DYNAMIC GRID SUPPORT WITH EV CHARGING MANAGEMENT CONSIDERING USER REQUIREMENTS

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ABSTRACT

The ongoing changings towards a more decentralized and renewable energy system in Germany requires a coordinating smart grid system. Due to its high power consumption and flexibility potential, the charging process of electric vehicles (EVs) is predestined to be controlled by such a system. To avoid a loss of acceptance for EVs, however, it is important to ensure that the mobility of the users is not restricted due to load control activities during the charging process. In this paper the necessity and functionality of a developed charging management system will be explained and the results of an extensive field test will be presented and assessed. In this respect, it will also be shown which impacts a growing number of EVs has on the grids and what challenges are likely to occur.

INTRODUCTION

Main objective of the electrical energy provision is a high supply reliability considering nature conservation and economic efficiency. To satisfy the ecological demands, a large number of renewable power plants has been connected to the grid in the recent decade and new ecologically advantageous consumers (like heat pumps or charging stations for electric vehicles) will be installed in the next years. These changes lead to essential challenges for the electrical grid.

Power system experts agree that smart distribution systems are the way to handle these changes in order to avoid an expensive grid expansion [1], [2]. While some approaches focus on a single component within the grid, e.g. voltage regulators, the authors of the present paper have developed an integrated smart distribution grid system which can control multiple components like voltage regulators and controllable generation and consumption units [3], [4].

Although the automatic control of PV feed-in reached market maturity in the meantime [5], [6], load management in the considered voltage level is still in the development phase. Main reason for this is that load management is usually accompanied by direct consequences for the users (e.g. a process is interrupted, an electric vehicle is not charged, a device cannot be used etc.), which do not only have a financial aspect – like lost feed-in remuneration – but also a loss of productivity, usability and comfort. These consequences cannot be balanced by compensation payments that easily. For this reason, load management measures can only be implemented, if there are high load shift potentials and sufficient information about the users' requirements so that a smart grid system can control the load without impairing the users.

Due to its high power consumption, a rising number of electric vehicles (EVs) may constitute a major challenge for the electric grid. However, the charging process of EVs therefore could be particularly suitable for a load management system also. Provided that a high load shift potential is present, EVs can make an important contribution to the flexibility needs of the electrical energy supply system, instead of just being an additional load.

IMPACTS AND FLEXIBILITY POTENTIAL OF THE ELECTRIC MOBILITY

The EV caused challenges for the grid and their grid supporting potential depend on the total number of EVs. Unfortunately, the future development of the electric mobility is hard to predict. Although generally a rapidly increasing number of EVs is assumed, the prognoses are very disparate. As an example Figure 1 shows different prognoses for the EV development in Germany.

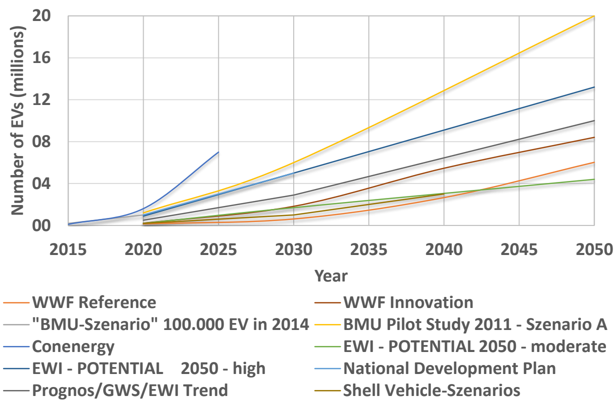

Figure 1: Different prognoses for the EV development in Germany

Due to the high forecast uncertainty the following analysis were executed on the basis of EV market penetration and are not connected to certain years.

Mobility simulation

To determine the additional EV charging load and their flexibility potential, the mobility behavior of the vehicle users is required. Therefore, a simulation of the usage of EVs was carried out. In order to obtain valid results the simulation is based on data of a study on mobility in Germany [7]. Based on the provided data probabilistic driving profiles are generated by means of a multistage algorithm that was customized for utilizing data available in this specific mobility study. The main aspects of the algorithm are depicted in Figure 2.

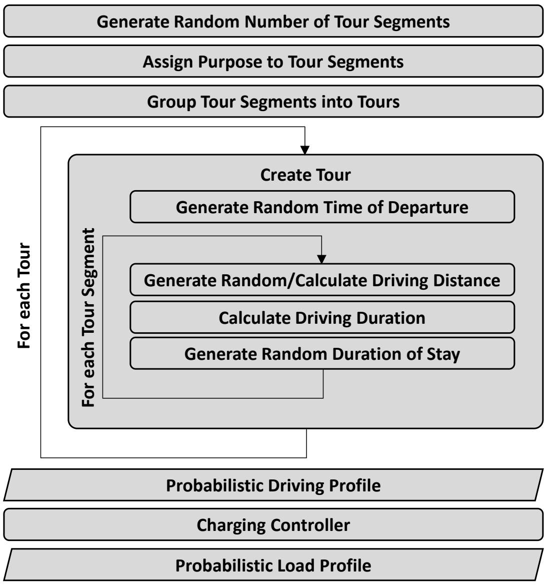

Figure 2: Simulation algorithm for generating probabilistic driving and load profiles

Grid impacts

The impacts of an uncontrolled loading of EV on the electrical grid were estimated by multiple load flow calculations for various grids with different EV-penetrations. In combination with probabilistic load profiles of households, the charging profiles of the EVs are the input data for the load flow calculations. The calculations revealed, that there are hardly any EV-caused impacts in the next years, but if the local EV-penetration exceeds about 20% first grid overloads will be observable without a charging management system. Figure 3 shows the average time of inadmissible grid states per year (branch overloads or inadmissible voltage deviations) in the areas examined depending on the EV-penetration.

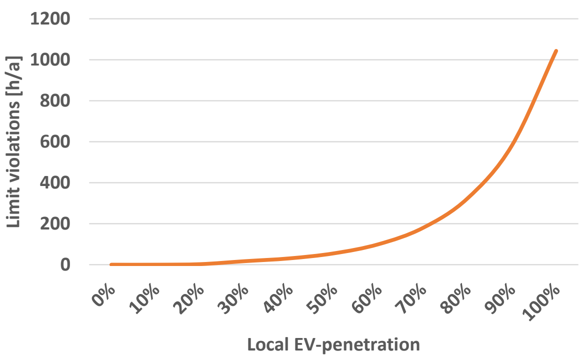

Figure 3: Average time of inadmissible grid states per year depending on the EV-penetration in exemplary distribution grids

Load shifting potential

The simulation model was also used to examine the load shifting potential of EVs via an analysis of generated driving and load profiles. Figure 4 shows that the charging power of the majority of all EV charging processes can be limited significantly without affecting the users' mobility. So with a maximum charging power of 11 kVA in more than 80% of all charging cases, the charging power can be massively reduced by about 80%. This implicates a worthwhile load shifting potential, especially with a rising number of available EVs.

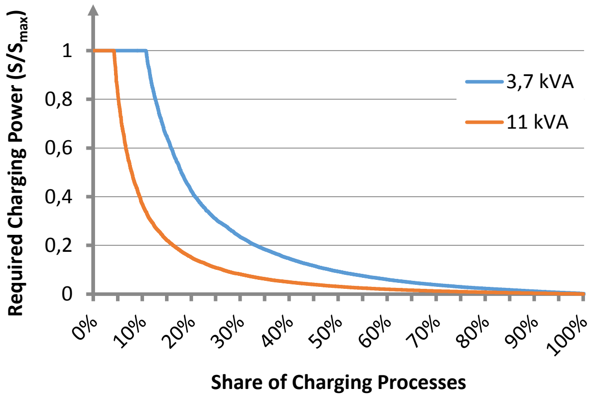

Figure 4: Required charging power for EVs without limiting the users' mobility

GRID SUPPORTING CHARGING MANAGEMENT

As shown in the previous chapter, limit violations caused by EV charging processes only occur few hours a year (considering moderate EV-penetration). Furthermore, there is a high flexibility in the charging processes without limiting the users' mobility. Therefore, it is economically not reasonable to expand the grid for these cases but to shift the charging processes during this period by using a charging management system. This grid supporting application of a charging management system for EVs, however, primarily requires a detailed knowledge about the actual power flow situation in the considered grid. More precisely, this application cannot work without a smart grid system. Therefore, the presented charging management system uses a previously developed distribution grid automation system, which includes a fast, intelligent power flow calculation algorithm and a three-stage control algorithm comprising the usage of controllable transformers, power factor control and active power control (sorted by negative effects of a control operation) [4], [8].

System components

The overall system consists of an autonomous control unit within the low voltage grid's substation, several current/voltage sensors and controllable actuators.

Furthermore, the control unit is connected to a control center which is able to aggregate the current grid state to the distribution system operator and comes with a customer interface in order to manage the charging processes user oriented. Figure 5 depicts the concept of the system in detail.

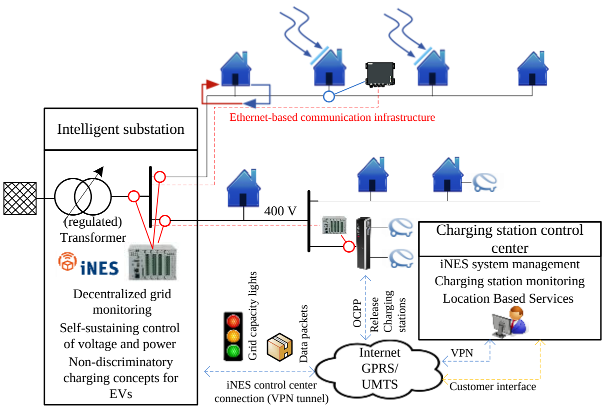

Figure 5: Concept of the intelligent integration of electric vehicles into the distribution grid

Smart charging concepts

In case of an off-limit condition that requires active power control, the charging management system can be used to remedy the problem. For this purpose, all charging stations that have a significant influence on the off-limit condition have to be identified in a first step. The suitability depends on the position of the charging station within the grid, the location and in particular the type of the off-limit condition and can be identified by a sensitivity matrix. Among the suitable charging stations the charging management system selects those with the least user impacts to reduce (or rise) their charging power by using different charging concepts depending on the available user information [9].
Figure 6 shows the different smart charging concepts sorted by the needed information.

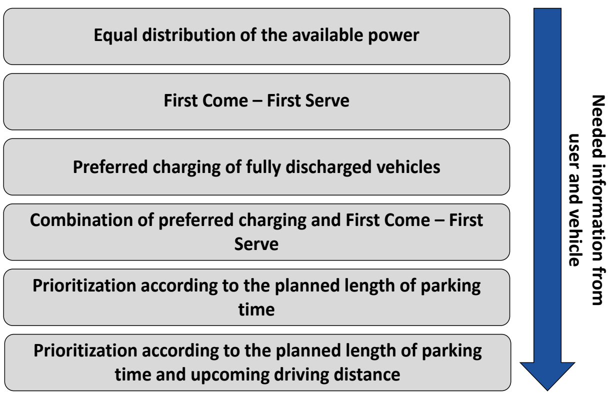

Figure 6: Smart charging concepts sorted by needed information

Charging station selection

If the needed user information are completely available, the charging management system is able to optimally adjust the available charging power to the user requirements. This means that EVs with greater temporal flexibility are charged subsequently, if necessary.
The temporal flexibility of an EV depends on the current state of charge (SOC [%]), the current time (t [h]), the planned departure time (T [h]), the upcoming driving distance (s [km]), the battery capacity (C [kWh]), the charging power (P [kW]) and the electricity demand of the car (E [kWh/km]).

$$flex_{EVx} = SOC_{EVx} \cdot C_{EVx} + (T_{EVx} - t) \cdot P_{EVx} - s_{EVx} \cdot E_{EVx}$$

If the flexibility is positive, the charging power of the EV can be throttled without impairing the user. The greater the flexibility the longer the throttling may last.

PRACTICAL VALIDATION

The functionality of the system has been validated in an extensive field test. At this, several charging stations, a 113 kWp photovoltaic system and a 200 kW cooling system of a mainframe were integrated in the smart grid system to simulate a flexible future grid. In times of high charging load and low photovoltaic feed-in the charging management system had to remedy the overload of the feeding branch by throttling one or several charging processes.
Figure 7 shows an exemplary section of the current measurement at the connection cable of eight charging stations on a testing day. The current limit is set to 100A, but because of the large thermal mass of the cable, brief overshoots were tolerated in the first tests in order to reduce the number of control commands.

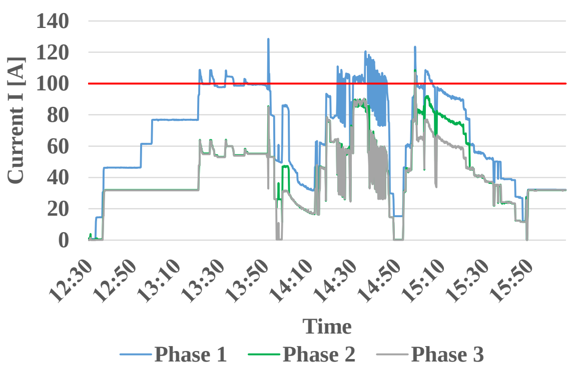

Figure 7: Current measurement on an early testing day

The illustration depicts three relevant points:

- The system is able to react correctly to limit violations
- The power flow is quite unsymmetrically
- There was a high-frequent charging power fluctuation between 14:20 and 14:50

Main reason for the unsymmetrical power flow is that several electric vehicle models charge single-phase and

mostly use the first. To prevent this, the DSO should urgently ensure that there is a random phase selection when installing charging stations to the grid, since it is unlikely that the manufacturers will change this behavior in the nearby future.
The high-frequent charging power fluctuation occurred, because different electric vehicle models have different minimal charging powers and permanently start and stop the charging process, if the allowed charging power falls below their minimum. To avoid this reaction, the minimum charging power of each vehicle has to be known by the smart grid system at the moment. In future, the manufacturers should avoid this charging behavior.
Considering the different minimal charging powers of the EVs and reducing the reaction time on branch overloads, the system is able to remedy any off limit condition fast and reliable without high-frequent power fluctuations. The asymmetry however cannot be balanced by the smart grid system, because there is no possibility to prescribe the used charging phase to the connected vehicle. Figure 8 shows the current measurement at the connection cable on a later testing day, on which the mentioned improvements were integrated.

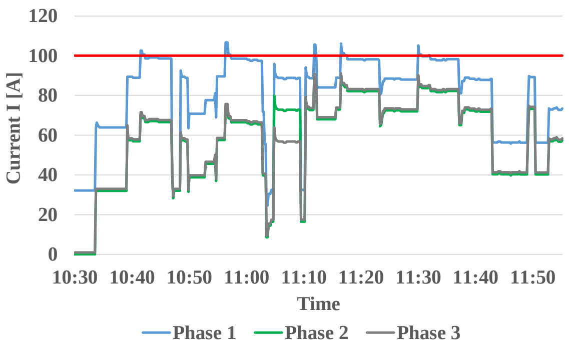

Figure 8: Current measurement on a later testing day

CONCLUSION & OUTLOOK

The present paper describes the integration of load management into a smart distribution grid automation system in order to avoid expensive grid expansions. Since load management measurements require sufficient flexibility of the controlled process, only certain loads are suitable for a load management system. Due to its high power consumption and the high flexibility, the charging processes of EVs are particularly applicable for this purpose.
To gain acceptance for such a system, it has to be noted that the mobility of the vehicle users is not restricted. Therefore, a charging management system was developed which is able to use the charging process flexibility without impairing the users.
The functionality of this system has been validated in an extensive field test. It turned out, that the internal charge controllers of several EVs are not grid-optimized, so that the power flow is very unsymmetrically. Furthermore, there are different minimal charging powers related to specific cars, which lead to a permanent starting and stopping of the charging process, if the allowed charging power falls below. This car-behavior should be changed urgently.
Since the demand for a grid supporting usage of the charging flexibility is limited to few hours a year, the flexibility can also be used otherwise during the remaining time. By marketing the flexibility e.g. at the control power market or the energy exchange, the economic advantage of a smart grid/charging system increases further. However, these application areas can only be used in case of a significantly increased total number of EVs.

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