# ECONOMIC ASSESSMENT OF ELECTRIC VEHICLE FLEETS PROVIDING ANCILLARY SERVICES

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## *ABSTRACT*

*The profitability of the usage of electric vehicle (EV) providing ancillary services is not answered yet. Therefore, this executed analysis examines this questions divided into a technical and economic assessment.*
*First, the electric vehicles have to be charged according charging strategies enabling the vehicles to provide services at all. Second, the size of the EV pool has to be determined as a basis for the economic assessment. An optimization of the strategies maximizes the possible earnings for the EVs. Third, the reserve energy market has to be analysed as a basis for the possible earnings for EVs. The estimation for the possible earnings will be given.*

## INTRODUCTION

In the context of V2G services, a lot of opinions exist concerning possible revenues for electric vehicles (EV) in the grid. However, a quantified calculation based on realistic technical restrictions such as driving data is necessary to determine the required number of EV that have to be aggregated to provide a constant power and energy necessary to participate in the reserve energy market in Germany. Using these inputs, the real revenue can be calculated. Therefore, the subject addressed is the maximization of revenue for EVs by providing ancillary services to the grid by using different charging strategies.
To provide ancillary services, in the following mainly frequency control, charging strategies have to be developed and implemented into a model that is based on real driving data of individuals in Germany which has been extracted from a survey. Other important parts of the model concern technical and economic aspects. The technical aspects include a battery charging curve and different technical restrictions. The economic aspects are based on the German reserve energy market and a battery degradation model to factor the higher battery usage. Based on the model, technical and economic results can be used to determine the profitability of EV for providing V2G-services to the grid. The technical results include the number of EV needed in a pool to provide a certain power and energy over a determined period of time. Moreover, the number of EV providing the service at one time can be calculated. Based on these technical outputs, the economic results can be evaluated in the German reserve energy market such as the revenue for the primary and secondary reserve.

## CHARGING STRATEGIES

Technically, EV can provide all kinds of ancillary services in Germany. However, to provide any services, EVs have to adjust their charging conditions according to a signal to reduce or increase charging power. To provide the different kinds of reserve energy (positive and negative), the charging process of the EVs have to be controlled based on different strategies and available infrastructures such as different charging places or connection powers.

### Negative frequency control

Negative reserve energy can only be provided, if the state of charge (SOC) of an EV is below 100%. Only in this case, the can provided negative reserve energy. Therefore, the charging process has to be delayed or reduced by different strategies.
To tackle these challenges, the following strategies have been identified:

- Energy strategy
- Power strategy
- Delay strategy (or time strategy)

The **energy strategy** changes the target state of charge (SOC) level from 100 % to a lower target. This permits that the spare capacity can be used for providing negative reserve energy. The EV charges only to a certain defined state of charge (SOC) level such as 90 % and stops until a request signal occurs. During this request, the EV can charge up to 100% SOC. Depending on the chosen spare capacity, the number of required EV in a pool fluctuates. During the charging to the target SOC the EV cannot contribute at the market. Figure 1 shows a typical charging curve for Li-Ion batteries. The capacity about the target SOC is reserved for the grid services.

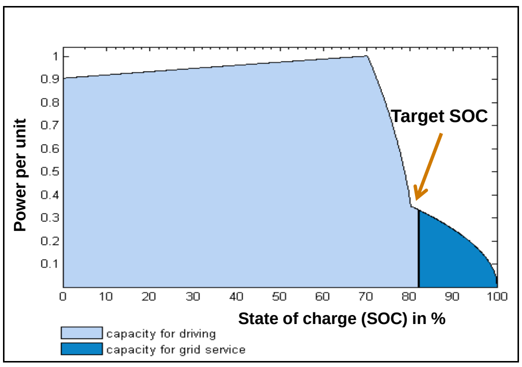


**Figure 1: Energy strategy for a Li-Ion battery [1]**

The **power strategy** reduces the power during the charging process until requested to provide a service. After the signal, the EV charges with 100% of its power connection. This reduction extends the charging time for the EV. This supports this strategy because the EVs can only contribute during their charging process. If the charging process is finalized, EVs cannot longer contribute.

The **delay strategy** does not influence the target SOC or the charging power. It only varies the point in time for charging. The charging process of the EV starts not automatically directly after its arrival but at a randomly chosen point in time afterwards. Before their charging process starts, the EVs are ready to provide negative reserve energy.

Each of the three strategies described before is able to provide negative frequency control. However, a combination is also possible (s. Figure 2).

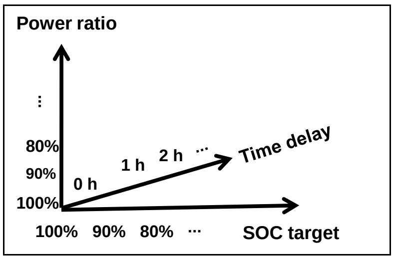


**Figure 2: Combination possibilities for the different negative charging control strategies**

## Positive frequency control

To provide positive reserve energy the charging strategies are simpler than before. The main idea is to reduce the load by either interrupting the charging process or feeding energy back. Moreover, this can be combined with the delay strategy described before.

The main differentiation is the connection infrastructure. EVs only connected through a unidirectional converter have to stop their charging to provide reserve energy. Therefore, they can only participate if they are charging. With a bidirectional connection, EVs can stop and feed back into the grid hence, doubled the effort compared to a unidirectional connection. EVs can always participate if they are above a minimal SOC, which is defined to guarantee to cover a certain distance.

# CALCULATION OF THE NUMBER OF EV REQUIRED TO PROVIDE RESERVE ENERGY

A single EV is not able to participate at these markets. Therefore, a certain number of EV have to be pooled to reach the power and energy requirements for the participation. Based on the charging strategies, a calculation to determine the number of required EV in a pool for providing frequency control is executed taking into account a realistic charging curve and stochastic driving patterns.

## Driving pattern

Realistic driving pattern are the base for the calculations because the availability of the EVs and their SOC determine the size of the pool. Therefore, the driving patterns of the "Mobilität in Deutschland 2008" [2] study are used to represent Germany. To guarantee an accuracy of the results, each EV obtains a specific driving pattern according to a typical driving pattern such as short distance commuters or private. Based on this specific driving pattern, technical attributes can be calculated for the whole calculation period for each EV, which is presented in the following:

- Accurate state of charge
- Driven distances and resulting reduction of the SOC
- Charging place of the EV

## Battery charging curve

For every EV the charging curve shown in Figure 1 is used with the consequence of a variation of the charging connection depending on the SOC of each single EV. Consequently, the available charging power of the pool has to be calculated for every EV separately according to the pattern of the charging curve.

Moreover, the effect on the charging strategies is immense because depending on the used target SOC, the available charging power is reduced severely.

## Prequalification for frequency control in Germany

In the German market for reserve energy, the highest prices can be earned for provision of primary and secondary frequency control [3]. Therefore, these markets will be analysed to assess a possible participation for EV depending on an existing profitability. Table 1 summarizes the prequalification requirements for a participation in these markets. In order to be able to participate, EVs have to provide the minimal power for a certain period of time (e.g. 24h).

EVs are technically able to provide any reserve energy technically. However, due to the existing legislation the pooling is only permitted for secondary control. Nonetheless, a change in the prequalification can be made to permit EVs participation.

| Frequency control | Primary | Secondary |
|---|---|---|
| Activation | Automatic | Automatic |
| Minimal bandwidth | ± 2 MW | +/- 10 MW |
| Activation time | < 30 s | < 5 min |
| Duration | < 15 min | 30s – 1h |
| Availability factor | 100% | 95 % |
| Pooling possible? | No | Yes |

**Table 1: Prequalification for frequency control in Germany**

## Results

The calculations for the pool size have been carried out with the following assumption for the infrastructure:

- Charging power: 3,7 kW
- Charging connection: at home and at work

There are two main results of the calculation: the first is the total size of the pool determined by the highest number of EVs that are necessary to provide the minimal required power. The second is the actual number of EV providing reserve energy. The method for a possible implementation of charging control and analysis of the technical restrictions is described detailed in [3].

Figure 3 shows the number of EVs that are necessary to provide 10 MW secondary reserve with the control strategy energy for a period of one week. The pool size is around 61.000 EVs to cover the worst case situation. The fluctuations are based on the driving behaviour. During the week, EVs are driving according to their driving patterns, they reduce their SOC and therefore, there are capacities free to provide ancillary services. On the weekends, vehicles are used seldom resulting in an increased number of EVs. The fluctuation in the number or EV providing reserve energy is caused mainly by the charging curve (Figure 1).

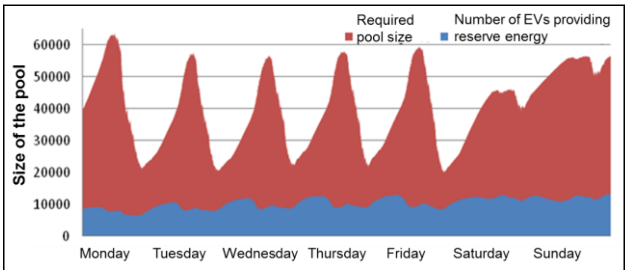


**Figure 3: Number of EV in a pool providing 10 MW secondary frequency control**

The results for the power strategy are significant inferior to the results of the other strategies for negative reserve energy. Even a combination delivered only slightly better results. Therefore, this strategy has not been analysed any further. The analysis other strategies introduced shows that the energy strategy and a combination of the energy and delay strategies requires the lowest pool sizes to provide negative reserve energy.

Figure 4 shows the course of the maximum number of the EV pool during one week. The numbers fluctuates between approx. 50.000 to 15.000 EVs for the combined energy+delay strategy for 10 MW and between approx. 12.000 to 4.000 EVs for 2 MW. The energy+delay strategy is always better than the others and will be used for the following calculations. The results for the strategies unidirectional and bidirectional providing positive reserve energy are also presented in Figure 4.

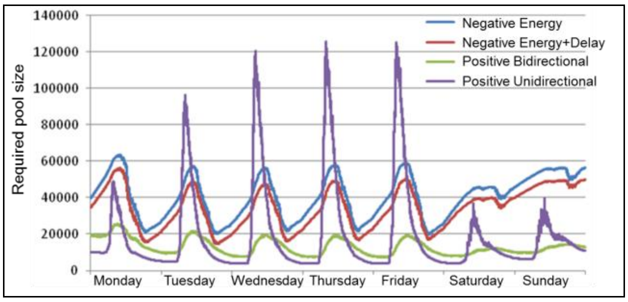


**Figure 4: Comparison of the maximum number of required EVs between different charging strategies**

The unidirectional strategy requires more than 125.000 EVs at most due to the requirement that the EVs have to be charging to be able to participate. Even a combination with the delay strategy influences this number only slightly. In contrast, the bidirectional strategy requires about 22.000 EVs at most and has the lowest fluctuations of all strategies based on the fact that EVs can participate nearly independent of their charging process.

## Optimization

The previous sizes of the EV pool are based on the prequalification for reserve energy in Germany today. However, due to the rising number of devices able to provide reserve energy such as EVs, a chance of rules will be possible in the future. This would have a high influence on the earnings of EVs because their capability to provide reserve energy varies peculiar over the day as Figure 5 demonstrates. If the size of the time slots for reserve energy will be reduced from 12 h to 2h, EVs can provide more reserve energy and maximizes their earnings. The effect for the unidirectional strategy is even more significant because of the highest fluctuation in pool size (compare Figure 4).

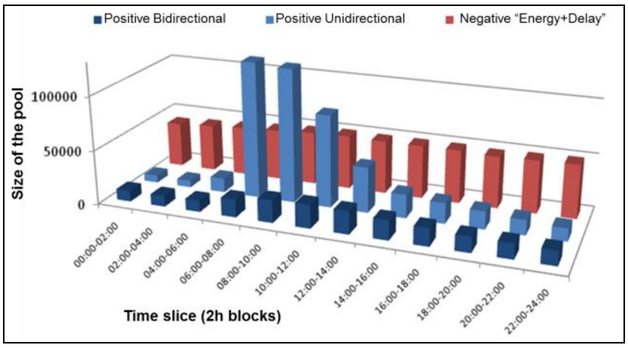


**Figure 5: Pool size for EVs for 2h time slots**

The approach to minimize the size of the pool fails to maximize the earnings for an EV owner because this is the wrong target. Therefore, the presented calculations are only the first part of the analysis and are combined in the following with economic calculations where an optimalization of the technical parameters is included.

## ECONOMIC ASSESSMENT

### Assumptions

The assumption for the economic calculations of the earnings of EVs is the usage of historic data from 2009 from the German reserve energy market [4]. The bidding behavior follows two different approaches. The first tries to maximize the capacity price for the allocated capacity of the pool. The second pursuits to maximize the frequency of dispatch and is valid for the pools providing negative energy control and the pools using the unidirectional strategy for positive reserve energy. In the case of the bidirectional strategy the approach has to be changed because the energy price has to be higher than the costs for battery degradation caused by the dispatch.
Using the model for the battery degradation costs in [5], the cost for battery usage rises significantly with a decreasing SOC [5]. Therefore, the bidirectional strategy is only worthwhile if the SOC is quite high. However, the most influencing factor for the battery degradation costs is the battery investment costs that are varied in these calculations from 500€/kWh to 200€/kWh.

The earnings for reserve energy consist not only from the capacity and energy prices but have to be extended on to saved costs for the conventional charging of the EV. In this case, the EVs are aggregated and buy energy at the European energy exchange. This represents a worst case because the savings, if in neglecting taxes and system usage fees prevents higher earnings.

### Results

The economic assessment extends the optimization for the charging strategies and was used to define the target SOC for the examined strategies shown in Figure 6. The reduction of the pool size for the energy strategies leads to reduced monthly earnings and moreover, influences the driving range negatively. Therefore, a target SOC of 90% has been chosen as a compromise between pool size, maximum earnings and disturbance of the usage of EVs.

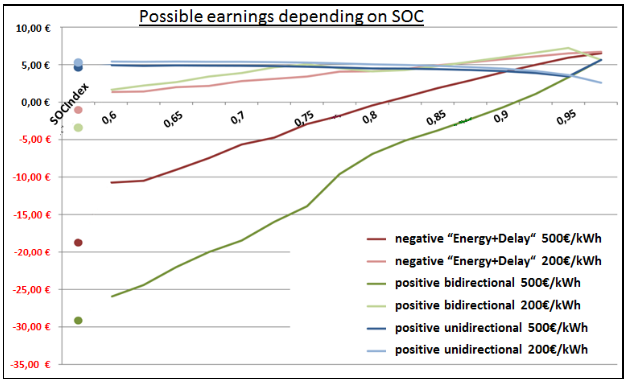


**Figure 6: Optimization of the target SOC**

Based on the presented charging strategies, a single EV can earn in the best case by providing negative reserve energy around 200 €/a for primary reserve energy and 137 €/a for positive reserve energy (unidirectional) assumed constant conditions at the reserve energy market. If the residential rates for energy are used, the earnings might be even higher.

However, the earnings have to be divided between the aggregator controlling the EVs, the EV owner and have to cover the cost for the communications or even charging infrastructure necessary to provide these services.

## SUMMARY

Providing ancillary services with a pool of electric vehicles is possible if certain strategies are used. The strategy with the highest potential for negative reserve energy is the energy and delay strategy which reserves a part of the battery capacity for the services and distributes the charging of EVs randomly. The unidirectional strategy for positive reserve energy gains the highest earnings because no battery degradations cost are generated.

These strategies can be optimized using economic assessments to maximize the earnings for EVs. For primary reserve energy around 200€/a can be earned and for secondary reserve energy 137 €/a.

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