Potential of Electric Vehicles for Providing Regulating Power Based on German Mobility

Mohammed Hijjo and Paul Scheer

Institute of Human Factors and Technology Management IAT
University of Stuttgart, D-70569 Stuttgart (*Germany*)
E-Mail: mohammed.hijjo@iat.uni-stuttgart.de

Abstract— The ongoing transition of the energy sector, as well as the rising adoption of electric vehicles (EVs), both have led to new requirements to keep up with these new technologies. One of the main challenges to the grid operators is to keep the balance between the generation and the demand through the so-called regulating power. As the reliance on renewable energy sources (RES) increases, the power network is expected to accommodate a greater amount of surplus energy. The increasing adoption of EVs has encouraged the researchers to investigate their capability to absorb the surplus power generated from RES and compensate the power network in peaking hours where supplemental reserve might be required. For this purpose, this contribution presents a simulation-based approach assessing to what extent EVs can assist the grid by offering supplemental regulating reserve upon request. The simulation is conducted based on German mobility behavior. Using the data of registered EVs in the German market as a reference, random fleets of EVs are generated. Considering the operational constraints such as the charging rate, stored energy, and the mobility requirements, the available regulating power at the workplace is derived considering two charging scenarios, namely charging at Home alone, or charging at Home and at Workplace. In both scenarios, the positive and negative regulating power profiles are derived over the day. The results show that the participation of EVs in the German reserve power market is technically possible, even during the day.

Keywords—Electric Vehicles, Regulating Power, charging at Home, charging at Workplace

NOMENCLATURE

B_C	Battery capacity
CH_F	Percentage of vehicles charging
D_d	Average daily distance
D_S	Reserve distance
E_{Neg}	Energy available for negative regulation power
E_{Pos}	Energy available for negative regulation power
MC	Number of Monte Carlo iterations
N_{EV}	Number of vehicles
P_A	Charging power
P_{Reg}	Regulating power
P_L	Power of the connection line
r	Correction factor
sC	Specific consumption
SoC	State of Charge
t_{Reg}	Duration of the query
η	Efficiency of charging and discharging

I. INTRODUCTION

In the "Renewable Energy Sources Act", Germany formulates the wish to cover 80% of its electricity requirements from renewable energy by 2050. The implementation of this goal leads to several challenges. Firstly, a high percentage of such unpredictable energy sources leads to a more volatile grid frequency. To keep this within a tolerable corridor, the transmission system operators (TSOs) use regulating power. Currently, mainly conventional thermal power plants can provide power for regulation. Renewable power plants alone cannot meet the requirements of providing regulating power. As an increasing share of renewables is accompanied by the simultaneous loss of many conventional power plants, an alternative source of regulating power is needed.

The increasing number of EVs and the political intention to support this trend have led researchers to consider EVs as potential new participants in the Operating Reserve Market [1, 2]. In addition to the transformation of the electricity sector, the restructuring of the mobility sector towards alternative drives and away from the conventional combustion engine is an objective of the German government [3]. Increasing the number of electric vehicles is a central component of Germany's efforts to meet its climate targets [4]. The increase in the number of EVs expected from these political objectives has also been seen in Germany in recent years. The stock of battery electric vehicles (BEVs) rose from 1.2×10^4 vehicles in 2014 to more than 8×10^4 in 2019 [5]. In view of the political targets and the increased efforts to reduce CO_2 emissions, it can be assumed that this increase will continue. EVs appear to be an ideal provider of ancillary services.

This is because they can respond fast to a signal from the market, are available in small increments and are distributed across the entire grid area [6]. The provision of electrical energy stored in the battery of an EV to the grid is described by the concept "*V2G*" (*Vehicle-to-Grid*). However, this work also deals with the possibility of grid services to store excess energy from the grid in the battery. In this case, the focus is on the bidirectional V2G.

Electric vehicles are suitable for energy storage since the car is stationary most of the day. The prime function of the vehicle is for transportation, and on average it is utilized for only 6% of the time in a day. The remaining 94% of the time it is in parking status and can be used for ancillary services [7]. Grid services can only be performed if the EV is connected to a suitable bidirectional charging infrastructure. The power and energy that a single EV can provide are relatively low. A grid service can therefore only be provided by a pool of EVs. This also requires communication between the EVs. In order to increase the willingness of vehicle owners to let their EVs participate in network services, it is important to ensure that the energy provided to the network is limited, so that the mobility behavior of the owner is not affected.

A. EVs Participation in German Energy Market

In principle, participation in various electricity markets is conceivable, such as intraday, day-ahead or the regulating power market. In spite of the ongoing discussions about the possible load shifting potential of EVs [8], participating in the reserve power market has major advantages: Firstly, the provision of regulating power alone is remunerated. Secondly, comparatively small amounts of energy and power are sufficient to participate in the market. Thirdly, regulating power is relatively well paid. The financial aspect is important. It must be worthwhile for the vehicle owner or the company to invest in the necessary bidirectional infrastructure. The investment costs are estimated at 100 € per year [1]. These advantages of the reserve power market outweigh the disadvantages to such an extent that most studies now consider only this market to be relevant. Thus, this paper focuses on participation in the regulating power market.

In addition to the supra-regional transmission of electricity, the German TSOs are also responsible for grid stability and thus also for the use of regulating power. Germany is divided into four control areas, for each of which one of the four German TSOs, Amprion, TransnetBW, TenneT TSO and 50Hertz, is responsible The TSOs procure the regulating power through tenders on the website *www.regelleistung.net*, which is set up for this purpose. There are three different types of regulating power in Germany: Frequency Containment Reserves (FCR), automatic Frequency Restoration Reserves (aFRR) and the manual Frequency Restoration Reserves (mFRR). The FCR is responsible for stabilizing the grid frequency in the event of a fault. It is automatically activated within 30s after the occurrence of an unplanned power plant outages or other unpredicted events. The aFRR replaces the FCR and returns the frequency back to the nominal frequency. It is in turn replaced by the mFRR.

A distinction is also made between positive and negative regulating power. Positive or up regulating power is activated if there is a deficit in supply (e.g. due to a sudden stop of a power plant), whereas negative or down regulating power is activated if overproduction occurs (e.g. due to surplus PV or Wind production). This is then referred to as positive or up regulation [9, 10]. There are separate products for mFRR and aFRR for positive and negative regulating power.

The FCR is traded as a symmetrical product [9]. The tenders for all three types of regulating power take place every day. mFRR and aFRR are required to dispatch regulating power for 4 h [10]. A minimum bid size of 1 MW applies for the primary reserve power, and 5 MW for the secondary and minute reserve power. However, bids of 1, 2, 3 and 4 MW can be submitted if the bidder submits only one bid per time interval and control area [10]. For all three types of reserve capacity, bids above the minimum bid value can be submitted in increments of 1 MW [9,10]. The answer to the question of whether and within what framework electric cars can provide regulatory power is focused in the following on the provision of mFRR and aFRR. The FCR market is not considered for two reasons. Firstly, the required dispatch time lasts a whole day and is thus six times longer than the mFRR and aFRR [10]. A long provision period makes it very difficult for EVs to participate, since, among other things, significantly more energy has to be provided. Secondly, the FCR is traded as a symmetrical product. This additionally increases the coordination effort.

In the context, this work investigates to which extent EVs are able to support the grid by providing regulating power. For this purpose, two simulations, one static and one dynamic, will be performed and evaluated.

The remainder of this paper is organized as follows: Section II describes the used dataset and the selection criteria of the user group before applying the analysis. Section III presents a static approach for evaluating the regulating reserve of an EV-fleet. In section IV, a dynamic approach for calculating the potential regulating reserve is presented. Section V discusses the results of the static and dynamic simulations. Finally, conclusion and outlook aspects are provided in Section VI.

II. German Mobility Dataset

A. Regulating Power

In order to be able to make statements about the regulating power requirements in Germany, data of queries of the mFRR and the aFRR of the last two years (06.2017 to 06.2019) in Germany is evaluated. The used data was published on the website "www.regelleistung.net". The resulting key figures for the control area of the TSO TransnetBW are summarized in Table-I.

TABLE-I KEY FIGURES OF THE REQUESTED REGULATING POWER IN THE TRANSNETBW ZONE

	Median Power (MW)	Mean Power (MW)	Median Duration (min)	Mean Duration (min)
Negative mFRR	42	88	30	40
Positive mFRR	45	106	30	40
Negative aFRR	18	70	90	213
Positive aFRR	21	88	75	220

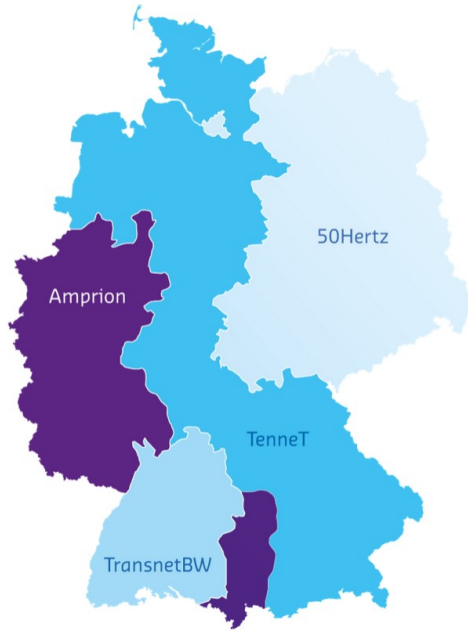The division of Germany in the four control areas can be seen in Figure 1.

Fig. 1. Areas of responsibility of the transmission system operators in Germany [11]

Looking at the key figures in Table-I, it can be seen that, on average, the quantity of the requested power from the mFRR is larger than from the aFRR. The aFRR was called up much more often than the mFRR but the duration of the query was on average shorter. In the period under review, regulating power was queried for the positive aFRR 87% and for the negative aFRR 86% of the time, it was 3% for the positive mFRR and only 2% for the negative one.

B. Mobility Behavior

The dataset of the study "*Mobility in Germany 2017*" is used to simulate the mobility behavior of vehicle drivers [12]. The participants in the study kept a diary for their journey, documenting the date, the distances traveled, and the starting time of the trip. For this work, only those participants are considered who covered their routes as drivers of a car on a working day. The possible locations of stay were divided into four different categories according to [8]: "*Workplace*", "*Home*", "*Driving*" and "*Other*". The evaluation showed a course of stay of the participants over the day, which is shown in Figure 2. It is clear to see that the cars stay at home most of the day. The cars are also at the workplace long enough to be able to provide regulating power. Since the provision of positive and negative regulating power requires the installation of a bidirectional charging infrastructure, the workplace is particularly in focus: It seems plausible that the installation of the required infrastructure on a company site in much larger numbers logistically and financially cheaper than the individual installation on private property. For a more precise assessment of the "workplace" location, the daily course of arrivals and departures is evaluated. This is shown in Figure 3. Furthermore, the distance from home to workplace is also taken from the record.

C. Electric Vehicles

For the technical description of the vehicles, the twenty most frequently registered battery electric vehicle models from January 2017 to September 2019 were considered.
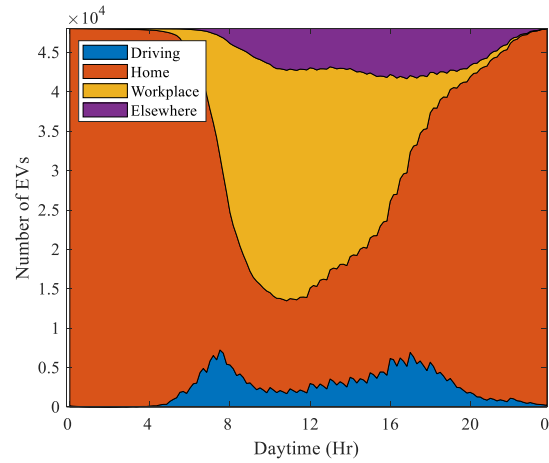

Fig. 2. Vehicle State proportion during a working day

By weighting the desired properties: capacity and specific consumption with the number of vehicles registered, retrieved from the Kraftfahrt-Bundesamt (KBA), the Federal Motor Transport Authority of Germany, average values can be determined [13,14]. Since KBA does not differentiate between different model variants, a minimum average value as well as a maximum average value is calculated.
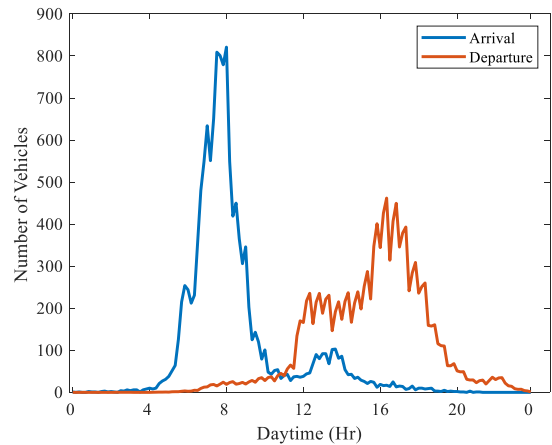

Fig. 3. Number of arrivals and departures to and from the workplace spread over the course of the day

For the calculation of the minimum value it is assumed that all registered cars belong to the model variant with the lowest specs. The maximum value is determined using the model variant with the highest values. The average values for all observed models can be seen in Table-II.

TABLE-II: EVS' AVERAGE CAPACITY AND SPECIFIC CONSUMPTION

	Min. value	Max. value
Battery capacity (*kWh*)	41,4	48,7
WLTP specific consumption (*kWh/100km*)	16,7	18

III. STATIC APPROACH

The static simulation approach is based on the studies [15, 16]. The regulation capacity that can be offered by a single vehicle to support the grid in both directions, i.e. down regulation by absorption the surplus generation or positive regulation by compensating the deficits, is determined. When determining the energy potential, the mobility behavior of the driver is taken into account, as this should not be restricted. The energy demand to cover the average daily distance can be determined by the specific consumption sC and the daily distance D_d. The maximum and minimum values for the specific consumption according to WLTP-standard as well as the battery capacities are listed in Table-II. Since this standard generally underestimates consumption, a correction factor $r = 1,3$ is to be multiplied by the consumption. The energy absorbed from the grid E_{Neg} can only be as much as the energy consumed in one day. The efficiency regarding charging and discharging is set to the factor $\eta = 90\%$. $E_{Neg} = 5,46\ kWh$ is calculated using (1).

$$E_{Neg} = \frac{D_d \cdot sC \cdot r}{\eta} \tag{1}$$

E_{Pos} is the amount of energy the owner is willing to discharge from the battery, minus the energy used. The maximum available energy is shown depending on the capacity B_C. The value for the capacity $B_C = 41.4\ kWh$ is set to the minimum value from Table-II. To ensure that the driver is not restricted in his mobility behavior, a reserve distance D_S of 32 km is also accounted for [16]. $E_{Pos} = 26.10\ kWh$ is calculated using (2).

$$E_{Pos} = (B_C - (D_d + D_s) \cdot sC \cdot r) \cdot \eta \tag{2}$$

In the next step, the capacity of the power line connection P_L for charging and discharging is defined. A main connection with a maximum load of 3.6 kW is assumed. The available regulating power is limited on the one hand by the available energy E_{Pos} or E_{Neg} or by the connected load P_L. Equation (3) is used to calculate the potential power for a number of vehicles N_{EV} for a duration t_{Reg}. Since the regulating power that can be provided safely is to be determined, the minimum of the two limiting factors is taken.

$$P_{Reg} = \min\left(\frac{N_{EV} \cdot E_{Pos/Neg}}{t_{Reg}}, P_L \cdot N_{EV}\right) \tag{3}$$

The available amount of regulation power for selected values for the number of providing vehicles N_{EV} and duration t_{Reg} can bin seen in Table-III. The results of the static simulation can be seen in Figure 4 for down regulation, and in Figure 5 for up regulation. There is a proportional relationship between the number of vehicles and available regulating power. The proportionality factor is, as can be seen, time-dependent in the case of supplying down regulation. If the query duration is 80 minutes or less for providing negative reserve power and for all observed durations of positive reserve power, the proportionality factor is constant. The factor becomes smaller for longer periods for the provision of negative regulation power.

TABLE-III CALCULATED AVAILABLE REGULATION POWER

	t_{Reg} (hr)	$N_{EV} = 100$	$N_{EV} = 1000$	$N_{EV} = 10000$
Down Regulation (MW)	$t = 1$	0,360	3,600	36,000
	$t = 2$	0,273	2,730	27,300
	$t = 4$	0,136	1,365	13,650
Up Regulation (MW)	$t = 1$	0,360	3,600	36,000
	$t = 2$	0,360	3,600	36,000
	$t = 4$	0,360	3,600	36,000

The following relationship seems to apply here: The longer the query period, the smaller the proportionality factor. These two areas can be explained by the two limiting factors. In the area of the constant proportionality factor, the maximum connected load limits the regulating power. In the area of longer query periods, the available reserve energy limits the output. For longer periods, with the same fleet size, the reserve power must be reduced in order to be able to provide performance over the entire period. The available amount of positive regulation power is only limited by the maximum connected load since the available energy is much higher.
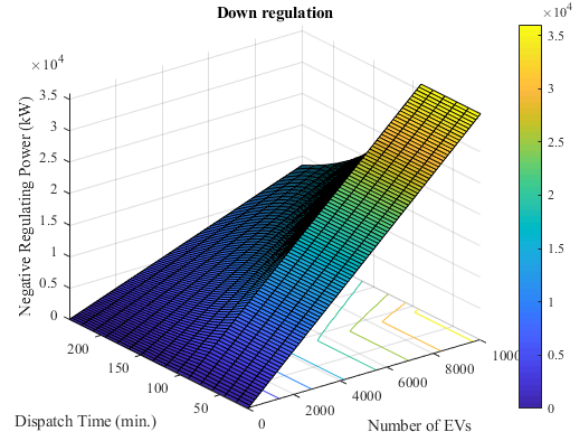

Fig. 4. Down regulation considering the number of participating EVs and the duration of the polling period
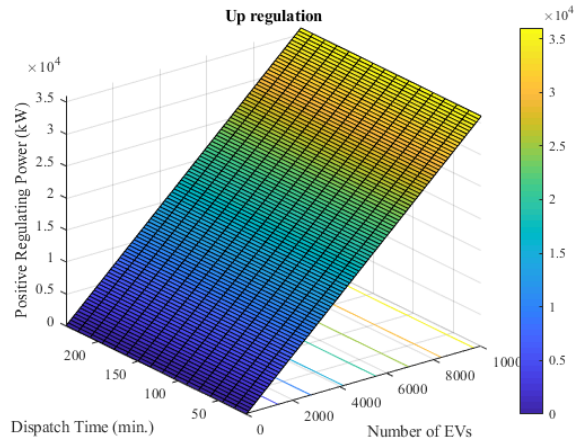

Fig. 5. Up regulation considering the number of participation EVs and the duration of the polling period

IV. Dynamic Approach

In order to be able to assess the effects of different scenarios on the amount of reserve power that can be provided by EVs, a certain scenario is defined at the beginning of each simulation. The size of the fleet of EVs, the duration of the provision of regulating power, the proportion of EVs charging, and finally the number of Monte-Carlo iterations are specified.

In order to be able to use the data in the dynamic simulation, probability density functions (PDFs) are fitted to the histograms of the respective data. With the help of the PDFs, a pool of virtual electric vehicles is generated by forming a random value according to the PDF for a certain property of a car. A virtual car is described by the following characteristics: capacity, fuel consumption, distance between home and work (it is assumed for simplicity that a car only travels two distances a day. From home to work and back again), arrival time at work and departure time. In addition, each virtual electric car is assigned a specific battery charge level at the beginning of the day. After generating the variables, the capacity and state of charge are corrected as required. It is ensured that the battery is charged with sufficient energy to drive back and forth to the workplace, taking into account the distance to the workplace.

The dynamic simulation is carried out with a Monte Carlo simulation. The following calculations take place within a Monte Carlo iteration. Virtual vehicles are generated based on the processed data. The amount of reserve energy is then calculated at any point in the day by adding up the energy available for the provision of regulating power from the cars present. If some of the cars are charged, the additional energy is also taken into account. The charging power P_A is assumed to follow the equation (4). It depends on the current State of Charge SoC and the capacity of the power line connection P_L.

$$P_A = P_L \left(1 - \frac{1}{1 + 50 \cdot \exp(-1.4 \cdot (SoC - 94\%))} \right) \quad (4)$$

The regulating power can be calculated from the retrievable amount of energy by considering the provision time. For displaying the influence of the individual parameters: share of charging vehicles at the workplace (CH_F), provision period (t_{Reg}), number of generated (N_{EV}), and the number of Monte-Carlo iterations (MC), a reference scenario is first presented, with CH_F = 100%, N_{EV} = 5000, t_{Reg} = *4 h*, and $MC = 100$. The daily course of the amount of reserve energy and the regulating power available in the reference scenario is shown in Figure 6. Since regulating power can only be provided if there are enough cars connected to the grid at the workplace, the relevant time frame is from the early morning hours until late afternoon. With the arrival and departure of the electric cars, the available energy and thus, the reserve power increases and decreases accordingly. Only at this time is sufficient balancing power available. The individual provision intervals are clearly visible. At the beginning of the interval, the possible regulating power for the interval is the lowest. If the regulating power measure is carried out directly at the beginning of the

provision period, there must be enough energy available to provide power until the end of the interval. However, the regulating power that can be provided is restricted by the reserve energy. If, however, the request is made shortly before the end of the provision interval, the same amount of regulating power can be provided in a much shorter period. In this case, the connected load is limited by the maximum capacity of the connection to $P_L = 3.6 \; kW$ per vehicle. For the reference scenario, the average SoC of the car batteries increases after the start of the working day, in the morning, as the share of charging cars CH_F is 100%. Accordingly, the amount of the positive regulating energy increases and the negative regulating energy decreases over the course of the day. As the available reserve energy limits the balancing power, the amount of available positive balancing power increases and the amount of available negative regulating power decreases over the time the vehicles are present.
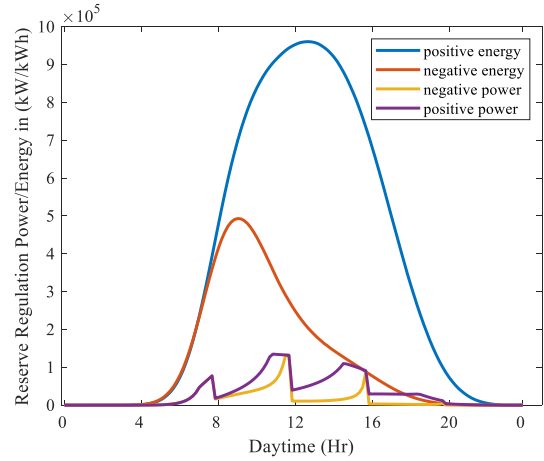

Fig. 6. Reserve energy and regulating power at the workplace over a day.

When changing CH_F to lower values, it can be observed that the conversion of negative energy into positive energy takes place less or not at all. With decreasing CH_F the energy curves become more dependent on the arrivals and departures of the vehicles.

In order to examine the effect of t_{Reg}, the reference scenario is modified so that the t_{Reg}, is set at a value of 2 hours while retaining the other parameters of the reference scenario. It can be seen that, with the same amount of reserve energy, the regulating power does not drop as much at the beginning of the provision intervals. In this scenario, the same amount of reserve energy as in the reference scenario only needs to be provided over half as much time. Thus, significantly higher outputs are possible. Finally, the influence of the number of Monte-Carlo-Iterations is discussed. The output of the simulation is the available energy and power at the workplace, which consists of the sum of the energy and power a single vehicle is able to provide. This fact alone dampens outliers to some extent. The more vehicles are generated the less is the influence of possible outliers. Therefore, we find that high number of iterations are especially necessary when observing small fleet sizes. In order to increase the robustness of the results, several iterations are carried out.

Each additional iteration corresponds to a new observed day. Therefore, the values of the arrival time, departure time and state of charge at the beginning of the day are regenerated at the beginning of each iteration. Capacity, consumption, and commute remain constant over the iterations. After all iterations have been completed, the regulating power is determined by the mean value of all powers of the respective iterations.

The robustness of the result is increased by the fact that, after going through all iterations, the lowest value of the regulating power in a provision period is taken as the maximum amount of power that can be supplied in this provision period. The results of the dynamic simulation can be seen in Table-IV. The amount of regulating power is calculated for selected values for the percentage of electric vehicles charging Ch_F, and the duration of provision t_{Reg}. The number of generated vehicles in this example is set to 1000.

TABLE-IV CALCULATED AVAILABLE REGULATION POWER

	t_{Reg} (hr)	$Ch_F =$ 0%	$Ch_F =$ 50%	$Ch_F =$ 100%
Down Regulation (MW)	t = 1	2.39	1.91	1.52
	t = 2	1.18	0,930	0,715
	t = 4	0,578	0,384	0,295
Up Regulation (MW)	t = 1	1.89	2.40	2.62
	t = 2	0,932	1.22	1.54
	t = 4	0,449	0,615	0,784

V. DISCUSSION

Comparing the results of the static and dynamic simulation, the first thing that stands out is that the specified performance of the static simulation is greater than that of the dynamic simulation for each case considered. This can be in part attributed to a fault in the dynamic simulation: When generating the values for arriving time and departing time it is possible that a car departs from the workplace before its arrival. In this case, the vehicle stays home. However, the values are in the same order of magnitude. Furthermore, the difference between the result values for $(t_{Reg} = 1h)$ and $(t_{Reg} = 2h)$ is significantly greater in the dynamic simulation than in the static simulation of down regulation. The static simulation of the up regulation is not time-dependent.
While almost all dynamic values are halved when jumping from $(t_{Reg} = 1h)$ to $(t_{Reg} = 2h)$, the static values of negative regulation power remain much closer to the power for $(t_{Reg} = 1h)$, especially the positive regulating power. A common feature of both results is a certain proportionality between regulating power and fleet size. This proportional relationship is immediately noticeable when looking at the static values.

The dynamic results show similar behavior, which, however, is not quite as clear. There seems to be an additional effect for the dynamic values when increasing the fleet size, besides the proportionality.

Almost all dynamic values of the two largest fleets are slightly larger than they should be by a proportional relationship alone. It would therefore appear that an increase in fleet size can compensate for the outliers to a greater extent. Another common feature is the temporal course of the regulating power. The characteristic steep increase followed by a plateau is found in the dynamic simulation as well as in the course of the down regulation in the static simulation.

VI. CONCLUSION AND FUTURE WORK

The aim of this work was to assess the potential of electric vehicles to provide regulating power. The impact of different operating conditions was analyzed by simulating different scenarios. In addition to the static analysis, a dynamic simulation was also performed.

The mobility behavior of the Germans and the technical characteristics of the electric vehicles registered in Germany form the basis of the simulations. Examination of the results of the static and dynamic simulations shows that the provision of regulating power at the workplace is technically possible. The workplace was chosen as the place of provision, as the vehicles spend a relatively long time there forming a pool. Additionally, it seems plausible that the required infrastructure could be easier implemented on company ground than on private property.

In all scenarios studied, 3500 EVs were sufficient to achieve the 1 MW required to participate in the regulating power market. If the number of EVs continues to increase, they have the potential to provide a significant share of the regulating power required by the public grid. Charging the batteries of the EVs has a comparably small impact on the amount of power that can be provided, due to the limited capacity of the power connection. The reduction in the maximum duration of the provision or an increase in the fleet size have a much greater impact on the amount of regulating power that can be provided. A larger number of EVs also compensates for the driving behavior of individual people and thus delivers more reliable values. To increase the potential of EVs for providing regulating power, reducing the maximum duration of the query is the easiest measure to implement.

Furthermore, promoting the expansion of bidirectional infrastructure would further increase the potential.

Due to the focus on the area of the provision of regulating power - at the workplace - it was not possible to deal with aspects such as reserve provision in other locations or the implementation of vehicle coordination in this work. However, these points could offer approaches for future research. In addition, the aspect of possible financial remuneration was not examined. A consideration of this area, especially for the provision of regulating power in the workplace, requires further research.

REFERENCES

[1] P. Jochem, T. Kaschub, W. Fichtner, "*How to integrate electric vehicles in the future energy system?*" Karlsruhe Institute of Technology KIT, Working Paper Series in Production and Energy ; 3 June 2013

[2] M. Stötzer, Z. A. Styczynski, K. Hänsch, A. Naumann and P. Komarnicki, "*Concept and potential of electric vehicle fleet management for ancillary service provision*," In: 2013 IEEE Grenoble Conference, 16-20 Jun. 2013.

[3] Federal Ministry for the Environment, Nature Conservation of Germany, Building and Nuclear Safety, "*Summary of the Climate Action Plan 2050*" Nov. 2016, [Online]: https://www.bmu.de/en/download/climate-action-plan-2050/ Last access: 24.1.2020

[4] Resolution of the German Cabinet "*Eckpunkte für das Klimaschutzprogramm 2030 [Key points for the climate protection programme 2030]*,", Sep. 2019, [Online]: https://www.bundesregierung.de/breg-de/themen/klimaschutz/klimaschutzprogramm-2030-1673578, Last access: 24.1.2020

[5] The Federal Motor Transport Authority – Kraftfahrt-Bundesamt, "*Bestand an Pkw in den Jahren 2010 bis 2019 nach ausgewählten Kraftstoffarten [Number of passenger cars in the years 2010 to 2019 according to selected fuel types*]." [Online]: https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Umwelt/2019_b_umwelt_z.html?nn=663524, Last access: 24.1.2020

[6] J. Tomić and W. Kempton, "*Using fleets of electric-drive vehicles for grid support*," Journal of Power Sources Volume 168, Issue 2, Jun. 2007, pp. 459-468

[7] P. Vortisch, B. Chlond, C. Weiß, T. Streit, M. Wirtz, D. Zumkeller, "*Deutsches Mobilitätspanel (MOP) wissenschaftliche Begleitung und erste Auswertungen*," Bericht 2011/2012: Alltagsmobilität und Tankbuch, Karlsruher Institut für Technologie (KIT) Institut für Verkehrswesen, 2012.

[8] Y. Wang, S. Huang and D. Infield, "*Investigation of the potential for electric vehicles to support the domestic peak load*," 2014 IEEE International Electric Vehicle Conference (IEVC), Florence, 2014, pp. 1-8

[9] CONSENTEC GMBH, "*Beschreibung von Regelleistungskonzepten und Regelleistungsmarkt [Description of control power concepts and control power market]*," Feb. 2014.

[10] "*Regulating Power Website - translated*", [Online]: *regelleistung.net*. https://www.regelleistung.net/ext/ Last access: 24.1.2020

[11] Amprion, "*Regelzonen und Verbundnetz [Control areas and interconnected system]*," amprion.net. [Online]: https://www. netzentwicklungsplan.de/ sites/default/files/ basisinformation_uenb_regelzonen.pdf Last access: 19.03.2020

[12] C. Nobis, T. Kuhnimhof: "*Mobilität in Deutschland – MiD. Ergebnisbericht*". Mobility in Germany – Result report. BMVI, infas, DLR, IVT, infas 360. Bonn, Berlin, 2019

[13] The Federal Motor Transport Authority – Kraftfahrt-Bundesamt, "*Bestand an Kraftfahrzeugen nach UmweltMerkmalen, (FZ 13) [Number of motor vehicles by environmental characteristics, (FZ 13)]*," [Online]: https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Uwelt/umwelt_node.html Last access: 16.3.2020

[14] ADAC, "*Diese Elektroautos gibt es auf dem Markt. [These electric cars are available on the market.]*," adac.de.

[Online]: https://www.adac.de/rund-ums-fahrzeug/e-mobilitaet/kaufen/elektroautos-uebersicht/ Last access: 11.11.2019

[15] D. Dallinger, D. Krampe and M. Wietschel, "*Vehicle-to-Grid Regulation Reserves Based on a Dynamic Simulation of Mobility Behavior*," in IEEE Transactions on Smart Grid, vol. 2, no. 2, pp. 302-313, June 2011.

[16] W. Kempton, J. Tomić, "*Vehicle-to-grid power fundamentals: Calculating capacity and net revenue*," Journal of Power Sources, vol. 144, issue 1, 2005, pp 268-279