ELECTRIC VEHICLE SMART CHARGING INFRASTRUCTURE

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Abstract-Future power systems have to meet the challenge of uncontrollable, decentralized generation through increasing renewable. Utilize energy storage to harmonize the load with fluctuating generation is an option. On the other hand in today's markets large scale energy storage systems are hard to find. The reason is assumed in the high costs. Electric vehicle utilization with smart charging could be an alternative solution, due to the secondary use of the electric vehicles battery when not used for driving. This paper will describe the electric vehicle storage capability which determinants influence the storage potential.

Index Terms-Battery Electric Vehicle, Energy Storage, smart charge, Vehicle-to-grid

I. INTRODUCTION

Current ecological, economic and political considerations will lead to a diversification of the traffic sector. Due to these tendencies electric vehicles (EV) will become a major part in future mobility. Based on studies of the International Energy Agency (IEA) it is assumed that the sales figures of EV are going to reach 2.5 Mio in 2020 [1]. The energy consumption of those vehicles should generally be covered by renewable energy sources (RES). But the increasing renewable energy infeed will cause new challenges for the power system operation to meet. As a consequence of regulatory aspects in Germany, renewable energy facilities are considered to behave like a negative demand, since their production is almost unable to be controlled. Energy storage systems are a suitable solution to harmonize an unbalance between generation and demand. Possible applications can becategorized as follows [2]:

- Voltage support .
- Energy trade
- Renewable energy implementation
- Grid services
- End user application •

However, in today's power markets large scale energy storages are hard to find [3]. Energy Storage sector is dominated by pumped Hydro. More than 127 GW are deployed worldwide [4]. European commission is looking

forward to transform hydroelectric dams to pumped storage systems to meet the challenges from renewable energy integration [5]. The installed storage capacity in Germany is 7 GW in total, which equals to roughly 8% of the total peak load demand. The main amount of the installed storage capacity is based on pumped-storage plants. It numbered to about 40 GWh, which covers 3% of the daily consumption in Germany [6]. Although the installed wind capacity has reached 24 GW in 2010, long periods with a high generation only occur few times a year. Therefore, the utilization hours cannot cover the high investment costs for conventional storage systems. The smart charging of electrical vehicles also offers the opportunity of energy storage, while the economic aspects vary widely [7]. It can be assumed that the vehicles' storage capacity will exceed the daily demand. This effect is caused by the variation of the daily demand on one hand, and the customer's fear of breaking down if the State of Charge (SoC)is below 20% on the other hand [8]. The technical issues are based on the standards SAEJ1772-2009, IEC62196-2010 and the so-called Smart Charge Protocol (SCP) [9], [10], [11]. Uncertainties arise from the technical details and parameters of the EV's battery system. Efficiency, capacity and nominal power are design factors and therefore vary depending on the choice of technology. Since the battery systems of electrical vehicles are secondary systems there is no clearly defined design process. That's why the determinants and their effect on the technical storage parameters have to be defined and evaluated. In the following the analysis is focused on the available power and storage capacity, since their determinantsare comparable.

II. EV AS MOBILE STORAGE

A. Approach of smart charging

A temporal and scheduled variation of the charging process is a precondition to exploit the power storage potential of electrical vehicles. This can be realized by the creation of a communication connection between the charging infrastructure and vehicle [7]. The international standardization already includes this fact in the standards SAEJ1772-2009 and IEC62196-2010. A feasible and state of the art communication technology for electric vehicles is the power line communication which enables communication via several communication protocols [11]. Furthermore, the EV's energy consumption should not be managed through a centralized system directly. It would be a more appropriate way the transmit incentives and grid constraints to the EV-charging controller. Thereby the controller can optimize the charging operation with respect to external and internal conditions and minimize communications volume. If incentives and grid constraints are expanded to for positive and negative domain the smart charging transforms to a V2G-application.

A. Charging Station



Fig. 1. Charging station architecture.

The charging station, as referred, is a prototype developed by the University of Beira Interior and a private company, which is located in the Health Science Faculty and it is connected to a low voltage grid point with the architecture seen in Fig. 1.

In the case of all electric vehicles and PEVs, the battery capacity is still limited and thy must be recharged regularly. The European Standards [14]–[17] establish the procedure for EV charge and in what conditions by setting modes, as they are described in Table I.

TABLE I. ELECTRIC VEHICLE CHARGING MODES

Mode	Connection	Sockets	Power	Current	Local
1	Direct	Common use	3.7- 11kW	16A per phase	Home
2	Direct	Common with special cables	7.4-22 kW	16A - 32A per phase	Home or Public Facilities
3	Direct	Specific sockets	14.8- 43 kW	64A per phase	Public Facilities only
4	Indirect, using an external charger	Specific sockets		DC	Public Facilities only

The charging station follows the standards EN 61851-1 of 2011 and NP 61851-22 of 2013. The voltage does not exceed 690 V and the frequency is 50 Hz \pm 1%. The station is able to operate with temperatures between -30 °C and 50°C and a relative humidity between 5% and 95%. The position of the plug is 1m from the floor. The protection index of the charging station is IP44 and it is prepared to work in Mode 3. This mode implies a direct connection and control communicationbetween

the vehicle and the grid, through specific charging stations and it provides a maximum current of 64 A per phase (14.8 - 43 kW). Due to technical requirements of the vehicle the tests here presented were performed with a maximum current of 32A in Mode 2.

The charging station has the particularity of making use of renewable energy with 20 photovoltaic panels installed in the facility structure with 3.68 kW of connection power. This micro generation is connected to the grid in order to partially cover the load demand on charging.

B. Acquisition system

The Fluke 434 Series II was the analyzer chosen for the tests. It is composed by four thin and flexible current probes, capable of measuring up to 600 A in each phase and voltage values up to 1000 V between phase and neutral. The device candisplay data such as power factor, active and reactive power.

C. Methodologies

The fast charge of the vehicle battery was monitored in terms of level of battery and elapsed time, as shown in Table I, relative to the expected time for the complete charge as indicated by the vehicle.

The experimental tests were defined to analyze the behaviorof charging station for different initial battery state of charge. The vehicle charges 2 stopped at 72 % of the battery capacity by the action. An error occurred during the load and the vehicle stopped the flow of current. This information was given by thevehicle in its dashboard, and this might be security mechanism, because of the high current values registered just before the vehicle stopped the communication. This data was seen in the acquisition data provide by the Fluke analyzer.

In this work the charge 2 and charge 3 will be considered due to their meaning in the power quality analysis. Particularly, they allow understanding the impact to the grid of the first period of charge (battery almost empty), with constant current, and second period of charge (almost full), when the current begins to decrease in steps. The other charges listed in Table II have presented similar power quality characteristics.

TABLE II. VEHICLE CHARGES

Charge	Battery State of Charge (%)		Charging Time (min)	
	Start of charging	End of charging	Real	Expected
1	63	100	71	30
2	11	72	43	65
3	49	98	38	40
4	67	98	34	25
5	79	98	19	20
6	91	98	9	10

III. MODEL BASED APPROACH

A. Assumptions

The underlining approach of the modeling is to calculate the value of the accumulated energy storage on basis of smart charging. It is assumed that the EV storage system is competing with other generation units. That's why a marketoriented model is chosen [12]. The economic viability is one of the main evaluation criterions. The evaluation comprises the duration of one year to take seasonable changes into account. Furthermore, the existence of pooling instances is assumed. They merge the individual EVs to one energy storage system and thereby overcome the existing marketbarrier. The number of EVs is not influenced by possible financial returns of the storage system. As a result of the number of possible determinants affecting the storage capacity of the EV fled, an identification and quantification of those is absolutely necessary. The determinants are classified into technology, consumer behavior and influence of energy market.



Figure 2. Comparison of user behavior

The duration of the charging process determines the conditions of the optimization. It is possible to postpone the charging process if the desired final state still can be reached. The charging duration is no technically influence able value since the value is only rated to the user. This leads to unpredictable variations. As a consequence, the start and stop time of the charging process is only shifted for $\pm 2h$ in the sensitivity analysis. The EV's energy consumption is defined by its mobility demand which has to be guaranteed. Furthermore, the accumulators required energy, its losses and the electric vehicle's energetic preconditioning are taken into account. The measurements during a field experiment indicate an average demand of 4.2 kWh per day and vehicle [13].

System Architecture

This section describes the overall system architecture and the main data flow in the ETL process. The two main challenges in the ETL process are described in details in Section V.The warehouse is described in Figure 3. The raw unordered data files are colored red, an initial ETL flow is colored yellowand the ETL flow of transforming data into a charging data warehouse is colored blue.

This section will introduce the basic ETL flow, describedby the red and yellow parts of Figure 3. This flow will load data into a data warehouse for GPS data, described in [7],from where data later is processed and transformed into the charging data warehouse, shown by the blue figures. This is described in Section V.

A. System Architecture

The system architecture is shown in Figure 4 and is an extension of the architecture described in [7].

The system is implemented as a layered architecture runningon a 64-bit Linux operating system. The system uses the PostgreSQL DBMS [8] for storing all data. The PostgreSQL DBMS is has very good support for spatial data in termsof the Postages extension [9]. These spatial data types arefor handling all the location (latitude/longitude) and polygon columns listed in the logical data model shown in Figure 3.

The Python programming language is used for the implementation of all logic including the complete ETL process and the ETL details described in Section V. A number of Python libraries are used including the PostgreSQL database driver *Psycopg*, the spatial-network library *NetworkX*, and the ETL framework *pygrametl* [10].

Due to the inherent inaccuracy in GPS positions all spatial data is map-matched to a digital road network. The *map-matching* process uses a hidden Markov model approach [11] that is very well-suited for the GPS data used.

In addition, there is a significant number of lines of Python code that is specific to the project. This is the top layer in Figure 4 called *project specific code*.



Fig .4 . overall system architecture

Model specification

The developed model represents the profit-optimized interaction of the accumulated EVs, based on hourly intervals of electrical energy prices. Both the EVs' mobility demand and the remaining and rechargeable capacity are respected.

The evaluation is based on the individual charging processes. Each of them is individually defined by initial and final state of charge. The state of charge can vary widely during the charging process and is carried out in a cost-optimized way respecting all boundary conditions. The overall costs of each charging process are registered. These costs are checked against the average costs of an unregulated charging process. The financial return of the storage system is the result of the system's direct return of smart charging and the consumer surplus which is influenced by the feedback on the electrical energy cost price. Fig. 5 shows a block-based depiction of the model.

Revenue/EV [€/a]

Possible values of charging capacity are defined by international standards [7],[8]. Thus standard applications in the home segment allow charging capacities between 3.6 kW to 10.8 kW. It is assumed that Li-Ion systems are the technology of choice. The efficiency of smart charging can bereduced by losses in the internal board electronics of the EV. To respect this effect efficiency between 81% and 99% is assumed. In addition the costs of the battery cycle-costs are an essential factor as well, since their lifetime is influenced by every additional energy exchange. The cyclecosts areestimated by the ratio of battery costs (500€/kWh) to the maximum value of cycles (8000). The deviation of the average value is numbered by $\pm 30\%$. The battery capacity ranges between 21 and 45 kWh. Additional costs for the charging infrastructure cannot be defined precisely. Those costs are taken as a constant value, because their impact on the financial return is assumed to be linear.



Figure 5. Schematics of the user model

Estimation of cost-optimized charging

Each charging process is optimized on basis of hourly energy prices for a year. The determination of cost optimized charging and recharging is performed by a dynamic optimization. The objective function is formed by the minimal costs and the marginal conditions of charging infrastructure and usage characteristics. The optimizations for every electric vehicle are each suspected to all side conditions andperformed precisely scheduled.

A. Consumer surplus

In addition to the benefit of every optimized charging process the storage system also creates a consumer surplus. Due to the fact that an energy storage system substitutes peakload generators with higher marginal costs from the meritorder curve. This leads to lower prices for all market participants during the feed-back process. Fig. 6 illustrates this effect. The left part represents the feed-back period. The demand on energy is almost inelastic and does not increase on account of decreasing prices. The increased consumer surplus is based on the price difference of p1 to p2 and the amount of consumed electrical energy E1. As can be seen on the right part of Fig. 6, the price for charging the electrical vehicle has increased, since the feed-back energy and the losses in addition have to be returned to the EV. But the rise in price (p3 to p4) is lower than p1 to p2 based on the less steep merit order curve. The consumed energy at this time is also minor. The resulting producer surplus is lower than the increased consumer surplus.



Figure 6. Principle of increased consumer surplus through energy storage

B. Model intensity

The impact of the determinants on the financial return of the energy storage system has been quantified by using an effect analysis [13]. The summation of all 14 determinants and their variation in two steps leads to a total amount of 16384 possible combinations. The model's yearly income pervehicle and year is chosen to be the evaluation criterion. The determinants' effect on the output value is based on the following equitation:

$$E_{z_{i}} = \frac{1}{n} \sum_{k=1}^{n} y_{k,+} - \frac{1}{n} \sum_{k=1}^{n} y_{k,-}$$
(1)

 E_{zi} represents the determinants' impact on the output value. It is a result of the average of the output values for the combination of both determinants with high $(y_{k,+})$ and determinants with low state $(y_{k,-})$. Results were scaled per unit to adapt the different ranges of the determinants.

IV. CASE STUDY

A. Impact of determinants

The effect analysis was carried out according to the mentioned variation of determinants. Fig. 7 illustrates the results and the significant impact of the technical determinants. The battery efficiency has the biggest influence with $+2.06 \in$ per vehicle, year and percentage point. The battery cycle costs are a further strong factor with an influence of $-0.86 \notin$ per vehicle, year and percentage point. Decreasing cycle costs result in an increasing efficiency. The impact of Wind, Biomass and electric consumption can be neglected, whereas PV has an effective impact of 0.32 €. The fuel costs of the peak load power plants are taken into account by a factor of $0.65 \in$ per vehicle, year and percentage point. The charging characteristics, modeled without reference to charging duration and mobility demand, have no influence to be considered. If the charging pattern is changed from 72 hours to 24 hours, the charging duration of each cycle will has to be reduced. Otherwise the determinants are not independent from each other anymore.



-2,00 -1,00 0,00 1,00 2,00 3,00 impact[Δ€/a/%]

Figure 7. impact of model determinantes

B. Energy Storage capability

The reaction between smart charging and feed-back causes an increase of demand and increasing initial costs. According to that effect the maximum number of electricvehicles in the analyzed energy system is economically limited. A case study is meant to determine this value. The total capacity and maximum power of the functional storage system using smart charging electrical vehicles can thereby be deduced from that study. The model was simulated in an iterative loop until the individual financial return of eachvehicle equaled zero or the assumed maximum number of EVs has been reached. The constraints are defined by the values given in table 1. The framework data of the energy sector is based on the energy concept of the German government [15]. The technology- and consumer parameters

are based on best-case assumptions.

TABLE I. SCENARIO PARAMETERS

parameter	2010	2020	2030	
EVSE power [kW]	10,8			
Battery efficiency [%]	90			
Battery cycle costs[cent/kWh]	5	2.8	2.8	
Batter capacity [kWh]	35			
Charging duration [h]	13.5			
EV energy consumption [kWh/day]	4.2			
Charging period	every 24h			
Wind generation [GW]	24	43	49.7	
PV-generation[GW]	11.9	33	37	
Biofuels generation[GW]	3.5	5.7	6	
electricity consumption [TWh]	608	562	540	
Peak fuel costs - gas[cent/kWh];	2,7	2,8	3,7	
oil[€/t]	40.4	((7	052	
	484	667	952	
CO2-costs [€/t]	15	24	54	
Power plant portfolio	nuclear p	ohase ou	t, CHP	
	constructing			
Smart charge costs [€/EV/a]	80	50	40	

The results of the simulation are presented in figure 8. Due to the fact the number of EVs on the road in 2010 is too small for participating on power market the capability of installed pumped hydro system is plotted. The total storage capacity is presented in hours per year and is related to the time period in which the storage's maximum capacity is disposable. In 2020 the EV storage system is used as a flexible load for 214 hours of full load with a power of 5600 MW, whereas the system's generation capability is assumed to be 4800 MW with a capacity of 63 full load hours. Boththe values differ because of increased RES. The consumption drops to 4300 MW and a capacity of 175 full load hours, the generation drops simultaneously to 3500 MW and 43 hours of full load. The impact of CO₂-ceritificates and peak load power plants are likely to cancel out each other. The expected increase of PVgeneration is almost completed after the analyzed scenario period. It is obvious that EVs could only contribute as a provider of power over a short period of time.



Figure 8. Energy storage capability

V. CONCLUSION

The paper has proven the request for storage systems and the introduction of electric vehicles and their capability of smart charging and V2G. The difference between a stationary and the described mobile storage system is defined by a

several determinants which have a direct influence on the storage system's characteristics. A market based model is presented to describe the effect of those determinants on the electric vehicle system. The effect analyze has demonstrated that the technical determinants battery efficiency, charging capacity, battery cycle costs have the hugest influence on the systems behavior. In comparison, the determinants describing customer related characteristics have a low effect per unit. However, it should be considered that Li-ion batteries have high efficiency rates already. On the other hand, there is the possibility that enhancements in charging duration could be realized more easily. Therefore, additional expenses for variation of the determinants haven't been evaluated. The model described the potential of a storage system realized by smart charging electric vehicles. The applied best-case scenario is characterized by a potential of 4.8 GW with 63 hours of full load. The storage quality of RES is therefore considered to be low. But nevertheless, in the authors' point of view smart charging electric vehicles can contribute to future electrical systems if they are used for power applications

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