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Costs and Gains of Smart Charging Electric Vehicles to Provide Regulation Services

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Abstract

With increasing liberalization in the electricity market and the expansion of distributed and renewable power generation in Europe, transmission and distribution, as well as market processes related to the allocation of energy, are undergoing an evolutionary development to accomplish efficiency and reliability in the presence of fluctuating energy availability and new technical and regulatory requirements. The paper at hand investigates from a business point of view the introduction of smart charging electric vehicles to enhance the reliability of the future electricity grid. A structured analysis of respective parameters is performed for business cases in existing short term energy markets. Market-based and regulatory concerns are considered to outline a scenario where an aggregator controls charging and/or discharging of electric vehicles and provides ancillary grid services. To extend the analysis further, a simulation based evaluation is implemented by means of an agent-based traffic simulation framework.

Keywords: electric vehicles, regulatory energy, vehicle-to-grid, smart charging, agent-based traffic simulation

1. Introduction

One Major challenge in the future electricity network infrastructure will be to integrate a significant share of energy sources with fluctuating grid input on different levels of the network. To make efficient use of these resources, time gaps between energy generation and consumption need to be narrowed, demanding for either flexible load control of energy consumers or efficient storage technologies. Grid services facilitated through battery storage are various. Possible applications comprise storing renewable DG production, time shifting of demand to avoid peak prices, price arbitrage in real-time pricing situations, off-peak charging, utility control for targeted enhancement, demand response, load management and reliability enhancement.

Nevertheless not all of these services can well be provided by vehicle battery storage, since mobility as their primary purpose may limit them in size and temporal availability for the electricity grid. A comprehensive IT-infrastructure can however facilitate joint operation of e.g., a pool of vehicle batteries to achieve the dispatch of relevant capacities with sufficient reliability. This approach requires that an aggregator must

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be granted tools and permissions to provide grid services or so-called ancillary services through controlled charging and discharging of a fleet of vehicles. Some of these services which are regarded in this analysis are desribed in detail in the following section.

For large scale electricity storage it is shown in [1] that primary regulation can be provided in a profitable way. Electric vehicles (EV) on the other hand can only under certain circumstances be used as spinning reserves and regulation [2, 3]. Possible regulation profits per year and vehicle are calculated to be within a range of 700 to 3.000 US$ [3]. With a focus on US electricity markets, two electricity markets that are interesting for V2G applications from an economic perspective are specified : (1) spinning reserves and (2) regulation [4]. They also point out that the market for peak power can be economic for V2G under some circumstances, whereas EDVs cannot provide base load power at a competitive price because of limited energy storage, short device lifetimes, and relatively high energy costs per kWh. In [5] various parameters wich are also regarded in the study at hand and which affect the profitability of EV ancillary services are specified and it is shown that, under certain assumptions, electric vehicles can be used in a profitable way for negative secondary regulation. However, regulatory changes in the provision of these services demand for an updated investigation of potentials for electric vehicle aggregators to participate and profit on these markets. Additionally, as the amount of smart charging infrastructure installed by the aggregator is the main cost driver, different charging infrastructures need to be evaluated with respective hardware installed e.g., at home and/or at work. In the paper at hand, these points are adressed in a scenario-based analysis which is then used as a basis for the implementation of an agent-based simulation to investigate further potential benefits from smart charging electric vehicles.

The remainder of this paper is structured as follows: We start by providing an overview of the framework of possible European markets that may facilitate ancillary services provided by electric vehicle aggregation (see Section 2). Subsequently, available electrical power for each energy product on these markets is calculated (see Section 3). We proceed by giving insight into the costs and revenues for each energy product (see Section 4). Subsequently, we substantiate the plausibility of our arithmetical data by means of an agent-based traffic simulation (see Section 5), before finally, we wrap up with a conculsion (see Section 6).

2. Regulation Markets

In Europe, different energy markets can be used to trade electricity for smart charging or V2G services as for example primary, secondary and tertiary regulation, which will be described regarding the markets in Germany in the following paragraphs.

2.1. Primary Regulation

Primary regulation is provided to automatically balance electricity supply and demand in the grid. It must be activated immediately when balancing is needed, must be available to full extent after 30 seconds and last for at least 15 minutes without interruption. Beginning in 2011, primary regulation may be provided through pooling multiple devices/generators. Minimum power is set to +/-1MW symmetrically with a minimum increment of 1MW. Tenders are published on a weekly basis for the subsequent week. Primary regulation is priced based on power provision. Electric work is not paid for separately. These recent changes in regulation facilitate EV-based ancillary services. On the one hand, aggregation of devices is legitimate; on the other hand, the reduced minimum power corresponds to 100 to 1000 vehicles, depending on maximum charging load, which appears to be a manageable pool size for an aggregator. Furthermore, the short term tenders of one week duration make planning for vehicle availability easier.

2.2. Secondary Regulation

For the provision of secondary regulation, two different time periods are distinguished and traded separately. Main time frame is from Monday to Friday 8:00 o'clock till 20:00 o'clock. All other times belong to the secondary frame. Tenders are also published for one week. Secondary regulation is traded with distinct prices for power provision and actual electricity or work provision. Secondary regulation control minimum power has been lowered to 5MW within 2011. The minimum increment amounts to 1MW and pooling of devices is legitimate. New devices or generators may be added to an active pool at the beginning of every 15 minutes. Secondary regulation must be available to full extent within 5 minutes. Although after 15 minutes tertiary regulation is supposed to take over grid balancing, secondary regulation may in some cases be needed for more than an hour.

2.3. Tertiary Regulation

As mentioned above, after 15 minutes of secondary regulation provision, tertiary regulation takes over grid balancing. Load will usually have to be provided for up to one hour, but may have to be provided longer in some cases. Tenders are issued on a daily basis for six separate time frames of the subsequent day and for positive and negative regulation separately. Prices are provided for power and electric work. Minimum power and minimum increment are 5MW and 1MW respectively.

Assumptions for the future development of electricity prices on these markets can only be made under some degree of uncertainty. Nevertheless, existing data published by transmission system operators[1] is used to estimate possible economic benefits from vehicle-based regulation services. Detailed market data on secondary regulation can be found in [6]. Prices for tertiary regulation represent the mean values of 2010 results for all 12 products (six time frames, positive and negative).

3. Available Electrical Power and Work for Ancillary Services

The viability of smart charging systems and a positive cost-benefit ratio depends on numerous factors. Some of them are related to the vehicle - including the battery - others depend on the infrastructure and user behavior. As future development of some parameters is difficult to predict, assumptions need to be made. The most basic parameter in this use case is the number of electric drive vehicles that will be provided at a specific point of time. Forecasts and estimations vary greatly in different studies. Many European countries have determined goals for the number of vehicles on the road by 2020. Besides, many of the large European cities have set ambitious goals concerning the number of EV on the street in the near future. For a scenario involving smart charging algorithms, these figures are more significant, since regional scenarios (e.g., restricting EV charging infrastructure eligible for an aggregators program to a specific region or city) are easier to implement, control and maintain. Hence, as an example, the 2020 goal for the city of Berlin in Germany is chosen, comprising 100.000 electric vehicles in the urban area.

The availability and distribution of charging infrastructure in urban areas is another parameter that requires focus. In this high level evaluation of the EV scenario, only three very specific infrastructure configurations will be regarded. In the first configuration, the vehicle owners have a possibility to connect EVs for charging at home; in the second scenario, infrastructure is provided at work only; in the third scenario, charging stations are installed both at home and at work. These simplified configurations serve as good indicators for available capacity in a realistic future scenario.

Diurnal driving distance and commuting patterns of EV fleet individuals are further important factors in this calculation. In Berlin, commuters with a private car travel an average distance of 35 km daily, including driving to work and back. While this does not vary greatly among weekdays and weekends, the destinations on weekends are different from the work place, so charging station availability at the work place will have no effect on the available storage here. Depending on the time of departure from or arrival at a charging station, the overall available battery capacity increases or decreases. Typical weekday commuting patterns of vehicle owners in large German cities are shown in Figure 1.

While this distribution may vary slightly in different cities, the overall patterns are very similar. To account for the fact that not every user will be able to connect their vehicle at the destination, even if a charging station is present, a reliability parameter is introduced here. A reliability of 0.5, as it is used in this arithmetical analysis, expresses that only 50% of all vehicles arriving at a charging station will be connected and therefore available for grid services. Altogether, these parameters influence the time dependent availability

[1] www.regelleistung.net/ip/action/index?language=en

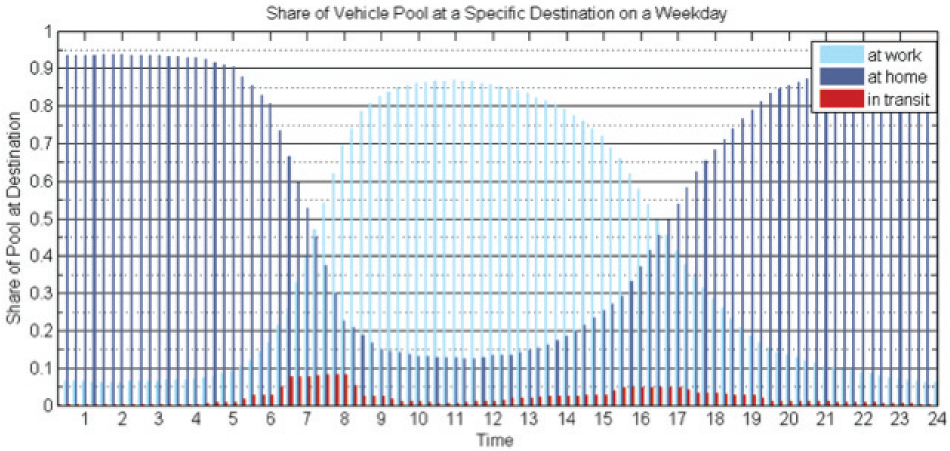


Fig. 1: Availability of Electric Vehicles at Home and Work Location on a Weekday.

Table 1: Available Capacity on Secondary Regulation Market in MW

Regulation Type Security Factor Time Frame	Positive 1.5 Main	Positive 1.5 Secondary	Positive 2.2 Main	Positive 2.2 Secondary	Negative non Main	Negative non Secondary
Home	11	26	5	12	8	19
Work	12	0	6	0	9	0
Home & Work	81	81	39	39	60	60

of load and capacity of an aggregated electric vehicle pool, and hence the potential capacity of regulation reserves traded by an aggregator. Depending on the ratio of maximum positive or negative load and capacity, either one can be decisive to achieve the requirements of a specific market. Maximum load per individual vehicle or station is set to 3.7kW positive or negative here and will be available constantly when the EV is connected and not completely charged or discharged. Other than this, the available capacity clearly varies with the minimum driving range and diurnal driving distance. To render a more realistic scenario concerning user acceptance, the available capacity is calculated not only on the basis of daily driving energy consumption, but also with a security factor (SF) of either 1.5 or 2.2. This expresses that at any point in time, driving range of all vehicles must be 1.5 or 2.2, times the capacity needed for daily commuting. The theoretical maximum load and capacity serve as input parameters for the calculation of the actual "marketable" load of the scenario. Market-specific requirements, as they have been mentioned before, are decisive for the scenario results, such as minimum available load and minimum duration of service provision. Capacities of 0 may also indicate that the actually available capacity is below the minimum market requirements.

In a scenario with (dis-)charging infrastructure installed at work only, available electrical work (as well as power) is zero for primary regulation, since this service is tendered for a weekly period with no subdivision into time frames and therefore missing availability of vehicles during the weekends becomes the limiting factor. Furhermore, primary reserve is traded symmetrically and therefore needs to be available positive or negative at any point in time. For home charging, the volume of primary reserves is 8MW and 5MW for SF=1.5 and SF=2.2 respectively. Table 1 depicts maximum capacities available for an aggregator for the example of secondary regulation services. These values serve as a basis vor profitability evaluation and have been calculated for all ancillary services and scenario configurations. Respective results are summarized in the following section.

Table 2: Aggregated Costs for ICT and Operations

Setup	Investment Costs	Annual Costs
Home or Work Charging — Unidirectional	€ 7.1Mio	€ 4.8Mio
Home or Work Charging — Bidirectional	€ 62.6Mio	€ 4.8Mio
Home & Work Charging — Unidirectional	€ 14.2Mio	€ 9.6Mio
Home & Work Charging — Bidirectional	€ 125.2Mio	€ 9.6Mio

Table 3: Annual Revenues from Secondary Regulation in Mio €.

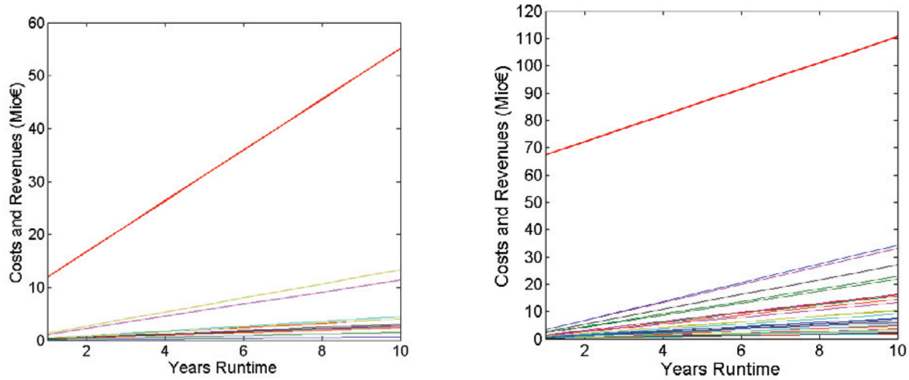
Regulation Type	Positive	Positive	Positive	Positive	Negative	Negative
Security Factor	1.5	1.5	2.2	2.2	non	non
Time Frame	Main	Secondary	Main	Secondary	Main	Secondary
Home	0.66	2.28	0.30	1.05	0.24	1.14
Work	0.72	0.18	0.36	0.00	0.27	0.00
Home & Work	4.84	7.12	2.33	3.43	1.78	1.14

4. Costs and Turnover from Power and Electrical Work within one Year

Estimation of economic factors for the electric vehicle scenario is done under some degree of uncertainty. Nevertheless in the following paragraphs, relevant cost and price estimations for the scenario simulation are listed. Since charging infrastructure will be needed for EVs anyhow, only additional costs are regarded here [5]. To facilitate market based control of EV smart charging, a communication and control system is needed. For V2G services additional bidirectional electronics are necessary. The price of an appropriate communication system is estimated to be around € 71 [5], bidirectional electronics about € 0.15/W which amounts to about € 555 per charging spot for a maximum discharge load of 3,7kW. The process of operating a pool of vehicles as described in the scenario is similar to a Virtual Power Plant (VPP) with mobility concerns as a specific characteristic. Therefore, operational costs are assumed to be € 1/month/connection for scheduling, control, costs of database and maintenance of ICT respectively [7]. The ecpenses for each configuration are summarized in Table 2.

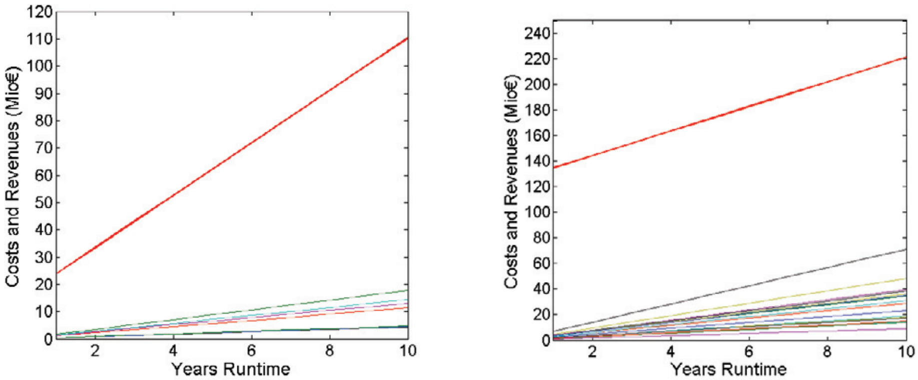
From these calculations and assumptions, the economic potential of the scenarios described can be calculated for the aggregator. In the scenario, primary and secondary reserves are calculated for weekly tenders, tertiary reserves are tendered on a daily basis or on the last work day of a week for the weekend. The amount of reserve electricity that will actually be provided within a tender period is difficult to predict. It depends on the price offered by the aggregator and can therefore be varied to a certain extent by increasing the range between price offer for power and work. Since primary reserves do not provide any additional revenues for electrical work, it is calculated on power capacity only. In all other cases, average values from above for power and work provision are added and calculated for the time span of one year to provide an overview of the overall revenue of the aggregator. It is assumed that during one tender period, electricity is provided on average for seven hours at full contracted capacity. In the case of tertiary regulation it is assumed that on average electrical work is provided at full capacity for 15 minutes per day. However, currently the average dispatch is yet below this value. Exemplatory results for secondary regulation are summarized in Table 3

Examplatory detailed results are shown in table 3 for secondary regulation. In figures 2 to 3, scenarios are depicted for all four infrastructure configurations (scaling of ordinate varies). The bold red line indicates aggregated costs, while each other graph depicts the aggregated revenues for one product that is theoretically feasible in this infrastructure configuration. However, with the assumptions described in the previous sections and according to this arithmetical analysis, no product would cover the annual costs of operations and maintenance for an aggregator. Clearly, investment costs and annual expenses are too high for any feasible scenario described so far. Nevertheless, further research will be necessary to investigate how variations in the cost structure, technical parameters and mobility patterns bear the potential to enhance the overall cost benefit ratio.



(a) Unidirectional Infrastructure (b) Bidirectional Infrastructure

Fig. 2: Costs and Revenues from Ancillary Services with Infrastructure installed at Home or at Work.



(a) Unidirectional Infrastructure (b) Bidirectional Infrastructure

Fig. 3: Costs and Revenues from Ancillary Services with Infrastructure installed at Home and at Work.

5. Simulation

So far, the presented numbers are strictly arithmetical. In order to be able to investigate variations in parameter setup and configuration variations in the future, we decided to evaluate our approach by means of a computer-aided traffic simulation and test the most suitable scenarios in the work at hand, which is tertiary regulation with unidirectional power flow and infrastructure installed at home only. However, as we were dealing with electric vehicles, we had put emphasis on several aspects. First, we had to consider the particular characteristics of the electric powertrain. Secondly, we had put focus on the driver's behavior. It is our opinion that drivers of electric vehicles require more comprehensive planning capabilities than drivers of conventional, fuel driven vehicles do, due to the limited operating range of electric vehicles. Accordingly, drivers of electric vehicles are likely to schedule their journeys more effectively to avoid restrictions in their mobility. Also, drivers have to account for charging and V2G intervals as both procedures usually occupy a fair amount of time. The bottom line is, that any reasonable driver conceptualization has to account for strategic planning features.

As we were not able to identify existing approaches with matching features [8], we decided to custom develop an event driven, microscopic traffic simulation framework [8]. Foundation to this framework is a driver conceptualization [9, 10, 11] which accounts for the requirements we have mentioned above. We followed the definition of *Wooldridge* and *Jennings* [12], and designed the driver as an agent, which is able to act autonomous, reactive, pro-active and socially competent and to incorporate changes in its environment. For the behavior conceptualization, we followed a popular model for the conceptualization of human behavior: *The BDI model* [13]. We configured the driver agents to be aware of their domestic charging infrastructure. Further, we designed the drivers to be able to dynamically recognize other charging options during the simulation and to consider those for their strategy generation henceforth.

We selected the capital region of *Berlin* and a scenario where charging infrastructure is installed at home. Based on a comprehensive mobility study [14], we configured a typical commuter behavior for the drivers. On average, the examined drivers completed a daily road performance of 35 kilometers. In total, we simulated three consecutive working days and focused on the potential amount of negative regulatory energy for the relevant hours between eight o'clock, in the evening and four o'clock, in the morning, which corresponds to two time frames of tertiary regulation. The short tender periods and narrow time frames of tertiary regulation are very appealing to smart charging scenarios. Planning and forecasting is enhanced due to the fact that available capacity needs to be specified only for the following day or weekend and especially these time frames are very well suited for home charging scenarios.The results are illustrated in Figure 4.

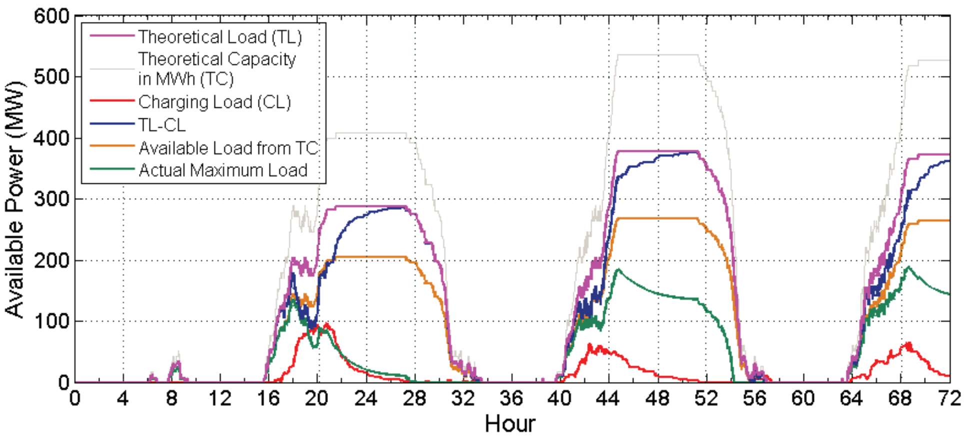


Fig. 4: Simulation Results

The red graph depicts the charging load drawn by the EV fleet. The blue line expresses available regulation load taking into account the actual charging load (red line). The purple line shows the theoretically available load of all connected vehilces, but does not reflect the actual state of charge of the battery. This however is factored into the values presented in the green line, together with the assumption that regulation must be available for at least two hours per regulation period. As can be seen, the restricting factor, or the smalles values, come from the available electrical work of the vehicle fleet (green line). For the example of tertiary regulation, available regulation power for the periods of 8:00pm to 0:00am and 0:00am to 4:00am (vertical dotted lines) amounts to 137MW and 118MW respectively for home charging from the third day on. Values of the first two days suffer from the fact that simulated vehicles start with a full battery at 0:00 am, which does not correspond to the energy charging need derived from diurnal commuting.

6. Conclusion

In this paper, a future scenario for the provision of ancillary services with a pool of electric drive vehicles has been investigated with a focus on profitability. The parameters used to model availability of energy, such as infrastructure configurations, reliability, minimum driving range and specific ancillary service products or time frames have a strong impact on possible revenues. However, given the parameter set and calculations at hand, no actual regulation product bears incentives or a positive contribution margin for this scenario. Further investigation should also incorporate a stronger focus on specific products as for example night time frames of negative tertiary regulation. These products are very suitable for commuters mobility patterns and benefit from short term tender periods. Due to uncertainty of future development of characteristic parameters, especially the development of market prices for reserves electricity, with increased volatile energy provision from RES, the average capacity of vehicle batteries etc., more detailed analysis is needed to further clarify under which exact circumstances this scenario could be implemented to narrow the gap between total costs of ownership between combustion engine vehicles and electric drive vehicles. To facilitate this, an agent-based traffic simulation incorporating planning capabilities of the EV driver and the given parameter set was implemented and tested, rendering the results described in section five. This tool will facilitate further, detailed investigation of simulation of mobility and market behavior to identify which market strategies and dynamic driver behavior has the potential to enhance or also to worsen profits of ancillary services through aggregated electric vehicles.

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