the help of Monte Carlo simulations. Second, cost and performance for the various local flexibility sources are presented. Third, an analysis of the choice of battery, charging process, and battery economy are provided. Finally, the paper discusses the optimal mix of flexibility resources to efficiently mitigate grid challenges at the INSPIRIA charging station.

Keywords: electric vehicles; grid challenges; flexibility; local storage

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1. Introduction

Electrification is considered an attractive solution for mitigating climate change [1]. In many countries, electrification of transport is seen as a key instrument for reducing carbon emission, and thus, stringent and ambitious targets have been set [2]. In Norway, electrification of personal transport has been paid particular attention. Exhibiting a strong governmental support through, e.g., tax exemptions and various benefits targeting drivers of electric vehicles (EVs), Norway is the world's leading country considering EVs per capita [3]. Impressively, the total market share of purely electric and chargeable hybrid vehicles combined is dominating the sales of new cars in Norway, reaching an all-time high of 79% during the first quarter of 2021 [4].

However, the intensive growth in the number of EVs poses challenges to the grid operation. Earlier research has investigated some of the challenges associated with EV charging and proposed solutions to those. Indeed, as pointed out by [5], the increased capacity needs, and particularly in relation to fast charging and unpredictable EV drivers' behavior, can create operational challenges for grid operators. In [6], power loss, grid unbalance, reduction in transformers' lifetime, voltage profile and harmonic distortions have been referred to as the main problems caused by uncontrolled EV charging. Expansion of the grid infrastructure as a solution to the grid challenges has been discussed as an expensive solution to which flexibility can be a good substitute [7]. Thus, the possibility to utilize upon various sources of local flexibility—such as, coordinated/smart charging, storage, and local generation—has been paid attention to in previous literature.

The study of [8] compares different management strategies, which aim to minimize the impacts of integration of EVs into grid system and claims that centralized coordination can effectively resolve EV-associated grid issues when the addition of smooth power from renewables is included in the system. The use of centralized coordination has earlier been supported by the research work of [9] where it was shown that the location of the vehicles is an important factor for predicting adverse grid impact and that the coordinated charging solution could allow 3 to 6 times higher EV penetration as compared to uncoordinated charging. The possibility to relieve EV-charging-induced grid problems through smart charging has been investigated and trialed in [10] and [11], concluding that smart charging is a good option to help withhold grid constraints and avoid high-capacity tariffs, with the approach being particularly beneficial during winter periods.

Furthermore, different studies have focused upon the possibility to utilize upon local generation and local storage to alleviate grid problems caused by EVs. The work of [12] proposed the utilization of home photovoltaic system for charging of EVs, arguing that, given that EVs are compatible with the dc fast charging CHAdeMO standard, the high penetration of EVs can effectively improve the self-consumption of the photovoltaic systems. The research of [13] proposed an optimization model for grid-connected photovoltaic/battery energy storage/electric vehicle charging station to size PV and battery energy storage system and determined the charging/discharging pattern of the battery. In [14], an algorithm to optimally size the PV, battery, and grid transformer for an electric vehicle charging station circumscribed by grid constraints was developed. It was shown that applying the algorithm described in [14], it is possible to accurately find the optimum values for the specific charging station elements, which will optimize the loss of load as well as the energy. In addition, when it comes to the economic benefits of utilizing solar and wind energy installation at electric vehicle charging stations, the research work of [15] showed that it can cause a reduction of up to 7% in the tariff for the sale of energy to EVs.

This paper refers to the potential capacity-related grid challenges that can arise given that the charging demand at the INSPIRIA charging station situated in Norway has increased and how the challenges can be mitigated by means of local flexibility resources. Indeed, with the Norwegian government's ambition that all new cars sold by 2025 should be zero-emission (fully electric or hybrid) [3], the number of EVs in the country is going to grow significantly. On the other hand, performing empirical analysis based on detailed data from all Norwegian distribution system operators (DSOs), the research carried by [16] concluded that an increase in the EV stock is associated with a positive and statistically significant increase in the DSOs' costs. In the study of [17] a statistical analysis of electrical vehicle charging was performed. It was found out that the energy peak brought by EV charging from the grid was between 7 and 10 a.m. when EV users came to work. Additionally, while the charging stations delivered most of the energy to all EVs during the daytime, it was further suggested in [17] that the peak load could be offset by installing PV panels and solar systems.

In the context of earlier research in the field, this work focuses on the possibility of efficiently mitigating grid challenges caused by the growing in number and capacity changing facilities at the INSPIRIA charging station. In particular, the paper discusses how an optimal combination of different local flexibility resources could alleviate potential grid problems. To answer this question, the rest of the paper is structured as follows: Section 2 describes the INSPIRIA charging station with its envisioned challenges and discusses the different flexibility resources that can be utilized locally in order to balance the high-capacity needs stemming from EV charging. Section 3 discusses the optimal combination of flexibility resources and analyzes the choice of battery, its size, and economy. Section 4 discusses the results, reflecting upon timeline of local flexibility resources utilization at the specific charging station. Section 5 concludes the discussion.

2. Materials and Methods

2.1. The INSPIRIA Charging Station

The name of the INSPIRIA charging station originates from the nearby science center—the INSPIRIA Science Center. The charging station organizes different charging offers, and approximately 200 parking spots are located at its vicinity. Currently, the charging station offers 2 chargers of 50 kW and 6 chargers of 22 kW. The initial plans for the future extension of the charging infrastructure include 1 superfast charger of 300 kW and 32 chargers of 22 and 50 kW. However, further installation of superfast chargers might be of interest and are, thus, part of the simulations carried prior to this work. In addition, the following flexibility resources are envisioned to help alleviate the EV-charging-associated problems in the local grid:

- Rooftop PV panels at the INSPIRIA Science Center;
- Battery storage at the INSPIRIA Science Center;
- Demand response at the INSPIRIA Science Center;
- Smart charging;
- Vehicle-to-grid/vehicle-to-building (V2G/V2B) applications.

In similarity to [18], Monte Carlo simulations have been used to find the daily charging profile under different scenarios considering the deployment of superfast charger(s) at the charging station. The results of the simulations are presented in detail in [19], where a simulation model has been developed for the INSPIRIA Charge Court based on empirical material from Fortum Charge and Drive [20]. The results presented in [19] indicate that, considering today's visitor numbers and a fast charger of 300 kW, the power output is below the maximum grid limit of 500 kW. However, the operating speed of the superfast charger becomes a limitation as the number of visitors increases. Additionally, when 8 charging points, including the 300 and 50 kW chargers, are used at the same time, the probability that the physical limit of 500 kW is exceeded will be close to 100% [19]. Finally, if more than one supercharger is to be installed at the INSPIRIA charging station, the grid limits will be exceeded posing major challenges to the grid operation. Next, this paper will focus on how flexibility resources can help mitigate the impact of increased maximum load at the charging station caused by increased demand for charging and the usage of superfast chargers.

2.2. *Utilizing Local Flexibility Resources*

The INSPIRIA charging station is organized so that flexibility from several sources (demand response, local storage, and EV charging) is consolidated and aggregated to the greatest possible extent. The main goal is to put together a concept that provides good opportunities to control, shift, and reduce the load in the local electricity system. At the same time, it is important to keep operational and investment costs down. For the purpose, an economically sound mix of local flexibility resources is highly desired.

2.2.1. Smart Charging

Smart charging can assist that process by charging long-term parked cars in a flexible manner, avoiding peak load periods. However, smart charging cannot be practiced for superfast charging, as the time is very limited, but to reduce the power to 150 or 100 kW during very critical periods may be seen as an alternative. Currently, very few cars are able to charge at a rate above 100 kW [19]. Yet, the common idea is that superfast charging will get more common in the future, thus posing even more challenges to the grid limits. Additionally, while the attractiveness of a superfast charger stems from the possibility to charge in a very short period, the option to decrease the power capacity of such charges for the benefit of smart charging should be seen as a rather unproper option. Furthermore, superfast charging should also mean "no waiting line", as time is of the essence for those using it. Thus, as provided in [19]'s simulation analysis, the superfast charging alternative is considered as "non-dispatchable" and is given first priority, so that smart charging will target the 50 and 22 kW alternatives.

2.2.2. Battery Energy Storage

To analyze the usage of battery energy storage in the flexibility mix, attention has been paid on two approaches for battery charging—"opportunity" charging and "depot" charging. The first means that a battery is charged at the first available opportunity. It requires a smaller energy capacity. The requirement for ampere hours is reduced (high power density relative to energy density). This implies cost saving. The second involves a larger battery with sufficient capacity to provide load reduction for an entire day before charging. The advantage of this type of charging is that the number of charging cycles is greatly reduced as compared to the first alternative. The battery lifetime and, thus, also the payback time for the investment will change accordingly. With reference to the analysis carried out by [21], it is considered that for the INSPIRIA charging station case "depot" charging is more favorable than "opportunity" charging. This means that the battery that is installed is only charged once a day, thus setting requirements for the battery's technical specifications. The specific method for the calculation of flexibility profit related to the battery under a capacity tariff regime is presented later in Section 3.2.1. The method sets the grounds for the analysis performed in Section 3 where the decision behind the choice of battery is also explained.

It has been shown that battery costs have fallen sharply in recent years [22] and are expected to fall further in the coming years [23]. Additionally, while the prices for Li-ion batteries may experience temporary increases due to the car manufacturers' growing interest in e-mobility, prices for redox/flow batteries are to fall further. The degradation factor is almost negligible for these battery types, and the payback time can, thus, be made longer. It is, therefore, highly probable that a suitable battery for an INSPIRIA charging station could cost less than 3000 NOK/kWh in a couple of years. Thus, flexibility based on batteries can advantageously be performed step by step and in line with the growth in demand.

2.2.3. Vehicle-to-Grid and Vehicle-to-Building Applications

During recent years, the prices for V2G/V2B chargers have fallen sharply, and a continuation of this trend can be expected. However, the argument on shortening the car battery's lifetime due to V2G/V2B applications, as exposed in, e.g., [24], is still present. According to [21], the envisioned depreciation of the battery is marginal in comparison to normal use. Some sources even claim that charging/discharging related to V2G could extend the battery's lifetime [25]. In this paper's context, a marginal cost per kWh that partly overlaps the costs for ordinary batteries is used (see Table 1). This is due to the fact that only the extra costs for charging points that handle V2G/V2B as well as some "wear and tear" of the cars' batteries are being considered.

Table 1. Cost and performance for various flexibility resources.

Flexibility Resource	Flexibility Potential (kW)	Maximum Duration of Flexibility (Hours)	Cost (NOK/kWh)
Demand response (in-house flexibility at the INSPIRIA Science Center)	20–30	1–2	<500
Smart charging	TBD	1–3	1500–3800
Battery energy storage	TBD	TBD	5000–7500
V2G/V2B	30–45	1–3	5000–8000

2.2.4. Solar Panels at the INSPIRIA Charging Station

Since the panels' production and possible role in the period November–March are very limited, the solar panels should be considered differently than the other sources of flexibility. The combination of solar panels and battery is seen as an ideal solution. However, as the INSPIRIA charging station can import electricity from the central supply at low prices (down to 30 øre) during all off-peak hours of the month, the photovoltaic system can have two primary functions: first, increasing the customer's attractiveness to the charge court by promoting sales of locally produced renewable energy, and second, acting as a life-prolonging measure for the installed battery pack. The last relates to the possibility to channel electricity directly from the PV installation to the chargers, thus reducing the number of charging cycles in the summer and extending the life of the battery. In this way, the capitalization effect of the investment is increased [21].

3. Results

3.1. Optimal Mix of Flexibility Resources to Support the INSPIRIA Charging Station Operation

An overview of cost and performance for the various flexibility resources at an INSPIRIA charging station is presented in Table 1. There, the cost of the V2G option includes the extra cost for the V2G charger, while the smart-charging-related cost is subject to discounts given for those who charge flexibly (10–30%). Of course, other methods can be used to estimate the costs.

The marginal costs for smart charging at the INSPIRIA charging station are lower than the 5000–7500 NOK/kWh values, which are indicative prices for current battery installations. However, the volume for smart-charging-associated flexibility is limited. A strategic proposal should, thus, be to dimension a battery with a capacity that can cover the need for the next few years until the INSPIRIA charging station is able to mobilize a sufficient smart-charging-based flexibility volume. The future need for load control can then be covered by smart charging and, thus, with limited investments in additional battery capacity. This is where the charge court concept can meet the future better than more traditional charging stations.

Thus, with reference to the above provided discussion, the INSPIRIA charging station is to utilize several flexibility resources with demand response (in-house flexibility), smart charging, and battery energy storage appearing to be the most affordable alternatives by 2022.

3.2. Strategy for Choice of Battery

The simulation results attained in [19] indicated fluctuating demand during the day (Figure 1). To alleviate the peak loads (as visualized on the right-hand side in Figure 1 given a future situation with increased demand), the choice between "opportunity" and "depot" charging presented in Section 2.2.2 has been evaluated. Clearly, such an increase in demand will lead to an exceedance of the grid limit of 500 kW calling for the utilization of local flexibility sources to avoid or postpone grid investments.

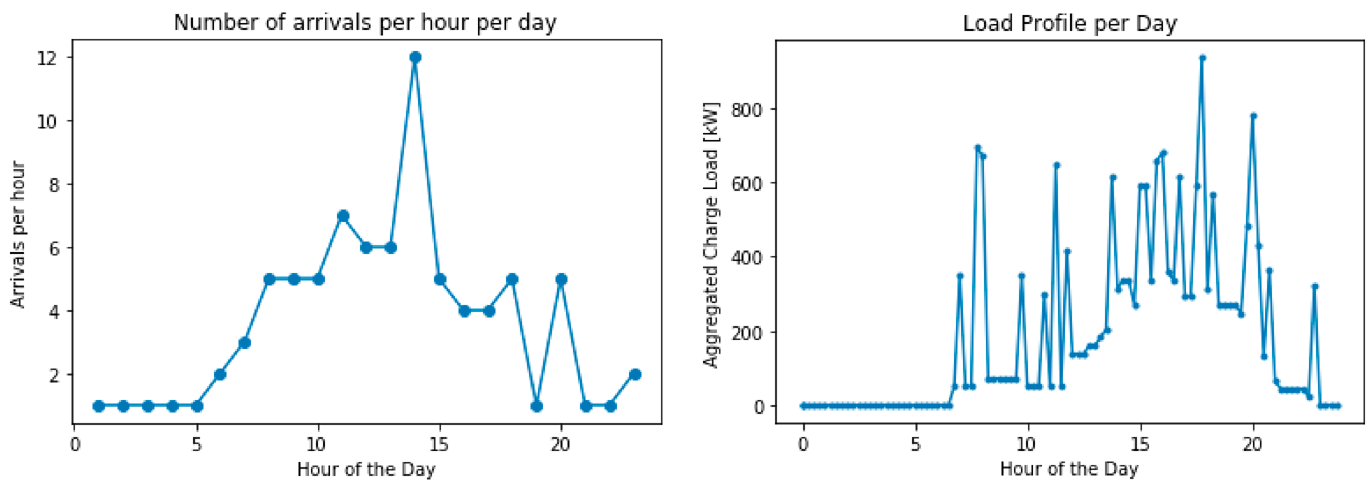

Figure 1. Results from the simulations carried in [19] showing arrival rates in one day (graph on the left) and estimated loads as a consequence of this type of arrival pattern (graph on the right). Here, an example of a future situation where demand is 4 times higher than today and where this demand is met with an extra superfast charger of 300 kW is presented.

In the process of battery type evaluation, the importance of long lifetime of the battery and the respective payback period of the investments is high. The method used in the process is presented in Section 3.2.1 below.

3.2.1. Calculating of Flexibility Benefits under a Capacity Tariff Regime

In recent years, capacity tariffs have been discussed as more cost reflective and fair compared to the fixed network fees [26]. Additionally, while the usage of capacity is to become more common, battery storage could help to minimize the capacity-tariff-associated costs. In this context, this subsection is to provide an approach to define the profitability of investment in battery storage by jointly considering the potential cost savings (as associated with capacity tariffs) and the battery capacity requirements. The mathematical representation is as follows:

$$R_T = P_{\max}, T - x,\ P_{\max,T} > x \tag{1}$$

R_T is the capacity requirement for the battery;
$P_{\max,T}$ is the maximum capacity used per time period T (month);
x is the demanded maximum.
Cost saved in relation to capacity tariff:

$$\Delta C_T = R_T * c_T \tag{2}$$

The possibility to bear a lower cost by using a battery (or another flexibility source) in the same time period T to attain the capacity requirement

$$R_T = P_{max,T} - x \tag{3}$$

will lead to capacity and energy savings during the same time period.

The necessary battery capacity measured in kWh without charging in the period T is then:

$$E_{B,T} = \int_0^T (P(t) - x)dt,\ \ P(t) >= x \tag{4}$$

The investment needed to cover the capacity needs $E_{B,T}$:

$$I = p_{B,kWh} * E_{B,T} \tag{5}$$

The cost of using the battery without degradation is calculated as follows:
First, the lifetime L is to be calculated:

$$L = \frac{\text{maximum number discharging cycles}}{\text{number discharging cycles per year}} \tag{6}$$

The battery cost for the period T then is:

$$C_{B,T} = I * \frac{i_T}{1 - a} \tag{7}$$

where $a = (1 + i_T)^{-L*T}$, $i_T = \frac{\text{interest rate}}{100*T}$ represents the investment interest rate during the period.

Thus, there should be a requirement that

$$\Delta C_T \geq\ C_{B,T} \tag{8}$$

so that the investment in battery is profitable. Here, it is possible to find x, which is the maximum limit that can be profitably maintained by means of a battery.

3.2.2. Load Requirements and Type of Charging

The expected load requirements at the INSPIRIA charging station, as based on the arrival rates presented earlier in Figure 1 and considering the possible utilization of a battery, are to be illustrated next. In addition, this section will discuss the choice of charging type (i.e., opportunity or depot charging). The analysis to be presented is a continuation of the simulation-based study performed in [19]. The data used in the simulations originate from [4] and [20]. In addition, cost data from the local DSO have been utilized. The simulations carried consider different future situations where the demand for EV charging, and, respectively, the requirements for maximum load in the system, increase. The results obtained have been illustrated in Figures 2–8. Unlike the study provided in [19], here, attention is paid to the utilization of battery storage, and the simulations' results presented below reflect the specificities of battery usage given the requirements and conditions at the INSPIRIA charging station.

If opportunity charging is used, the number of full charging/discharging cycles with respect to the maximum load demand is presented in Figure 2. An amount of 500 kW is the absolute maximum due to the grid capacity limit at the INSPIRIA charging station. Thus, the "maximum load requirement" refers to criteria set where the EV charging demand (as associated with an increased number of both EVs and charging facilities) is covered without going above the 500 kW grid limit. With higher load requirements, the number of charging/discharging cycles decreases. Thus, the higher the load, the closer opportunity charging will come to depot charging.

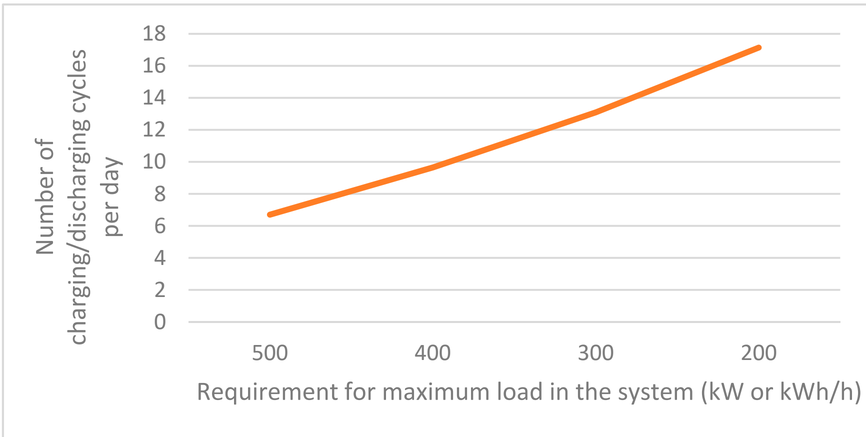

Figure 2. Opportunity charging: Number of charging cycles per day as a function of the load requirement stemming from the EV-charging-associated demand. The graph is based on the rainfall method described in [21].

Undoubtedly, the importance of an increased battery lifetime and the respective change in the payback period is huge. With opportunity charging, a battery with a power capacity of 100 kW will have its life reduced by almost 10 years, according to the calculations made due to 5–6 more charging cycles per day than depot charging. Here, again the rainfall method is used. Thus, a battery with a lower capacity and with more daily discharges becomes less attractive, even if the CAPEX ratio should be favorable in relation to depot charging. It should be pointed out, however, that the difference between opportunistic charging and depot charging is gradually erased the greater the demand for power reduction is. In further work, depot charging is used as a basis. This means that a battery is selected, which is charged only once a day. The arguments in favor of this choice are better elaborated upon below, where the rapid depletion of the battery's lifetime as a result of a high number of charging sessions has been referred to.

Figure 3 illustrates the relationship between the battery's lifetime and the maximum load requirements. Again, the requirement for maximum load refers to the EV-charging-associated demand (based on both more EVs and more charging facilities), with an upper grid limit set to 500 kW. Looking jointly at Figures 2 and 3, it is made clear that the lower the maximum load requirements are (and the lower the battery's capacity), the more charging cycles will be performed at INSPIRIA, and the shorter the lifetime of the battery will be. Thus, given a battery lifetime that includes 6000 charging cycles for a battery size of

100 kWh, the battery lifetime could be depleted in one year given the frequent peaks (see Figure 1—right-hand side) that need to be covered at the charging station during the day.

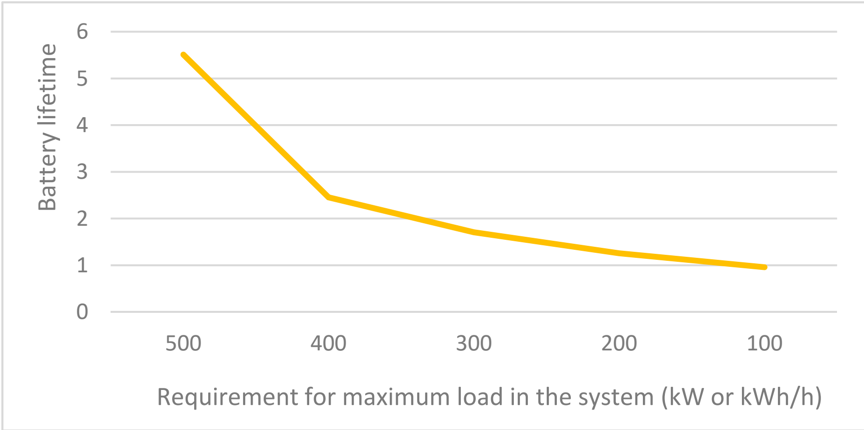

Figure 3. Reduced lifetime due to increased requirements for maximum load—consequence of increased number of charging cycles per day (as illustrated earlier in Figure 2).

3.3. Requirements for the Battery—Size and Economy

With depot charging, the battery will typically not be charged during normal office hours when demand is greatest. Charging during high demand hours would lead to a significant reduction in the battery life and, thus, a change in the requirement for the payback period. This, in turn, will lead to higher annual costs. A related measure would be to use solar panels as the primary supply during the high load periods in the middle of the day during the summer. The solar panels will help to relieve the battery. In this way, the life of the battery could be significantly increased.

NOK 6000 per kWh was used as a cost norm for batteries in 2020 when a major part of this analysis was carried out. Based on the economic considerations described in Section 3.2.1, one can approximate the relationship between demand, battery cost, power reduction requirements, and battery capacity measured in kWh for a battery that will provide a favorable economic gain for the INSPIRIA charging station.

By simulating load situations as a function of demand, it is possible to obtain relevant load profiles that will provide a basis for estimating a battery capacity that will be able to give a positive economic result. The ratio between maximum peak and average consumption is important. A battery investment will pay off better if it manages to eliminate a peak without "scraping off" the rest of the bottom load (Figure 4).

From what can be observed in Figure 4, it could economically make more sense to use a battery to reduce power (kWh/h) rather than energy (kWh). Here, economic gains can be achieved by cutting peaks, while the cost is generally related to energy capacity. The curve shown in Figure 4 provides the average load profile values for the INSPIRIA charging station and shows an example of curtailment that can be handled by the battery with a gain.

It is the storage capacity of the battery and its cost that determine the power-reducing function of the battery. The higher the power reduction requirements, the larger the storage capacity needed (Figure 5). Normally, loads over several hours should be reduced or eliminated in order to achieve a grid capacity tariff gain. The investment costs for the battery based on a unit cost (NOK/kWh) must be less than or equal to the tariff gain that can be achieved per month with such an investment.

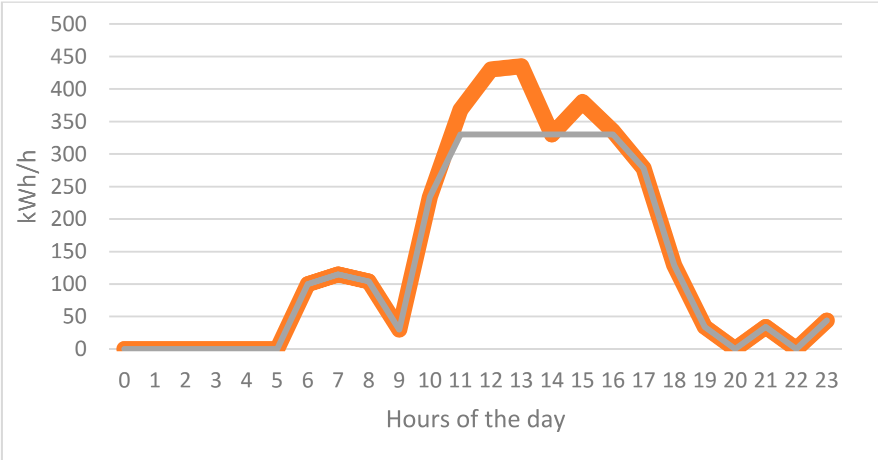

Figure 4. Average daily load profile at the INSPIRIA charging station (orange line) versus a daily profile where battery storage has been utilized (grey line). The storage-enhanced load reduction is represented by the difference between the orange and the grey line.

Figure 5 shows the relationship between demand, power reduction, and economy for a battery cost of 6000 NOK/kWh. As it can be seen from the dashed line in the graph (representing an average of several simulations), a unit price for the battery of 6000 NOK/kWh will be able to justify reductions in the order of 50–100 kW (kWh/h). However, the specific requirements vary with the demand.

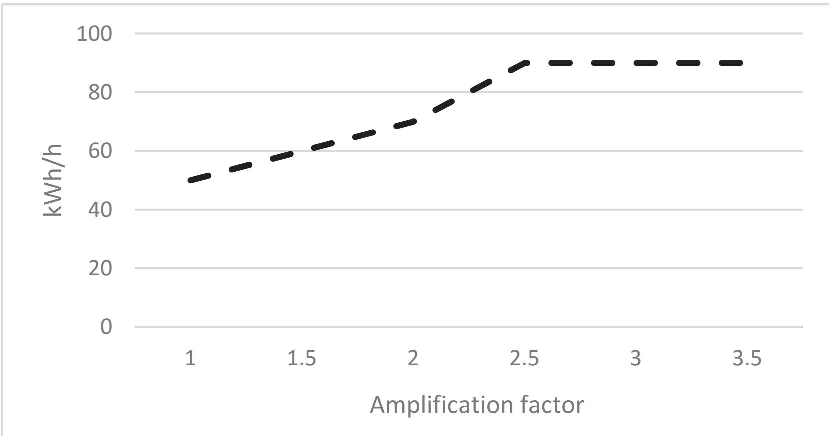

Figure 5. Battery capacity requirement under different demand levels given a battery cost of 6000 NOK/kWh. Amplification factor 1 means the current situation, while 2 refers to a situation where demand (as associated with the arrival rate in each hour) is doubled.

Figure 6 shows a similar ratio as in Figure 5, but with a focus on energy measured in kWh. It shows that a battery capacity of 200–325 kWh can be defended economically with a unit cost of 6000 NOK/kWh. In the vast majority of cases, such a battery capacity will also be sufficient to charge only once per day outside the high load period. If you look at Figures 5 and 6 together, for an amplification factor of 2 it is possible to reduce all load peaks by up to 70 kW in one day. In general, one can conclude that a 500 kWh battery will be able to handle a demand growth of over three times the current level 95% of the time.

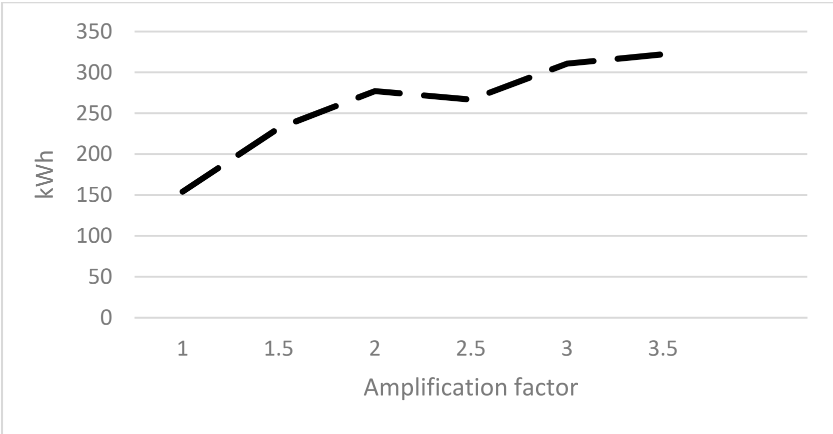

Figure 6. Battery size measured in kWh as a function of different demand levels presented by an amplification factor. Amplification factor 1 means the current situation, while 2 refers to a situation where demand (as associated with the arrival rate in each hour) is doubled.

Referring to the graphs illustrated in Figures 5 and 6, which both represent the average of several simulations, attention should be paid to both the exhibited saturation and the observed change at, e.g., amplification factor 2.5. Several reasons can explain the observed trends. First, it should be noted that the amplification factor is estimated based on the effects of future sales and the future development of charging services in Norway. The extrapolation on the arrival rate is a linear function of the expected sales and service offers. The dip in Figure 6 is, thus, partially related to the prognoses at the time of performing the simulations. Another impactful issue has been competition. The prognoses made at the time of the simulations considered that more service offers with more capacity would eventually be established along the road where the INSPIRIA charging station is located. These expectations, incorporated in the simulation scenarios, also justify the saturation effect. Furthermore, the ratio between the number of service facilities and number of EVs changes over time, in favor of EVs. In the course of the simulations, a change in the overall EV fleet has also been anticipated. Based on the estimated life of an EV, it was found that at some point there would be an increased demand for bigger EVs where EV drivers move from Nissan Leaf and Mitsubishi i-MiEV to, e.g., Audi and Jaguar. All the above specificities determined the weighting of different parts of the original probability distribution (needed service time and demand per hour) for arrivals and, thus, the effect of the amplification factor. Finally, because of the included stochastic elements, a spillover effect could be observed when several EVs arrive at the same time. In this case, EV drivers would rather move to another service facility (if available) than wait.

In addition, the price of the battery will be crucial to achieve a significant power-reducing gain. The results from the simulations with different amplification factors where the relationship between load reduction and battery prices is investigated is shown in Figure 7. As it can be seen from the graph, demand has a certain significance. However, it is the unit cost of the battery that gives the greatest impact. If the battery price falls below 4500 NOK/kWh, there is an exponential development. This is primarily due to the fact that the energy storage will to a greater extent be able to shave off secondary peaks, which often are far more than the largest. Further, Figure 8 illustrates the relation between the increasing demand, energy capacity, and the battery unit cost. A similar major difference for a battery unit cost below 4500 NOK/kWh can be observed. The simulation-based data used for generating Figures 7 and 8 are reflected upon later in Section 4.

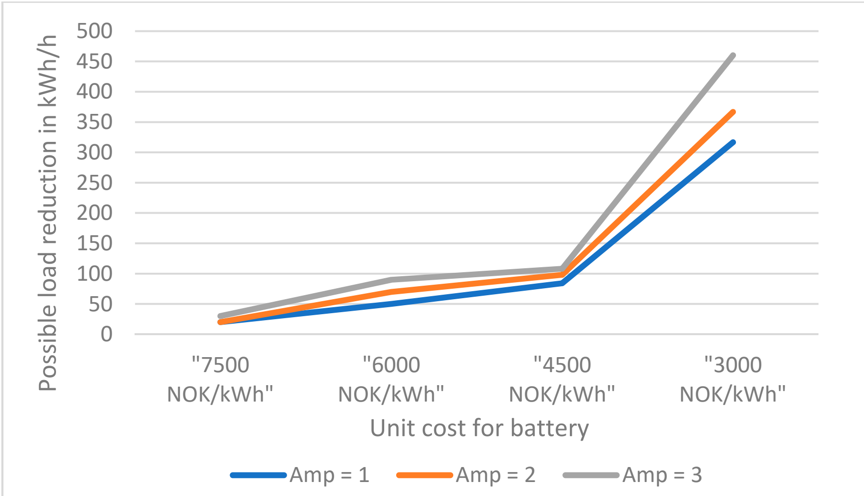

Figure 7. Possible load reduction as a function of the demand (amplification factors 1, 2, and 3) and the battery cost.

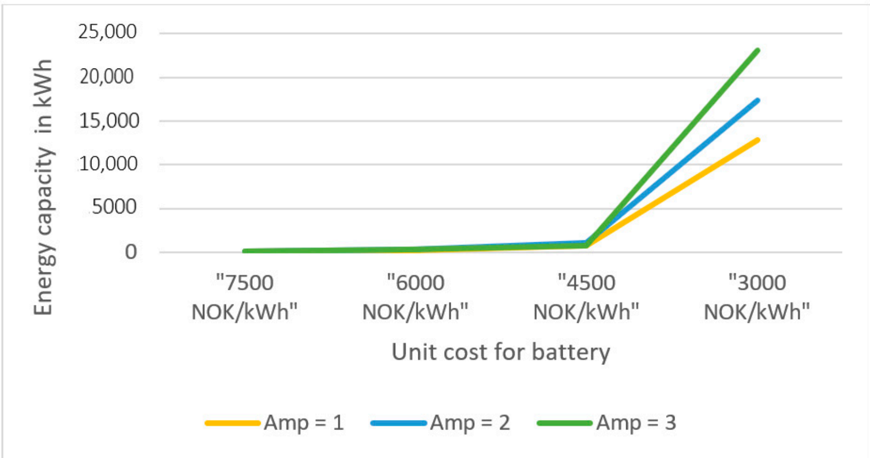

Figure 8. Energy capacity as a function of the demand (amplification factors 1, 2, and 3) and the battery cost.

From the results presented so far, it can be concluded that a small capacity battery with a limited amount of energy available can only take on small and infrequent peaks, while a bigger battery can do more. With a lower unit cost, there is a possibility to utilize more capacity, which again yields a higher gain. Additionally, with a lower battery unit cost, more peaks can be handled. Thus, it can be concluded that, considering the simulation results where different battery sizes, type of charging, and battery unit costs have been evaluated, a larger size battery (of, e.g., 500 kWh), depot charging, and battery unit cost of below 4500 NOK/kWh are most preferable for the needs exhibited at the INSPIRIA charging station.

4. Discussion

Clearly, the size and ability of the energy storage to reduce peak loads caused by EV charging is primarily conditioned by the unit price. The demand ratio is less important until the battery cost falls below 4500 NOK/kWh. The numerical basis for the graphs in Figures 7 and 8 (as originating from the simulation results) is shown in Table 2, where a unit cost down to 3000 NOK/kWh is presented. At a unit price for a battery of less than 2000 NOK/kWh, such an investment will always pay off. This will also apply to other forms of power-reducing measures. Based on this, one can also make conclusions about "smart charging" and V2G/V2B. If the comparable cost for these alternatives can be kept lower than 4500 NOK/kWh, these should always be used in front of a battery and utilized to the maximum.

Table 2. Battery unit cost versus the possibility to match power and energy requirements at the INSPIRIA charging stations—used as input to Figures 7 and 8. Increasing demand, as represented by amplification factors 2 and 3, has been considered.

	Power (kW)	**Power (kW)**	**Power (kW)**	**Energy (kWh)**	**Energy (kWh)**	**Energy (kWh)**
Cost per kWh	Amp = 1	Amp = 2	Amp = 3	Amp = 1	Amp = 2	Amp = 3
7500 NOK/kWh	20	20	30	30.4	37.6	54
6000 NOK/kWh	50	70	90	154	277.2	310.8
4500 NOK/kWh	84	98	108	738.8	1096	728
3000 NOK/kWh	316.666667	366.666667	460	12,854.4	17,395.3333	23,106.8

Thus, as a first step, the following recommendations towards investments to handle the increased demand associated with EV charging can be made. For the period 2021–2022, a flexibility mix solution with 70 kWh battery capacity, 70 kWh flexibility potential from smart charging, PV installation of up to 70 kWp, 30 kWh V2G/V2B, and 10 kWh of in-house demand response can be recommended to deal with the upcoming capacity problems (Table 3). After 2022, an increase of up to 100 kWh for the smart-charging-related flexibility is envisioned on behalf of a reduction in the flexibility utilized from demand response. Here, it is important to notice that, with reference to the scenarios with more superfast charging installations, the overall capacity needs and the associated flexibility requirements will change. If more superfast chargers are to be installed, the proposed set of flexibility resources will no longer be sufficient.

Table 3. Possible utilization of local flexibility resources at the INSPIRIA charging station and their timeline.

Phase	**Battery**	**Smart Charging**	**Solar Panels**	**V2G/B**	**In-House Demand Response at the Nearby INSPIRIA Science Center**
2021–2022	70 kWh	70 kWh	60–70 kWp	30 kWh	10 kWh
After 2022	70 kWh	100 kWh	60–70 kWp	30 kWh	——

However, to be able to optimally scale and utilize the local flexibility resources, a better understanding and continuous follow up of the charging behavior of an EV user is needed. As suggested by [27], this could help improve both the planning of charging infrastructure as well as the exploitation of smart charging technologies. Additionally, the use of machine learning, as proposed by, e.g., [28], could help EV charging network designers find an optimal configuration for charging infrastructure, given their design objectives. Thus, the current scientific contribution is planned to extend in two directions: (1) improved methods for analyzing the demand for EV charging; (2) machine learning applications for optimal utilization of local flexibility given the uncertainty of demand.

It should be also noted that an optimization analysis of opportunity versus depot charging has not been performed in this research work. The relationship between capacity, the need for power reduction, and the number of charging cycles provides a broad research space that requires more extensive work.

5. Conclusions

This paper focused on the INSPIRIA charging station in Norway and how the challenges associated with increased EV charging demand can be mitigated by means of local flexibility resources. Specific attention has been paid to the choice of battery, its size requirements, and economy. Based on simulation results, it has been shown that as the unit cost of the battery decreases, battery energy storage as a flexibility resource becomes better fit to cover the increasing requirements for peak load reduction. Thus, a strategic proposal has been made to dimension a battery with a capacity that can cover the need for the next few years until the charging station is capable of mobilizing a sufficient smart-charging-based flexibility volume. The idea is that in the future limited investments in additional battery capacity will be necessary.

Until 2022, the goal is that the INSPIRIA charging station manages to cover its load needs by means of a combination of various local flexibility resources (battery, smart charging, demand response, solar panels, and V2G/V2B). The envisioned demand growth after 2022 is to be covered by increased smart charging volume, while the envisioned battery storage is to remain the same. Additionally, while this work has paid strong attention to the battery storage as a flexibility resource, the performed analysis suggests that larger battery and depot charging will be the optimal storage option for the INSPIRIA location. The attractiveness of battery storage as a flexibility source will, however, further increase given that the battery unit costs become lowered. Thus, depending on the development of the battery prices, storage may eventually prove to be the most economically beneficial option.

On the contrary, if the battery unit costs remain high, a combination of the other flexibility options discussed should be utilized upon. Here, the combination of various sources can also strengthen the robustness of the charging station and make it less dependent on unexpected events. Importantly, this also strengthens the environmental and high-tech profile of the location and contributes to attracting even more visitors.

Equipped with a variety of flexible resources at a local level, it can be expected that the INSPIRIA charging station is fit to better cover the demand in the future. This is where the INSPIRIA charging station can serve as an exemplary pilot case, which can be successfully replicated at charging station locations with similar challenges and with ambitions to enhance both the electrification of transport and the use of renewables.

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