EV Charging Coordination to secure Power Grid Stability

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***Abstract*—Electromobility is one approach to foster a CO_2-optimized transportation and mobility sector. At the same time, increasing adoption of electric vehicles (EV) bares challenges for the whole electricity system, and mainly for the power grids. Coordinated charging of electric vehicles can help alleviating the pressure that an increasing e-mobility sector will exert on the power grids. Simultaneously, e-mobility holds ready some interesting opportunities, only one of them being a CO_2-reduced transport and mobility sector. The ELECTRIFIC solution approach for coordinated charging is presented in this paper. We suggest a combination of three different software components: 1) An advanced driver assistance system (ADAS) that helps EV drivers to plan their charging and navigate their trips; 2) A smart charger, which adjusts the charging capacity of each charging station (CS), considering the power grid's needs and 3) A charging scheduler, which optimizes the charging of EV fleets, also taking battery-friendly charging into account.**

Keywords-coordinated charging, ADAS, charging behavior, routing algorithms

I. INTRODUCTION

E-mobility is the answer to many problems of our current lifestyle: it reduces air-pollution in urban areas, avoids health issues from too much noise, and potentially utilizes environmentally friendly electricity, generated from renewable energy sources for the batteries. In order to live up to its potential, however, attractiveness of e-mobility has to be increased. High acquisition costs and the so-called "range anxiety" are currently the main obstacles towards wider adoption of EV-based mobility [1]. As soon as these obstacles are abated and EVs will be used by a majority of drivers, the power grid will face big challenges regarding demand peaks and power quality (e.g. voltage fluctuations) due to uncoordinated charging [2][3][4]. A potential solution must be reconciled with these emerging challenges for the power grid.

Dealing with the issues of EV attractiveness, user acceptance and pressure on the power grid is combined within the ELECTRIFIC[1] approach. These matters lead to the notion of guiding EV users in their driving and charging experience. The concept comprises coordinated charging of multiple EVs, predicting energy consumption and power demand from e-mobility and monitoring repercussions on the power quality in the grid. At the same time, ELECTRIFIC aims at maximizing the intake of local renewable energies when charging the EVs.

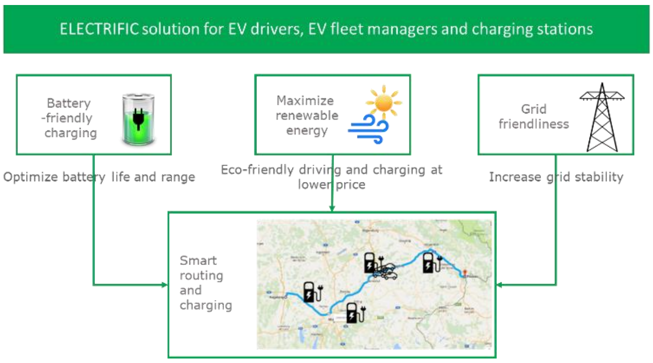

Figure 1: Challenges of the ELECTRIFIC Approach

To achieve these objectives (see Figure 1), collaboration between various actors in the e-mobility ecosystem is required. The proposed software solution therefore offers different mobility services to the EV driver. These services comprise trip planning, selection of CS and booking of a suitable EV from a fleet for the desired trip. In order to do this, the ADAS in the form of a mobile app, suggests optimized routing and charging options to the driver. Behavioral aspects of EV users with the ADAS are dealt with

[1] http://www.electrific.eu

in an interdisciplinary approach, combining experience from computer scientists, economists and psychologists.

II. The ELECTRIFIC Approach

The ELECTRIFIC approach does not only offer a technical/software solution but comprises much more elements. These include business models for service providers, pricing schemes, contract design between stakeholders and incentive schemes for the end users. This paper solely presents the technical solution that ELECTRIFIC offers to the different actors in the EV eco-system. The technical approach consists of three components that interact with each other: the ADAS to coordinate public and home charging processes, the smart charger adjusting the charging capacity during the charging process according to grid requirements and the charging scheduler to coordinate fleet charging processes.

III. Advanced Driver Assistance System

One of the major challenges for coordinated charging is to change the drivers' behavior and make their charging decisions adaptive to requirements of the power grid, both avoiding congestions and maximizing the intake from renewable energy sources. The logic behind the ADAS is a combination of smart charging and routing, that is underpinned with monetary and psychological incentives.

A. ELECTRIFIC ADAS Frontend

The ADAS Graphical User Interface is a frontend application which the EV driver can use to optimize his impact on the grid, the health of the EV's battery and the utilization of locally available renewable energy. From the perspective of the user this application helps to save time, money and to be environmentally friendly while transparently displaying various routing and charging options with specific tags of cost, duration and greenness.

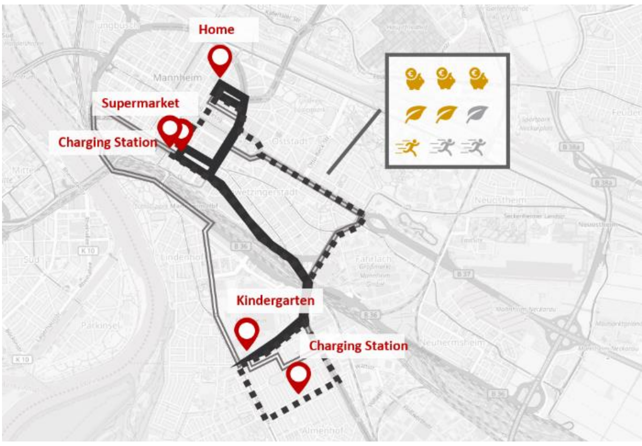

Figure 2: Smart Routing

In Figure 2 the idea behind smart routing is shown: At the beginning, the driver needs to specify the trip and planned activities that will be completed in a predetermined time frame, e.g. one day. This includes personal constraints which a driver might have, like latest arrival or earliest departure time. Then, a set of routing algorithms (developed by the Czech Technical University[2]) computes the fastest, the least costly and the "greenest" route including charging options. All three route characteristics (cost, greenness, time) are comprised of different parameters. For example, the cost factor considers potential battery degradation and charging or energy prices.

In the example from Figure 2, the EV user specified a trip with two activities, kindergarten and charging station. The black line represents the fastest route which might be the same route as the suggestion of a traditional navigation system. The least costly route is the dotted line that suggests a charging station near the kindergarten. This CS for instance has a slow charging point with low grid impact and therefore is cheaper compared to other charging points in the area. The third alternative route, proposed by the ADAS, is the greenest route. In the example at hand, this route is the greenest, because the CS at the supermarket is fed by roof-top photovoltaics. For the proposed charging timeslot, the sun is expected to shine brightly. As this CS is highly frequented and offers fast-charging, it is costlier than the second alternative.

B. ELECTRIFIC ADAS Backend

In order to calculate the three different routes, various inputs need to be considered. For example, information about the grid status is essential, e.g. about power quality, renewable energy predictions, price estimations, peak planning and more. Additionally, driving and charging data about other EV drivers need to be gathered, analyzed and processed. Also, the driving and charging suggestions should be conform to the user's profile and preferences. In order to consider these inputs, the ADAS is connected to a multitude of Microservices via API. Sticking to these modular services makes the ELECTRIFIC solution interoperable to other systems. Additionally, this architecture enables the remaining technical components to smoothly interact and exchange necessary information with each other.

IV. Smart Charger

Currently, the charging process of EVs takes care of only fulfilling its objective (i.e. charging) without taking into account other facts such as the grid status, available renewables, etc. With ELECTRIFIC, a certain level of smartness is integrated during the charging process that considers not only its objective of charging the EV, but also the status of the grid in terms of its power quality, percentage of available renewables as well as the available power capacity. However, adding smartness to the charging process requires additional effort in terms of coordination between different involved stakeholders. For the implementation of smart charging (see Figure 3), both the Distribution System Operator (DSO) and Charging Service Provider (CSP) require to tightly communicate.

The DSO sends within specific frequency (e.g. every 15 minutes) the predictions about the available power capacity of the grid (including renewables) as well as information about voltage fluctuations, flickers, harmonics, etc. The CSP upon receiving this information, can compute the available capacity for charging of the EVs without neglecting power quality KPIs such as voltage fluctuations, flickers, harmonics, etc. These calculations serve to provide the ADAS with all possible offers of CSP for charging EVs.

[2] http://cs.fel.cvut.cz/

Note that these offers are listed based on the available charging connectors.

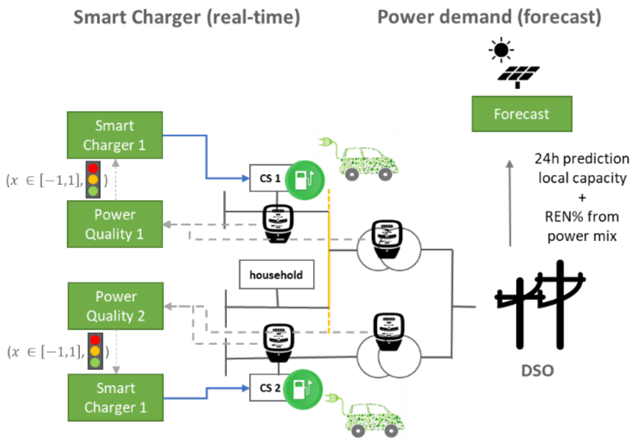

Figure 3 ELECTRIFIC Smart Charging System

Apart from the aforementioned EV charging planning phase, the smart charger has also the responsibility of regularly checking the current grid status. It has to take appropriate measures when the grid stability conditions are in jeopardy. For instance, assuming that after sending offers to the ADAS and the charging process being planned, during the charging of the EV the grid's power quality conditions change drastically. Hence, the smart charger takes this fact into account and starts to reduce gradually the charging rate of the CS for the already connected EV. It proceeds to reduce the rate until the grid status is back to the green/yellow level according to the traffic light concept (see Figure 4).

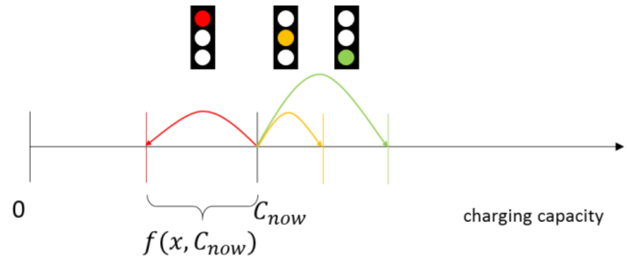

Figure 4 Grid status levels

If still the power quality values are at the red level, the smart charger completely stops the charging process in order to guarantee the stability of the grid. Thus, it can be noticed that for the smart charger the grid's stability has the utmost priority.

V. CHARGING SCHEDULER

Since electromobility is not only restricted to EVs of single users, but also to commercial fleets, further steps have to be taken. In the case of Germany, more than 90% of the EVs in the country are brought to the streets by Electric Vehicle Fleet Operators (EFOs) [5]. Therefore, we develop a charging scheduler (see Figure 5) which optimizes the charging process of a whole fleet according to different optimization criteria.

For this objective, different input parameters need to be incorporated into the technical solution. Firstly, the State of Charge (SoC) of each EV's battery at the start of a charging schedule is a crucial information. This is necessary in order to determine the required energy to charge the battery to 100%. Secondly, the charging scheduler needs to know the booking schedule of the fleet, i.e. when each of the EVs is needed for a certain trip. Based on these data, the charging scheduler can derive a time interval, in which a charging process should be performed. Depending on the booking schedule, some EVs might be needed earlier in the morning compared to others. For this reason, the charging scheduler may prioritize them in order to guarantee availability to EFO customers or employees.

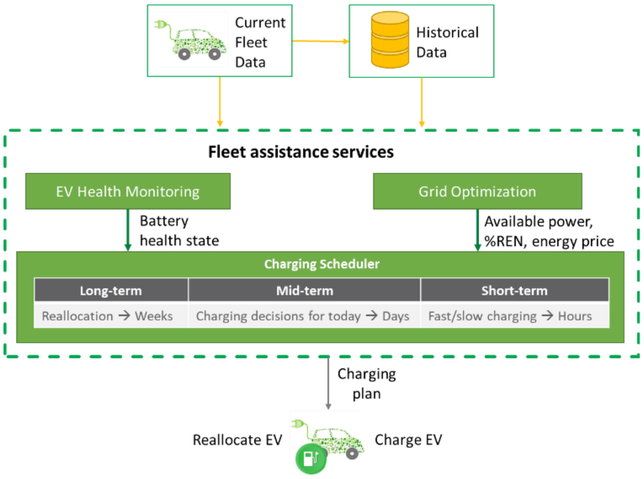

Figure 5 Charging Scheduler

Besides these basic preconditions, four optimization criteria are provided to the EFO. These are the (1) maximization of renewable energies in the energy mix, (2) increasing grid stability, (3) lowering the energy price for charging the fleet and (4) retaining battery health of the EVs. For criteria #1 to #3, forecasts from the charging infrastructure are needed in order to plan the charging schedule for the next hours or days. Regarding criterion #1, a forecasted series of Ratios of Renewable Energies (%REN) in a certain time interval is important. This way, the charging scheduler can decide for which timeslots to set charging processes in order to keep %REN high during charging. In a similar way, a forecast of available power capacity is a precondition to schedule charging processes in order to exploit the grid without causing breakdowns. For example, in times of oversupply, EVs could store the energy which isn't used by other consumers in the grid. As EFOs want to optimize their business, criterion #3 might be helpful. Based on a predicted energy prices at certain times in the future, charging schedules can be organized in such way, that the EFO pays less for the required energy. As last optimization goal, criterion #4 is based on the idea to prolong the lifespan of EV batteries. Here, different charging techniques (e.g. slow charging at ~3.7 kW or fast charging from 20 to 50+ kW) might have different influence on the battery's degradation process. Thus, by analyzing the health status of the battery beforehand and by investigation of the charging influences on the battery health, the charging scheduler can create an individual schedule which retains the overall fleet battery health.

The actual charging processes, proposed in the charging schedule, need to be (manually) accepted by the EFO in a last step, as this significantly influences the EFOs business. Here, it should be possible for the EFO to accept or freely move charging slots in a graphical user interface according to its own decisions. Consecutively to this process, CS are reserved by the charging scheduler so that the EVs can be charged later on according to the schedule. Furthermore, the individual charging processes are controlled by the smart charger (see section IV).

VI. Evaluation and Outlook

The ELECTRIFIC solution offers a comprehensive approach to tackle large-scale coordinated charging, considering interests of end-users, charging and fleet service providers and grid operators. Different technical components for various actors in the e-mobility ecosystem interact and collaborate with each other in order to manage the distributed coordination of EV charging. Those components are developed, tested [6] and evaluated regarding securing the power grid stability threatened by an increasing grid impact from EV charging. The experiments are executed in Germany, Spain and Czech Republic. For example, in Germany the trials take place in the Bavarian Forest and are coordinated by the E-Wald GmbH[3] in close collaboration with the Bayernwerk AG[4]. Besides the technical challenges (e.g. infrastructural limitations) within the different areas, economical and regulatory challenges need to be considered. The constantly evolving e-mobility market also needs new legal frameworks and adjusted business models to comply with future technical innovations.

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[3] https://e-wald.eu/

[4] https://www.bayernwerk.de