Agent Based Assistance for Electric Vehicles An Evaluation

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Abstract. Even before car manufacturers start offering series-produced electric vehicles in a large scale, expectations in the electric powertrain are considerably high. Prospective business perspectives are additionally driven by the so called *Vehicle-to-Grid* technology, which allows electric vehicles to not only procure electric energy, but also to feed energy back into the grid network. However, by using Vehicle-to-Grid, energy literally degenerates into an article of merchandise and becomes of interest to several stakeholders. We have developed a multi-agent system, which embraces this exact view and maximises the interest of several stakeholders in using Vehicle-to-Grid capable electric vehicles. The purpose of this paper is to describe the evaluation of our assistance system and to present collected evaluation results.

1 Introduction

In the next few years, the face of the German road network will be subject to one of the most substantial changes compared to the changes occurred in the last decades. Slowly but steadily, major car manufacturers have been selling their first generation electric vehicles (EVs) in the German automobile market. Efforts in selling electric vehicles are further facilitated by the German government which defined the objective to ensure no less than one million EVs on German roads by the year 2020 [1].

However, this ambitious goal of the federal government is not easily accomplished! Even today, there are still many unsolved problems associated with EVs, for example, consider the limited ranges of EVs and also the insufficient charging infrastructure. The frequency of charging for EVs require significantly more times than the frequency of refuelling conventional petro-fuelled cars. These are only obvious problems!

The additional one million electric consumers will impact the energy grid network. Although the million EVs will not significantly affect the grid network's stability because of the allowable capacity of the German energy grid, the negative effects will increase to urban and industrial electricity needs. Based on the target of the federal government [1], we estimate roughly 200.000 EV registrations –and respectively additional electric consumers– for the capital region of Berlin [2]. Based on previous work [2] we can state, that an addition of 200.000 EVs will compromise Berlin's energy grid significantly. The main reason for this

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negative impact is that the grid network's structure can only allow few EVs to be charged simultaneously at the same low voltage systems.

The bottom line is that when it comes to electric mobility, there are still many problems and constraints which have to be considered. These problems and constraints can also be understood as interests of the involved stakeholders. For example, a driver would be mainly interested in unrestricted mobility and in low energy prices. Another example would be from the perspective of an energy supplier. The energy supplier is interested in not compromising his grid infrastructure and to preferably use $C0_2$ efficient energy from renewable energy sources (for the reason of legitimate requirements) in order to charge EVs.

Recently, we have developed a comprehensive assistance system which optimises the utilisation of vehicle-to-grid (V2G) capable EVs for several stakeholder groups. They are: the driver, the vehicle manufacturer, the charging infrastructure provider and the distribution system operator (DSO).

In our previous publications, we have described the concept [3] and provided implementation details [4,5] of our assistance system. We further proposed several business concepts [6]. In this paper we focus on the evaluation of our assistance system.

The remainder of this paper is structured as follows: In the following section (see Section 2), we will give a short introduction of our assistance system. Then, we present the simulation-based evaluation results of our assistance system (see Section 3). After presenting evaluation results, we discuss the efficiency of our assistance system and wrap up with a conclusion (see Section 4).

2 Concept

In this section, we provide a brief description of the implemented assistance system. The interested reader who wants to learn more about our assistance system can obtain our previous publications [3,4,5,6].

In order to facilitate the effective utilisation of V2G capable EVs (in the interest of all stakeholders), we developed an anticipatory approach in which software agents negotiate a charging and discharging profile for a given amount of time.

This profile reflects the interests of the involved stakeholders and complies with several constraints (e.g. mobility of the driver, restrictions of the energy grid, renewable energies, etc.). For the implementation of an anticipatory system, we required information on the expected behaviour of the driver and his EV. We demanded participating drivers to maintain a personal calendar from which we derived the expected usage pattern. For this purpose, we equipped drivers with a Microsoft Exchange calendar and implemented a smart phone 'app', which allowed mobile users to enter his/her activity patterns on-the-fly. Different facets of the smart phone app are illustrated in Figure 1.

Although it was our intention to affect drivers as little as possible, we required the information of the drivers schedule of the day and the expected usage of his EV in order to optimise charging and feeding (e.g., sending energy back to

Fig. 1. Home screen, calendar and vehicle view of the smart phone application

grid network from EV's battery) schedule that will impact all the stakeholders involved.

We use this information not only to calculate an expected energy requirement curve for the battery of the electric vehicle, but also to identify potential charging or feeding intervals during in the driver's the day. In order to finalise charging and feeding schedule for the day, we compare the potential intervals with a so-called priority curve. We obtain this curve from the DSO, and it represents the share wind energy in the overall electricity production. An example priority curve is shown in Figure 2. While high values indicate an increased availability of wind energy and an interest of the stakeholder for charging processes, low values indicate a low availability of wind energy and an interest for feeding energy back to the energy grid network.

Our assistance system accounts for the driver's preferences. It is possible to specify an individual level of risk tolerance. This tolerance factor determines the driver's willingness to exploit profitable charging and feeding intervals on the expenses of his mobility. Further, drivers are able to specify a comfortability factor, which determines the tolerated distance from a charging station to an appointment location.

In addition to the information on the user, we take infrastructural information into account. For example, our system is aware of detailed characteristics of the charging infrastructure, including the location of charging stations and the available charging rates. Time-dependent information, such as the current availability of charging stations and local load management constraints are supported as well. We retrieve the above mentioned information from a web-service interface provided by the DSO.

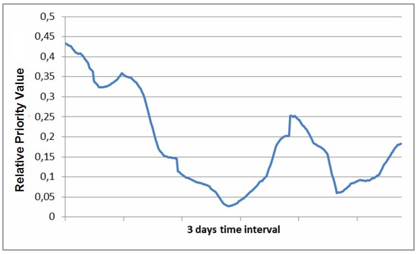

Fig. 2. Share wind energy in the overall electricity production over a three-day interval in the north-eastern region of Germany

In the following we will proceed by presenting our evaluation approach. We evaluated our assistance system in two different ways. First, the main evaluation was performed in a three-week field experiment for which we deployed our application on real hardware components (e.g., charging stations, vehicles, cell phones, etc.). We selected test drivers to evaluate the reliability and suitability of our system. Results of our field test are presented in previous publications [2,5].

In this paper, however, we focus on presenting results of a computer simulation. We developed a simulation framework [7] to draw large-scale implications on future eco systems. As a matter of fact, we initially used our simulation framework to ensure the applications' reliability for the field test. Based on the data we collected from our field tests, we were able to adjusted input parameters (e.g. consumption and charging characteristics, vehicle ranges, etc.) to the simulation framework in order for us to perform large-scale, simulation-based evaluations.

In the following we describe our simulation-based evaluation in more detail.

3 Evaluation

The purpose of our simulation was to measure the efficiency of our assistance system. In order to do so, we compared the effects of the assistance system between drivers which apply our assistance system and those who do not. We defined two different vehicle control patterns: (1) unplanned vehicles and (2) W2V2G (Wind-to-Vehicle-to-Grid) vehicles. We used the patterns to define the behaviour of the simulated vehicles. To have a better understanding of the particular characteristics of each behaviour pattern, we describe the two different types below:

Unplanned Vehicles have no knowledge of the priority signal or the local load management signal which is broadcasted by the DSO. We defined their behaviour in compliance with a driver conceptualisation [8,9]. Unplanned vehicles follow a given activity pattern in the form of several appointments during the day. Whenever an unplanned vehicle arrives at a car park, the current state-of-charge (SOC) is compared to the minimal value tolerated by the driver. In case the SOC is not rated as 'sufficient', the vehicle is charged. For the current rating, unplanned vehicles always select the minimum from the vehicle's and the charging station's capacity.

W2V2G Vehicles apply the driver assistance system. As opposed to unplanned vehicles, charging (and also feeding) intervals are added to the given activity pattern of the drivers. The assistance system is aware of the priority curve and local load management signals, charging intervals are optimised with respect to both, including the selected current rate. W2V2G Vehicles follow their calendar specifications in an exact manner.

For the simulation, we selected three future scenarios, in which we respectively configured the charging infrastructure according to expected numbers [2]. In more detail, we defined six different types of charging stations and configured both, their overall amount as well as their mixture from scenario to scenario. We present details on the charging infrastructure in Table 1.

Table 1. Charging station types that were used for the simulation scenarios 2015, 2020 and 2030, including their charging- and V2G specifications (given in ampere), as well as their absolute number and percentage distribution for each scenario

			Mixture		
	Charging	V2G	2015	2020	2030
Type I	64A	64A	0%	0%	10%
Type II	64A	–	32%	32%	40%
Type III	32A	32A	6%	6%	0%
Type IV	32A	–	32%	32%	0%
Type V	16A	16A	14%	14%	10%
Type VI	16A	–	16%	16%	40%
Absolute number of charging stations			27.900	167.000	200.000

We also defined three different driver types for each future scenario, namely commuters, field workers and a delivery service schema. For the specification of each driver type we used a widely accepted mobility study [10] from which we derived characteristic values for the frequency in which vehicles are used and also for their daily mileage. As such, we defined a typical commuter to travel roughly 100km per day, a field worker to drive around 200km per day, and a deliverer with a daily mileage of approximately 400km.

For each year (2015, 2020 and 2030), we respectively simulated the tree driver types twice. In the first simulation we used our W2V2G assistance to control the behaviour of the vehicles and in the second simulation we used the unplanned control pattern that we have described above.

We evaluated the performance of our assistance system in two general aspects. First, we were interested in the efficiency of our assistance system to increase the utilisation of wind energy. Secondly, we sought to determine in how far our assistance system is able to facilitate the mobility of their drivers. In the following present our simulation results and explain on how we measured the performance of our assistance to contribute to both above mentioned aspects.

3.1 Utilisation of Wind Energy

Whenever it comes to the utilisation of wind energy (or renewable energy in general), the so called 'simultaneity factor' plays an important role.

The simultaneity factor can be understood as the average share of wind energy of all intervals during which electric power was drawn from the grid network. We determined the simultaneity factor by averaging the shares of wind energy during which vehicles were charged. Our simulation results are illustrated in Table 2.

Table 2. Utilisation of renewable energy without considering the current which is applied for charging intervals. The values indicate the average share of renewable energy which was used to charge the simulated vehicles.

	2015		2020		2030	
	Unplanned	W2V2G	Unplanned	W2V2G	Unplanned	W2V2G
Commuter	15.28%	16.00%	15.03%	15.59%	14.28%	15.98%
Field Worker	14.90%	16.83%	15.31%	16.81%	15.19%	16.61%
Delivery Service	15.31%	16.82%	15.19%	17.44%	15.84%	17.41%

Differences between the W2V2G planning system and unplanned drivers are comparably small. We explain this phenomenon with the one-dimensional nature of the simultaneity factor, which takes the average share of wind energy into account, but neglects the intensity of the current that is used to charge vehicles.

To emphasise the importance of the applied current, we performed a second analysis in which we again determined the simultaneity factor, again. Yet, instead of calculating the average value, we weighted the charging intervals according to the applied current. The results for each simulation scenario are illustrated in Table 3.

Compared to the unweighted simultaneity factor, the efficiency of the W2V2G assistance becomes more obvious. As an example, the difference between commuters that were using the assistance system to those who were not, is almost 10%. With an increased daily mileage, both factors literally converge, until –in the 2030 delivery service scenario– the difference between assisted- and unassisted drivers decreases to a little over 2%.

We explain this convergence with the fading optimisation options for the assistance system, which is a direct result to the increased usage of delivery

Table 3. Utilisation of renewable energy under consideration of the applied current. The values indicate the average share of renewable energy which was used to charge the simulated vehicles.

	2015		2020		2030	
	Unplanned	W2V2G	Unplanned	W2V2G	Unplanned	W2V2G
Commuter	12.80%	22.70%	12.36%	22.73%	12.39%	21.38%
Field Worker	15.24%	18.26%	15.43%	18.45%	14.75%	18.04%
Delivery Service	15.02%	17.49%	15.28%	17.82%	15.09%	17.69%

vehicles. An increased usage as well as shorter idle times aggravate the utilisation of periods with a high share of wind energy and cause the performances of the W2V2G and the unplanned control pattern to converge.

For a given driver type, there were only little differences between the results of varying charging infrastructures. We were not able to identify any connection, here.

3.2 Mobility Issues

As a second aspect it was our intention to measure the efficiency of our assistance system to increase the driver's mobility. In order to provide reliable numbers, we analysed our simulation results and counted vehicles that had to cancel at least one scheduled trip due to an insufficient state of charge. The results are illustrated in Table 4.

Table 4. Share of electric vehicles that were affected in their mobility as a result to an insufficient state of charge

	2015		2020		2030	
	Unplanned	W2V2G	Unplanned	W2V2G	Unplanned	W2V2G
Commuter	60.00%	10.00%	53.30%	10.00%	59.30%	07.69%
Field Worker	96.70%	03.33%	93.30%	10.00%	92.30%	13.19%
Delivery Service	100.00%	36.67%	100.00%	48.33%	100.00%	42.86%

The results emphasise the capability of our W2V2G assistance system. While for the commuters and for the field workers the amount of affected W2V2G vehicles remains relatively constant, there is a significant increase of affected vehicles between unplanned commuters and unplanned field workers. This number further increases in the delivery service scenario, where each unplanned vehicle was somehow affected. The W2V2G planning system, however, was able to roughly halve this number.

As the total number of affected vehicles may be a misleading indicator for the degree of mobility, we performed a second analysis in which we determined the total amount of all scheduled trips and compared this number to the amount of trips which actually failed due to an insufficient state of charge of the respective vehicle. The results of this second analysis are illustrated in Table 5.

Table 5. Share trips that failed as a result to an insufficient state of charge

	2015		2020		2030	
	Unplanned	W2V2G	Unplanned	W2V2G	Unplanned	W2V2G
Commuter	02.21%	00.78%	02.00%	00.60%	02.30%	00.47%
Field Worker	04.90%	00.13%	04.55%	00.39%	04.80%	00.51%
Delivery Service	08.68%	01.49%	08.33%	01.95%	08.71%	02.39%

The results underline the efficiency of the W2V2G assistance system to increase the mobility of their drivers. While W2V2G commuters were affected in less than one percent of their scheduled trips, unplanned commuters had to deal with almost three times as many affections. While there were almost no differences between the amount of affections of planned commuters and planned field workers, the number almost doubled between unplanned commuters- and field workers.

In the case of delivery drivers the numbers increased in both cases, nevertheless, the W2V2G planning system was able to lower the number of failures by the factor of 4.

4 Conclusion

In this paper we presented a simulation based evaluation of a recently developed assistance system. This assistance system optimises the utilisation of vehicle-to-grid (V2G) capable electric vehicles with respect to the intentions of several stakeholders.

For this work, we put the main focus on two stakeholder, namely the driver and the distribution system operator (DSO). While drivers are generally interested in an optimised degree of mobility, we understood the interests of the DSO to increase the utilisation renewable energy[1] and to account for structural deficiencies of the low voltage grid.

Indirectly, we account for the interests of other stakeholder as well (though, not as obviously as for driver and for DSO). As an example, for the calculation and for the execution of charging processes we use charging profiles which are recommended by the vehicle manufacturer in order to increase the battery's

[1] In fact we focused on wind energy only. However, an additional integration of other types is possible as well.

lifetime. We also account for the interests of the charging infrastructure provider by maximising the utilisation of his charging stations and –as in the case with the DSO– by ensuring a proper operation without jeopardising his low voltage energy grid.

In order to evaluate our approach we defined several future scenarios. We respectively simulated three different driver types for each future scenario and compared the results of drivers which apply the assistance system to those who do not. The simulation results underlined the efficiency of our assistance system in all respects. We were able to increase the utilisation of wind energy by almost 10%. This value decreases with the utilisation and the daily mileage of the vehicles. We explain this phenomenon with the fading alternatives for the assistance system.

We were also able to substantiate the capability of our assistance system to increase the mobility of their drivers. Assisted vehicles encountered significantly less mobility restrictions than unassisted ones. Especially for field workers, the effects of the assistance becomes apparent, as mobility restrictions were reduced by up to 90%.

To conclude — based on our evaluation we can state, that the W2V2G algorithm is able to facilitate a more effective utilisation of renewable energy sources. Further, we demonstrated that our application is able to account not only for individuals but to support the interests of many stakeholders, namely the drivers, the vehicle manufacturer, the charging infrastructure provider and the DSO.

Based on our evaluation we can argue that a respective system is able to contribute to the domain of electric mobility.

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