# *OPTIMIZED OPERATION OF AN ELECTRIC VEHICLE DC FAST CHARGING STATION IN COMBINATION WITH STORAGE AND PHOTOVOLTAICS*

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## Overview

In order to reduce the time to charge electric vehicles (EV) and thus strengthen the competitiveness of electromobility nowadays fast charging techniques are used more frequently. Since the needed infrastructure for fast charging in the majority of cases comes along with a relatively high investment, fast charging stations are primarily placed next to busy roads such as highway service stations where utilization rates are expected to be high (Ensslen et al. 2013). Substitution or complement of conventional petrol pumps by electrical fast charging points offers a great potential for their operators, though may as well cause problems to the power grid and energy system (IEA 2012). Within the energy system incentives and conditions can be established to favor load shifting to keep network loads low (Dusonchet et al. 2013). This may be necessary for remote charging stations or an inadequately developed electricity grid. This paper first gives an overview of the current state of the art of DC fast charging stations in combination with stationary storage as well as their combined application. Focus is set on vanadium redox (and redox flow) batteries (VRB) by reason of their various advantages (e.g. discharging for long periods with no ill effects) despite their relatively poor energy-to-volume ratio which is irrelevant as it is used stationary. Subsequently, the cost-optimal operation of a fast DC charging station in combination with a storage and electricity generation by photovoltaics (PV) is modeled. Finally, appropriate parameters (e.g. for load shifting) and dimensioning of the system are determined with a sensitivity analysis.

## Methods

Modelling of the system is done using linear programming. To analyze different aspects, two consecutive models have been developed. Both models minimize the systems costs subject to different constraints (e.g. cover demand) for 24 hours in 15 minutes steps. The first model is used to analyze how electricity delivery costs of the DC charging station can be minimized by operating it in combination with a stationary storage subject to different electricity price profiles. Therefore, four different electricity price profiles are defined, whereof three consist solely of a price per kWh (overall average price, high/low tariff, and real spot market prices) and one of a combined profile (spot market prices plus capacity price for maximal load). Additionally, the model allows to choose storage parameters (like maximal storage capacity and power) in order to maximize electricity costs savings with regards to each price profile. The second model extends the first model by three significant points: (i) Capital costs of the stationary storage are included into electricity delivery costs minimization. (ii) Electricity generation by a PV system (installed on site) is integrated into the model (s. Kaschub 2013 and Jochem et al. 2014). (iii) Next to the cost optimal operation of both stationary storage and PV system the optimal dimensioning of both devices in different scenarios is determined.

## Results

The settings within the two models offer three possibilities to reduce electricity delivering costs using a stationary storage: arbitrage, load smoothening, and increasing the own consumption of PV electricity.

In energy-only markets (solely price per kWh), a stationary storage can exploit arbitrage by storing energy during low-price periods and providing it when the DC charging station has to meet the EV demand at currently higher prices However, this is only reasonable if the price spread overcompensates the extra costs induced by energy losses due to storing processes. Thereby, arbitrage may be maximized if sufficient energy is stored at minimum price to cover the whole DC charging station's electricity demand between the occurrence of that price and the end of the reviewed period. Figure 1 illustrates that the stationary storage is charged solely at the minimum electricity price. Later, the stored energy is used to cover all the electricity demand unless the spread between the minimum price and the current price does not comply with the energy losses due to storage processes.

In contrast, a capacity price offers an incentive for load smoothening (reducing peak power for the electricity grid). The use of arbitrage and load smoothening thus implies oppositional storage strategies: short time high charging power against smoothed charging power over a longer period of time. When electricity and capacity prices apply jointly the dominant strategy depends on the size of the electricity price spread and the capacity price chosen. Nonetheless, the extended model shows that possible energy savings offset capital costs of the stationary storage merely under favorable conditions. If the on-site PV system is taken into account additionally, energy savings exceed capital costs even under less favorable conditions. In this case, the stationary storage is charged primary at low electricity prices in the night as well as around noon when PV power is generated. The storage is discharged either at highest electricity prices or smoothly to reduce peak load. Figure 2 shows that peak power supplies from the grid can be significantly reduced compared to the situation in figure 1 due to two factors: first, the storage covers a constant share of every demand so that the power provided by the electricity grid to meet the demand can be lowered. Second, the stationary storage is not only charged at the minimum price but also at higher prices. However, the influence of the price per kWh is still existent since charging processes remain restricted to relatively low prices.

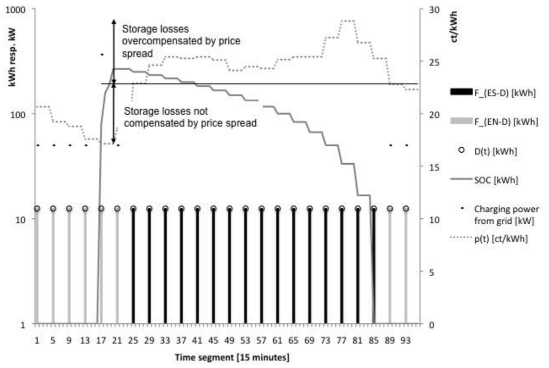

**Figure 1: First model with energy-only market**

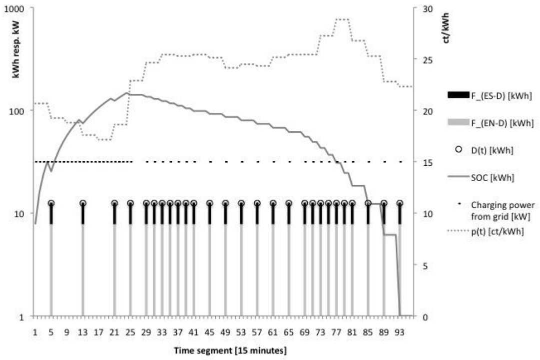

**Figure 2: First model with capacity price**

Figure 3 and figure 4 illustrate the optimal operation for the extended model (including capital costs and the PV system). The charging process can be divided into two parts: The first peak of the state-of-charge curve appears at night when electricity prices are low. The second peak is due to the generated PV electricity that is charged into the stationary storage if not coinciding with an EV charging.

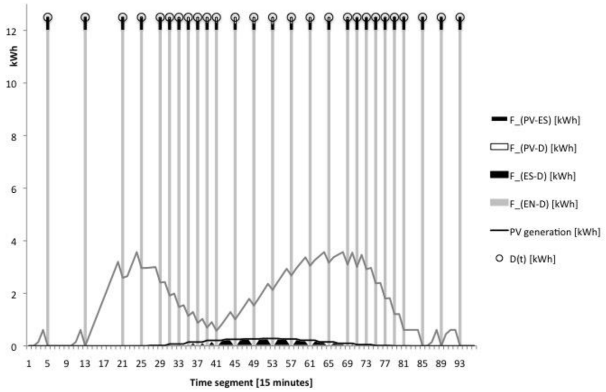

**Figure 3: Optimal operation in the extended model**

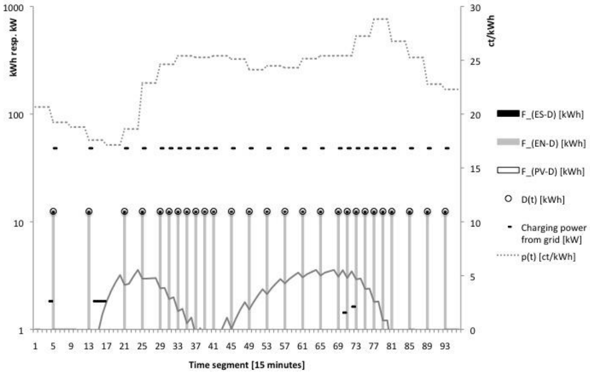

**Figure 4: Extended model (kWh in log. scale)**

## Conclusions

In this paper the optimized operation of a DC fast charging station is modeled using linear programing. Different scenarios (energy-only-market, capacity prices, etc.) and conditions (system configuration, capital costs, etc.) are taken into account and are evaluated. The model shows how input parameters do affect the modeled system. Results show how (e.g. via variable prices) and under what circumstances (appearance of EV to be charged) a DC fast charging station can be operated economically.

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