32nd Electric Vehicle Symposium (EVS32)
Lyon, France, May 19 - 22, 2019

Energy storage to reduce the power requirements and operating costs of fast charging stations

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Summary

This study proposes an effective model and algorithm to determine the required energy storage system (ESS) for fast charging stations based on the contracted power available and the projected frequentation of electric vehicles. A stochastic arrival of vehicles using a probability distribution is used to predict power demand profiles and achievable reductions in power connection requirements. The economic relevance of energy buffers for charging station operators subject to demand charge pricing schemes is analysed.

Keywords: EVSE (Electric Vehicle Supply Equipment), fast charge, load management, energy storage, business model

1 Context

The electrification of road transport raises legitimate questions as to the required charging infrastructure and the associated power connection requirements. Several companies are planning and installing fast charging station networks with 150 kW and up to 350 kW available per charging point. Notably, the latest Tesla supercharger architecture is based on 1 MW power cabinets and supports peak rates of up to 250 kW per car [1]. With an average of 8 charging points per station and more than 1200 stations, the Tesla supercharger network is currently the most important one [2]. However, a grid connection in the megawatt range is first of all expensive due to linkage fees and monthly capacity charge, and secondly not available in several locations.

Until now, according to the data collected by Fastned™ [3], it appears that fast charging stations are largely underused with an average of 7.12 charging sessions per station per day reported in June 2018. With half of the utilities in the US having a demand charge above 15 $/kW [4], up to 27 000 $ per fast charging point can be spent annually by charging station operators (CSOs). Therefore, a common practice consists in splitting power with the next stall, known as powershare between stations, resulting in extended charging times during peak hours. Such practices degrade the user experience and cannot be sustained with the current growth of electromobility [5].

Alternatively, a local energy storage system (ESS) can act as a buffer to ensure the availability of power during peak hours, without additional investment in grid tie and monthly demand charge expenses. Rufer [6] and Cunha [7] have examined power electronics circuits and buffered charging units for fast charging stations. Off-the-shelf products are being commercialized by companies such as Porsche™ [8], ads-tec™ [9] and Volkswagen™ [10] with modular solutions in the range of 70 to 360 kWh.

Herein, we present a versatile stochastic approach to size ESS for fast charging station, allowing multi-stall installations with limited grid connection.

2 Method

The specificity of the demand curve of electric vehicles (EV) charging stations is that the average daily demand is much lower than the peak power demand. Thus, the installation of an ESS buffer can significantly reduce the peak power demand, using idle periods to recharge the ESS, and being discharged during peak demand periods. This potential was investigated using probability distribution of charging events described in [11] and confirmed in [12] [13] [14]. Assuming charging sessions of 12 to 30 minutes peaking at 150 kW (25 to 70kWh transferred), we obtain the power demand curves presented in Figure 1.

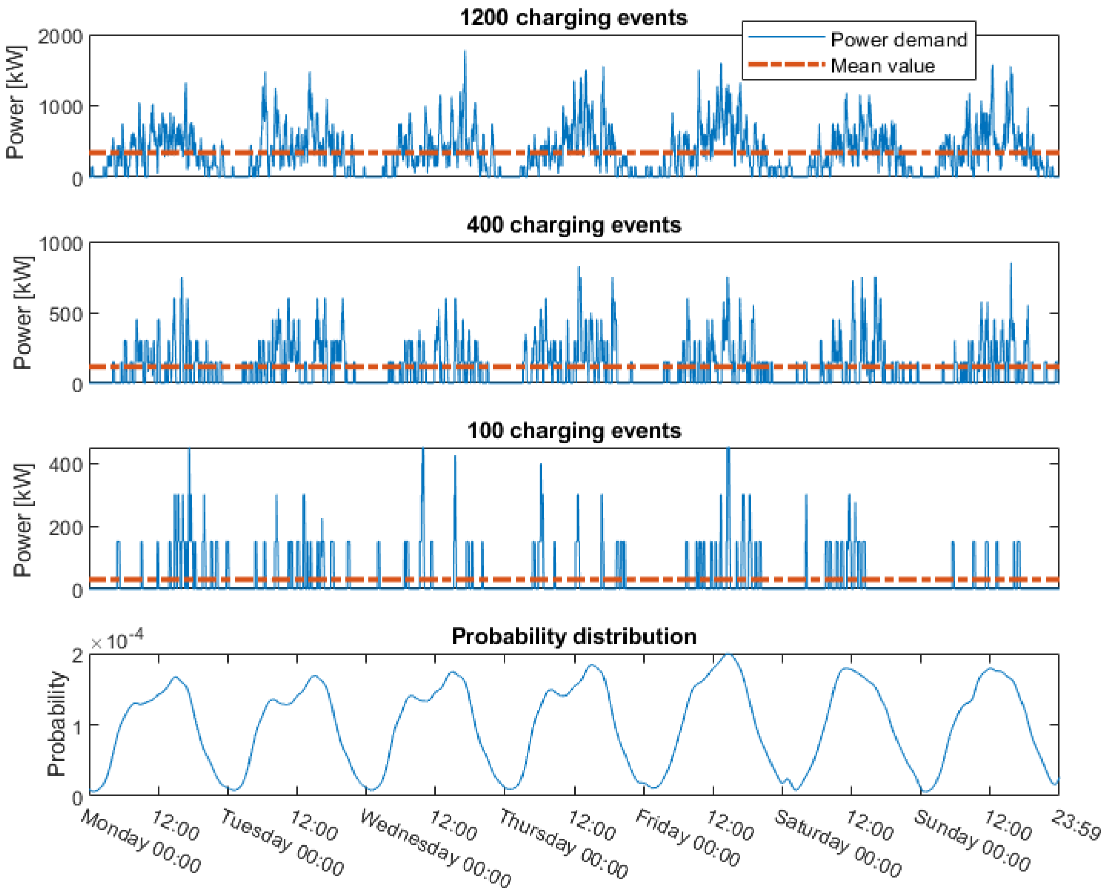

Figure 1 - Power demand curves based on stochastic distribution of charging events

Due to the stochastic nature of the problem, it also appears that, even with very few charging events per week, multiple vehicles can be at the station at the same time. A queuing system was included in the algorithm in order to introduce a constraint relative to the number of installed charging points and to compute queuing metrics. The proposed sizing ensures that less than 5% of the users need to wait more than 5 minutes to get access to a charger. The results are presented in Table 1 and are in line with Fastned™ projections [15].

Table 1 – Peak-to-average power ratio for various stations capacities and recommended number of charging points

Charging events per week	Recommended number of chargers	Peak power / kW	Average Power (max) / kW	**Power ratio**
0 - 150	2	300	43	**7.0**
250 - 550	4	600	157	**3.8**
600 - 1000	6	900	287	**3.1**
1400 - 2000	10	1 500	573	**2.6**

Finally, an algorithm was implemented in MATLAB for the operation of the ESS. The available power to charge the ESS is equal to the grid connection power minus the power demand at the station, and if this value is negative the ESS is discharged. The algorithm runs with one point per minute over a month, and the ESS capacity is iteratively increased until a full month can be covered. 100 months were simulated to exclude outliers due to the stochastic distribution of charging events. The ESS is assumed to have a 90% round-trip efficiency. An exemplary week is presented in Figure 2.

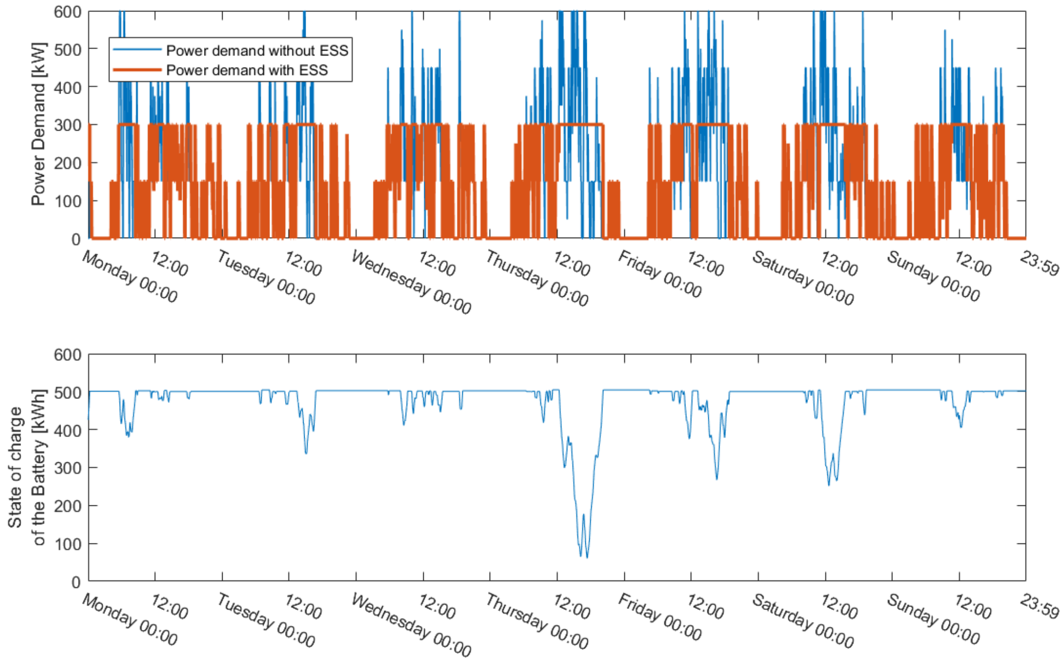

Figure 2 - ESS impact on power demand to the grid and SOC variation during a week for 500 charging events with 4 charging points and 300 kW grid connection

3 Results and discussion

Stations with up to 10 charging points and grid connections up to 1.2 MW were analysed to determine achievable reductions in power connections requirements with ESS. The results are presented in Figure 3. It appears that even the smallest ESS considered, 100 kWh, brings significant savings with 100 to 150 kW reductions for the grid tie.

Considering a location with a 300 kW grid connection, installing a 160 kWh/150 kW ESS allows to install one more charging point and to multiply the weekly capacity of the station by 2.2. And with a 710 kWh/300 kW ESS it is even possible to install 4 charging points with only half of the peak power coming from the grid.

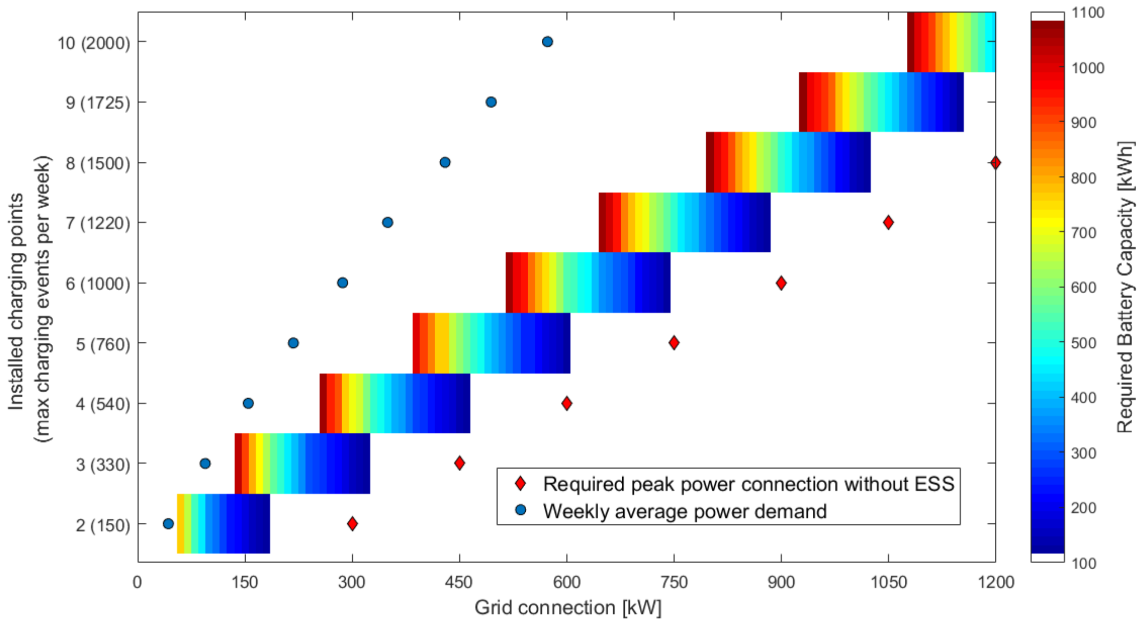

Figure 3 - Required ESS capacity as a function of the available grid connection

We investigated the fixed costs for two types of charging stations, with and without ESS, over a period of 10 years. Installing an ESS significally improves the business case for small stations mostly due to demand charge savings as presented in Table 2. The expected sales revenues for stations used at full capacity amount to 250 kCHF/year and 430 kCHF/year for respectively 3-stalls and 4-stalls with a selling price of 0.3 CHF/kWh. It was found that the additional energy consumption due to the losses in the ESS represents a negligible amount between 0.3% and 1.1% depending on the level of grid tie reduction.

Table 2 - Fixed costs for fast charging stations

Installed charging points	3	3	4	4	4
Grid connection	450 kW	300 kW	600 kW	450 kW	300 kW
ESS	0	160 kWh 150 kW	0	150 kWh 150 kW	710 kWh 300 kW
Linkage fees (100 CHF/kW)	45 kCHF	30 kCHF	60 kCHF	45 kCHF	30 kCHF
ESS cost, installed (400 CHF/kWh)	0	64 kCHF	0	60 kCHF	284 kCHF
Demand charge expenses (for 10 years at 10 CHF/kW/month)	540 kCHF	360 kCHF	720 kCHF	540 kCHF	360 kCHF
Total	585 kCHF	454 kCHF (-22%)	780 kCHF	645 kCHF (-17%)	674 kCHF (-13%)

This stochastic approach can easily be adapted to other probability distributions, include extreme charging demand periods and various charging modes. Different charging patterns can be tested to target others types of users such as taxis or freight transporters. Future work could also introduce a constraint on the grid power supply regarding the availability of renewables, and discuss examples such as the 1.5 MWh battery installed to charge EVs in Utrecht, Netherland [16], or the charging test site from ElaadNL with a 138 kWh ESS coupled with V2G capabilities [17]. The aggregation of grid services in low utilization periods would be also relevant for future research [18], but might be challenging due to the stochastic nature of the arrivals at the station. In combination with EV deployments scenarios, electricity grid reinforcement alternatives and local ESS installation can be compared for countrywide transition strategies towards electric mobility.

Acknowledgments

This work was performed with the support of the Swiss Federal Office for Energy (Grant number: SI/501286-01), the Canton du Valais, SINERGY and the City of Martigny.

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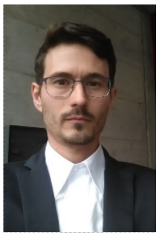
Yorick Ligen holds an engineering degree from Ecole Centrale Paris and a MSc in Energy and Economics from ETH Zürich. After one year managing projects related to the commissioning and the installation of hydrogen refilling stations in Germany, he joined the doctoral program in energy at EPFL. In the group of Prof. Hubert Girault, he is currently developing a demonstrator for electric mobility infrastructure, including a redox flow battery, a fast DC charger, alkaline and PEM electrolyzers, compressors and dispensers for battery electric vehicles and hydrogen fuel cell vehicles.



Dr. Heron Vrubel received his PhD from EPFL in 2013 working in the field of electrocatalysts for the Hydrogen Evolution Reaction. He later joined the group of Prof. Hubert Girault as a post-doctoral research fellow. In 2014, he became responsible for the installation of a Demonstration site dedicated to new technologies for renewable energy production and energy storage. Since 2019 he works for the biogas plant in the city of Martigny.

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