PROFITABILITY ANALYSIS OF GRID SUPPORTING EV CHARGING MANAGEMENT

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ABSTRACT

The electrification of the mobility sector is a key issue for achieving the European climate goals. However, a massive increase of electric vehicles leads to a significantly higher utilization of the power grid — especially in the lower voltage levels — which may results in overloads or deviations from the allowed voltage range.

In order to avoid those inadmissible grid conditions, there are two possible solutions: Conventional grid enhancement or automated charging management alternatively. In this paper these two solutions are compared economically. Therefore, the expectable average grid expansion demand caused by EVs will be outlined. To this end, a probabilistic grid load simulation for several different grid structures was conducted. As a smart charging management system also enables the use of the EV's charging flexibility for additional market applications, these options will be discussed too.

INTRODUCTION

Today fighting the climate change poses the main challenge for all parts of the energy supply sector. In the recent decade the transformation process of the electrical energy sector towards renewable energy resources proceeded and reduced the consumption of fossil resources substantially. In contrast in other energy sectors renewable energy resources are introduced more hesitantly. Especially the energy-intensive mobility sector relies largely on fossil fuels. Although the share of biofuels increased they are inadvisable for satisfying a high proportion of the total energy demand because they directly compete with the food production. Therefore, it is reasonable to reduce the fossil energy demand by using electrical energy instead, so that in the next years the share of electric vehicles (EVs) probably will increase significantly.

These developments lead to essential challenges for the electrical grid. Since the increasing generation of decentralized renewable power plants already caused inadmissible grid conditions (limit violations) in many rural distribution grids, an increasing number of EVs will also affect urban grids. So in the next years an extensive grid reinforcement will be required.

Especially in urban areas grid reinforcement involves high expenditures, as these grids largely use underground cables. Therefore, power system experts agree that smart distribution systems are the way to avoid an expensive grid expansion [1], [2]. An intelligent charging management system can control the charging processes of EVs and use their flexibility to avoid inadmissible grid conditions [3], [4]. Furthermore, it also enables the use of the EV's charging flexibility for additional market applications. However, those systems will only be installed, if they manifest concrete (economic) benefits.

GRID EXPANSION DEMAND

To assess the benefits of such a system, it is important to quantify the upcoming grid expansion demand. In case of urban grids, mainly the share of EVs and the charging behavior of the users is decisive. Therefore, a grid load simulation for several different low-voltage (LV) grid structures was conducted which is based on probabilistic charging load profiles [4] that are added to smart meter based loads of other grid participants (especially loads of residential buildings).

Simulation Inputs

In order to determine the future grid expansion demand, the temporal development of the electric mobility has to be estimated first. Unfortunately, the future development of the electric mobility is hard to predict and the forecasts are very disparate. As an example Figure 1 shows different forecasts of the EV development in Germany.

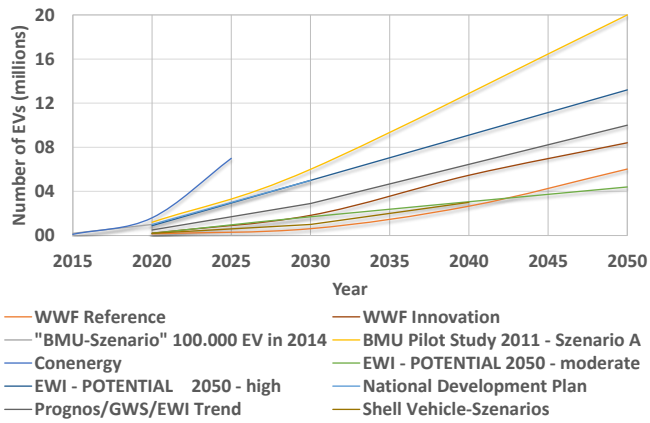

Figure 1: Different forecasts of the EV development in Germany

For this reason, the following simulation was executed on the basis of EV penetration rates and is not connected to certain years. For all further investigations average penetration rates of 10 %, 30 % and 70 % are considered. In addition, local accumulations were simulated by using a binomial distribution (1 % significance level). For this purpose, the mentioned penetration rates represent the probability for an EV to be assigned to a specific load node. For each considered EV several probabilistic load profiles were simulated. The charging power was considered as constant and set to 11 kVA.

Expansion demand

For each analyzed LV-grid multiple power flow calculations were conducted with the number, locations and charging profiles of the EVs and the power consumption of the other grid participants being assigned randomly. Within these calculations, inadmissible grid states were detected in one-minute steps. Figure 2 depicts the share of the analyzed grids with at least one inadmissible grid state depending on the total share of EVs and their distribution across the networks' nodes.

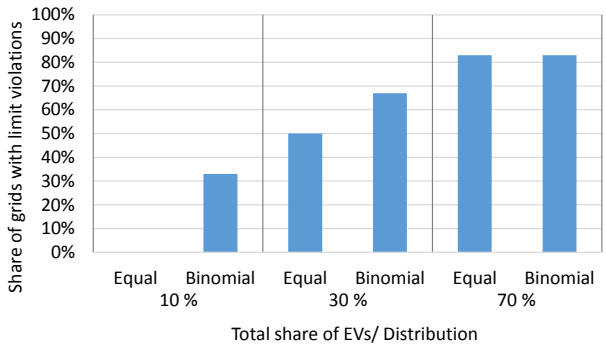

Figure 2: Share of grids with limit violations depending on the total share of EVs and their distribution across the networks' nodes

The illustration shows that EVs hardly cause any limit violations at very low penetration rates – except for local accumulations. However, if the local EV-penetration exceeds 10 % first impacts can be observed and at 30 % already every second analyzed grid were affected by limit violations. Then, at the latest, the grid has to be expanded or a charging management system has to be installed.

COST COMPARISON

In general, each grid has to be analyzed individually in order to calculate realistic expansion costs. However, a few individual considerations lack a fundamental validity. Therefore, the following cost calculation is based on the average expansion demand of the regarded grids. Nevertheless, for comparison reasons a single grid with a high expansion demand (in the following called: severely affected grid) is presented too.

Conventional Grid Expansion

The following table shows the average expansion demand of all regarded LV-grids and of the single severely affected grid depending on the total share of EVs (binomial distribution). At this, only those grids with an already existing expansion demand at the specific share of EVs were examined.

Table 1: Grid expansion demand depending on the total share of EVs

EV share [%]	10	30	70
Cable expansion required by the severely affected grid [m]	223	323	375
Average required cable expansions [m]	122	198	241
Share of grids requiring transformer upgrades [%]	50	67	67

To calculate the conventional expansion costs the following asset prices were considered (Table 2) [5]. Furthermore, for cables the annual operating costs were set to 1 % of the investment and for all other components to 2 %.

Table 2: Cost components of conventional grid expansion

Assets	Price
LV cable including laying (urban area)	90 €/m
MV/LV transformer S_r = 630 kVA	12.000 €
Walk-in substation	15.000 €

Since a significant expansion demand is not expected until 2030, the price development up to this point has to be considered too. To this end, a price increase of 2 % per year is assumed (targeted inflation rate of the ECB).

The following Table shows the calculated conventional expansion costs in prices of the year 2030. The total operational costs were estimated by the PVA-method[1] using an interest rate of 5 % and a service life of 40 years.

Table 3: Expansion costs of the conventional planning variant

EV share [%]	10	30	70
Severely affected Grid			
Cable costs [€]	27.000	39.100	45.400
Substation incl. transformer [€]	36.300	36.300	36.300
Operational costs [€]	17.100	19.200	20.300
Total costs [€]	**80.400**	**94.600**	**102.000**
Average			
Cable costs [€]	14.700	24.000	29.200
Transformer incl. substation [€]	18.200	24.200	24.200
Operational costs [€]	8.800	12.400	13.300
Total costs [€]	**41.700**	**60.600**	**66.700**

[1] Present Value of an Annuity, $PVA = A \cdot \left(\frac{1}{i} - \frac{1}{i(1+i)^n}\right)$
i = interest rate, n = number of periods, A = annuity

The calculation shows that a major part of the expansion costs has to be funded in the early years. Especially the replacement of the transformer is very cost-intensive. Furthermore, it is shown that there is a significant difference between the expansion costs of an average and a severely affected grid.

Charging Management System

A grid supporting application of a charging management system for EVs primarily requires a detailed knowledge about the actual power flow situation in the considered grid. More precisely, this application cannot work properly without a smart grid system.

In this case, the considered system consists of an autonomous control unit within the low voltage grid's substation, several current and voltage sensors and the controllable actuators. Furthermore, the control unit is connected to a control center that aggregates the current grid state and passes it on to the distribution system operator. It features a user-friendly customer interface to manage the charging processes [4]. In this way, also external (non-grid-relevant) control demands could be executed. Figure 3 depicts the concept of the system in detail.

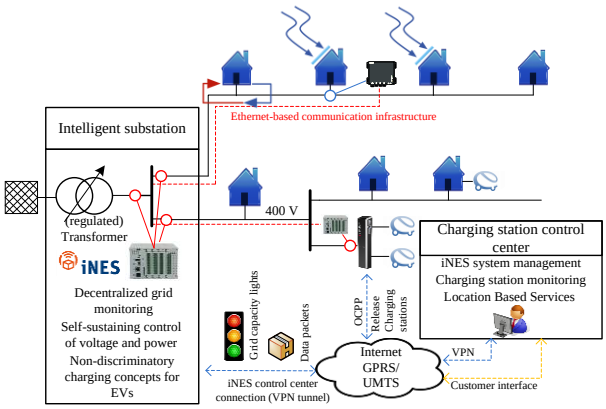

Figure 3: Concept of the smart grid and charging management system

The costs of such a system depend on the specific demand of a grid. It can be assumed that about 15 % of the grid's nodes have to be measured in order to be able to calculate a sufficiently accurate grid state (control unit has an integrated sensor) [3]. In addition, all charging stations get a powerline modem that connects them to the control unit and enables them being controlled. Equipping the total amount of charging stations is not necessary for local grid purposes, but for further application fields.
Table 4 shows the total quantities of the different smart grid devices for the average and the severely affected grid depending on the share of EVs (in this configuration no additional regulated transformer is needed, because all limit violations can already be avoided by the system).

Table 4: Demand of smart grid devices

EV share [%]	10	30	70
Severely affected Grid			
Control unit	1	1	1
Current / voltage sensor	12	12	12
Powerline modem	9	26	64
Average			
Control unit	1	1	1
Current / voltage sensor	10	10	10
Powerline modem	8	21	56

As shown, there is a minimum number of devices in order to establish the fundamental smart grid system. Further EVs could be integrated easily by connecting them to the control unit via a powerline modem. The following table sums up the actual prices of the mentioned components and the associated engineering effort (prices of 2016).[2] Furthermore, the annual operational costs for the smart grid system are estimated to be 2 % of the investment.

Table 5: Cost components of the charging management system

Assets / Engineering effort	Price
Control unit (Smart RTU)	5.000 €
Engineering Control unit	2.500 €
Current / voltage sensor	2.800 € / piece
Engineering sensor	1.400 € / piece
Powerline modem	100 € / piece

Since smart grid systems are still at the beginning of their product development, in the next years prices probably decrease significantly. Therefore, until 2030 a price decline of 1 % per year is estimated (except for the powerline modem).

Due to the shorter service life of smart grid components compared to conventional assets, replacement investments will be necessary. It is assumed, that these have to be realized after 20 years. The replacement investment is discounted using an interest rate of 5 % (no further price decrease of smart grid components after 2030).

The resulting costs for the use of a charging management system in the average and the severely affected grid are presented in Table 6. Since this system requires a fixed minimum number of devices to operate properly, the major part of the costs have to be borne at a low share of EVs already. Therefore, charging management systems are more advantageous for grids with a high share of EVs. However, for weakly dimensioned grids (like the severely affected grid) charging management systems already have significant cost advantages at lower shares of EVs.

[2] Smart grid system: iNES from SAG GmbH; Powerline modem: G3-PLC Modem 500k from devolo AG

Table 6: Cost calculation for the charging management system

EV share [%]	10	30	70
Severely affected Grid			
Hardware and Engineering costs [€]	34.100	35.800	39.600
Operational costs [€]	11.700	12.300	13.600
Replacement costs [€]	12.200	12.800	14.200
Total costs [€]	**58.000**	**60.900**	**67.400**
Average			
Hardware and Engineering costs [€]	29.200	30.500	34.000
Operational costs [€]	10.000	10.500	11.700
Replacement costs [€]	10.500	10.900	12.200
Total costs [€]	**49.700**	**51.900**	**57.900**

Figure 4 recaps the cost comparison of the two variants and shows the saving potential of a smart grid system (only considering the local grid supporting applications). It is illustrated that the average of the grids only benefits at higher shares of EVs.

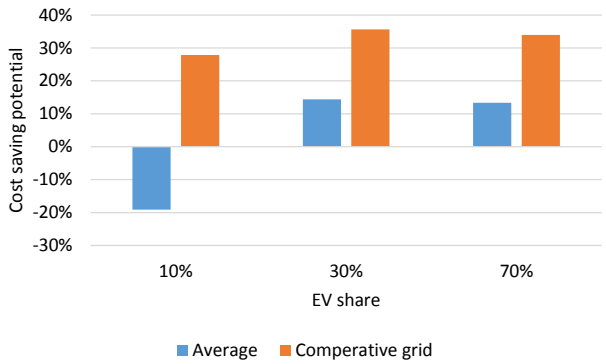

Figure 4: Cost saving potential of a charging management system compared to conventional grid expansion depending on the share of EVs (local grid supporting only)

ADDITIONAL APPLICATION AREAS

The presented critical utilization of the feeding distribution grid only occurs few hours a year. Figure 5 depicts the simulated average time of inadmissible grid states per year in the considered grids without enhancement.

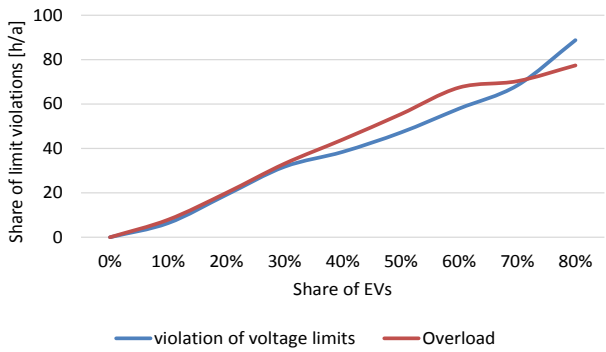

Figure 5: Average time of inadmissible grid states per year depending on the share of EVs in the considered grids

The charging flexibility of EVs, however, is available continuously and can be used otherwise without additional costs. There are various options to exploit the flexibility potential.

Ancillary Services

The most obvious application of the unused charging flexibility is the support of a higher voltage level via ancillary services. Balancing power is required year-round on a large scale and therefore a very suitable field of use.

Because of the required low response time primary control power is coordinated decentralized and therefore needs a precise and independent frequency measurement. For this reason, currently it is much more complex and expensive to provide primary control by EVs. In contrast, both the secondary control power and minute reserve are requested by the TSO with a significant higher response time which can easily be met by the EV charge controller. On that score, the provision of primary control power by EVs is currently not reasonable and since the minute reserve reaches a significantly lower remuneration, secondary control power is the most convenient product.

In Germany the minimum quantity of balancing power per provider for the considered product is determined to 5 MW and has to be available for the defined time slice. For this reason, many EVs have to be pooled in order to meet the minimum power requirements and ensure availability for the entire time slice. In the following a pool-size of 15,000 vehicles is assumed. Based on the aforementioned mobility simulation this size allows a continuous ancillary service-supply of 5 MW for about 10 hours, without impairing the users' mobility. On the basis of ancillary service prices of the recent years, the pool would have been able to achieve about 800,000 € per year.[3]

Exchange Trading (Intraday)

If the participation in the balancing market is not possible or desired, the charging flexibility of EVs can be marketed at the Energy Exchange (especially intraday-market). In times of high prices, the charging processes can be throttled or interrupted and a share of the provided energy can be sold. If the price is low or even negative, all connected vehicles should charge with the maximum power.

If an electricity trader had purchased the energy demand of the considered EV-pool at the intraday-market solely and had used the total charging flexibility, the total

[3] Optimized pricing provided, based on historical prices of 2012-2015

energy costs would have been more than halved compared to average prices in the last years.[4] The annual savings are similar to the revenue potential of the ancillary services (about 730,000 € per year).

Accounting Grid Optimization

In addition to the grid operators, the charging flexibility could be sold to balancing group managers (BGM) as well. In order to avoid the usage of cost-intensive balancing energy in case of a forecast deviation, the BGM could use EVs to harmonize feed-in and consumption. For this purpose, however, it is necessary that the BGM has detailed knowledge about the current situation in his balancing group. Furthermore, it is difficult to estimate the fitting price for the flexibility, because the balancing energy prices are communicated only a month after the delivery period. The revenue potential of this application area is also likely to comply with the already mentioned.

Total economic advantages

In addition to the presented cost savings by avoiding an EV-based grid expansion the additional application areas could generate further profits. Figure 6 depicts the total economic advantages of a charging management system depending on the share of EVs. It is assumed that all EVs support the further market applications.

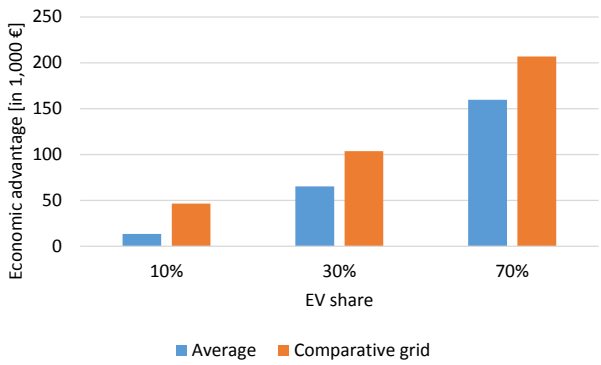

Figure 6: Total economic advantage of a charging management system depending on the share of EVs

It is shown that there are significant economic advantages by using a charging management system. The additional applications taken into account the use is profitable even at low shares of EVs. However, EV owners probably will not provide their vehicles without a financial participation.

[4] Based on the mobility simulation and linear optimization, prices of 2013 - 2015

CONCLUSION

The present paper shows the impacts of a higher share of EVs on the electrical grid. Subsequently, it compares two solutions which avoid the resulting inadmissible grid conditions: A conventional grid expansion and an automated charging management system. Since the charging flexibility of EVs is only needed few hours a year for local grid purposes, further application areas are considered too.

The comparison demonstrates that charging management systems provide significant economic benefits compared to conventional grid expansion measures. In order to gain acceptance for such a system, however, the vehicle owners have to be rewarded which reduces the profit margin for the grid operator substantially. Nevertheless, the presented charging management (and smart grid) system possesses further advantages like online grid state identification and grid control options, so it is advantageous for the grid operator anyway even at lower financial benefits.

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