Optimized Integration of Electric Vehicles with Lithium Iron Phosphate Batteries into the Regulation Service Market of Smart Grids

Enhanced Vehicle-to-Grid Business Model

Marco Roscher, Jonas Fluhr and Theo Lutz
FIR at RWTH Aachen, Pontdriesch 14/16, Aachen, Germany

Keywords: Regulation Service Market, Integration of Electric Vehicles into Smart Grids, Vehicle-to-Grid (V2G) Business Model, Prediction of Electric Vehicles Batteries Degradation, Optimization Model.

Abstract: In the “Li-Mobility” project, a battery management system (BMS) for lithium-ion batteries was developed. It particularly aims to perform online diagnoses while driving as well as to predict the impact of additional cyclization through grid control and balancing functions on the degradation of the battery. The information about the predicted degradation and the overall decision whether a car battery is providing balancing power or not is based on an optimization model run by an aggregator- The aggregator’s ICT system uses information based on the number of available electric vehicles, their configuration, battery characteristics and information about market prices for supply of balancing power in order to optimized offers. Hence, it is, possible to make realistic cost estimations for vehicle-to-grid (V2G) scenarios and to determine economically profitable ones for each vehicle individually. The optimization model was tested on the basic principles of conventional lithium-ion cells in general and with lithium iron phosphate (LiFePO4) cells in particular.

1 INTRODUCTION

The increasing shortage of fossil resources during the last decades makes the search for sustainable energy resources more and more essential (APPELRATH 2012). The pertinence of renewable energy source (RES) like wind power or photovoltaic solar power plants is constantly growing during the last years in most European countries. Though, the energy generation through RES indeed is complicated due to fluctuations over time. Volatile power producers increase the grid´s demand for balancing power because the overall grid stability depends on the balance between production and consumption at every point in time. Hence, options are needed to use the electricty produced during times of low consumption on one hand and to obtain addition electricty during times of low production on the other hand.

An excellent cost-effective alternative is perhaps the Vehicle-to-Grid (V2G) principle. The concept of V2G not only provides additional value to the batteries of the electric vehicles by serving for balancing power services, but also contributes to the reduction of global CO_2 production by decreasing the need of fossil fueled regulation plants. As a result of additional charging cycles due to balancing services, additional degradation of the battery occurs. This consequently incur costs. It is important to account this factor in existing V2G business models and establish the necessary requirements in the electric vehicles systems, in particular the battery management system (BMS).

The subsequent sections are structured as follows. Section 2 provides a short overview of the state of the art in the energy market and electric mobility. In Section 3, an enhanced V2G business model and its key market are described. Section 4 discusses the business model underlying optimization model. Section 5 offers a brief summary and conclusion of the paper.

2 STATE OF THE ART IN V2G

Due to the attractiveness of the idea to combine the

Roscher M., Fluhr J. and Lutz T..
Optimized Integration of Electric Vehicles with Lithium Iron Phosphate Batteries into the Regulation Service Market of Smart Grids - Enhanced Vehicle-to-Grid Business Model.
DOI: 10.5220/0004551600880092
In *Proceedings of the 2nd International Conference on Smart Grids and Green IT Systems* (SMARTGREENS-2013), pages 88-92
ISBN: 978-989-8565-55-6

two large energy conversion systems - “electricity grid” and “mobility” - with each other (KEMPTON; LETENDRE 1997), several studies from various perspectives with regard to the realisation of V2G have been done so far. For instance, studies have been performed on the potential availability of electric vehicles (FLUHR; AHLERT; WEINHARDT 2010), the target market (base load, peak load, regulation) and the profitability including other aspects like the influence of the car type (BEV, FCEV, HEV) for (DALLINGER; KRAMPE; WIETSCHEL 2011).

The effect of V2G on the German electricity grid has also been investigated (BIRNBAUM; LINSSEN; MARKEWITZ [et. al.] 2009). In addition, there are studies with regard to the integration of RES by V2G (KEMPTON; TOMIC 2005).

In summary, while intelligent charging of batteries might be applicable in Germany´s electricity market model without problems even at present day, the application of V2G would however need serveral modifications (GUDERGAN; ANSORGE; FROMBACH 2011). A complete and optimized integration of electric vehicles into a Smart Grid requires a bi-directional energy and information flow. This accounts particularly for the regulation market, because of high requirements with respect of reliability and response time of the ICT system.

3 BUSINESS MODEL

There are different concepts of V2G business models that can be applied for regulation market services. Every business model can be assigned to one of two types of models. The first model focuses on vehicle specific aspects and the second focuses more on the information respective infrastructural perspective. The business model described in this paper is the second one (infrastructure-focused). It was further investigated for the application for regulation market services. It is an extension of existing business models by the very important factor of battery degradation through additional cycles because of balancing power services. In this context, every cycle incurs costs by decreasing the electric vehicles battery monetary value. Only by knowing these costs allows to deduct adequate fees for the supply of balancing power services as a basis for a robust business model.

3.1 Aggregator of Electric Vehicles

The business model "aggregator of electric vehicles" is developed exemplary and is based on the optimization model and the additional information about degradation available from the car’s BMS.

It is very important to get a deep and clear understanding of the business model especially from the very beginning of the conception and planning stages to enable and facilitate an optimized integration of the electric vehicle´s batteries into the regulation service market of smart grids. To comply with the requirements of smart grid integration, a structured scientific substantiation and documentation of the business model would also be essential. For this the strategic management template Business Model Canvas was adapted (OSTERWALDER; PIGNEUR 2010) delivering a broad overview of the business model´s key issues (Table 1) as a start and subsequently offering a base of operation for the deduction of specific requirements regarding a smart grid integration.

Table 1: Key Issues of Electric Vehicles Aggregator’s Business model.

Key Partners	Key Activities
▪ Individuals ▪ Organisations ▪ Public and private infrastructure operators	▪ Backup storage for renewable energy sources ▪ Regulation market services
Key Resources	**Value Propositions**
▪ Electric vehicle´s battery capacity	▪ Arbitrage profits due to variable prices
Customer Segments	**Revenue Streams**
▪ System Operators ▪ Individuals ▪ Organisations ▪ Public and private infrastructure operators	▪ Arbitrage profits due to variable prices ▪ Shares of arbitrage profits ▪ User fees

Within this business model the aggregator represents a crucial instance, which initially divides the required total power into smaller packages, so-called load profiles. It then translates them into a format of time and performance vectors that is interpreted by the BMS of electric vehicles. Finally, it sends corresponding inquiries to pool of electric vehicles. The primary objective is to optimize the use of the battery by additional cycles for the provision of balancing power, aside from the single application for driving, so that the battery´s life is optimally utilized.

Arbitrage profits due to variable prices are in no doubt the business model´s crucial revenue stream with regard to smart grid regulation service market. The realization of arbitrage profits could allow at least a partial refinancing of the relatively high investment costs of the vehicles batteries and as a consequence the reduction of the overall investment risks.

3.2 Regulation Service Market

In order to maintain the security of energy supply, the transmission network operators is obliged to guarantee the balance between energy production and consumption in every point in time. Occasionally, there is a deviation from the predicted demand or supply of electric power in the grid, e.g. because of failures or volatile energy producers. Transmission network operators are keeping additional equipment available to be able to react at all times.

Three different types of balancing power are established in Germany. The overall amount of each balancing power type for the four German transmission network operators is advertised online for bidding on Germany´s national regulation market platform. The regulation market place is open to all technical entities which have successfully carried out the pre-qualification by the responsible transmission network operator of the control area. Every balancing power type is characterized by a set of properties listed in Table 3 to Table 5 for each type and outlined in the following subsections.

3.2.1 Primary Balancing Power

Primary balancing power constitutes the first and immediate action that can be taken to restore the balance within the grid. It possesses the highest value for the grid and has to be activated automatically within 30 seconds after the request call. The adduction may take up to 15 minutes. It is advertised weekly on the regulation market online platform with a minimum power quantity of 1 Megawatt (MW) positive or negative. There are no time slices such that the balancing power which was sold on the regulation market has to be available at all times during the week it was paid for. Only a fix rate per MW is paid for primary balancing power services, regardless of the service delivery.

Regarding the required minimum size of aggregators´ electric vehicle fleet, the primary balancing power is the type that needs the fewest electric vehicles, since transferred energy volumes are normally low.

Table 2: Characteristics of primary balancing power.

Bidding frequency	Minimum quantity
Weekly	+ / - 1 MW

3.2.2 Secondary Balancing Power

Secondary balancing power substitutes the primary balancing power in the event of longer technical disturbances. The activation of the balancing power adducted has to start maximum 5 minutes after the request call and can last up to 1 hour to stabilize the power grid. Secondary balancing power is advertised weekly on the regulation market online platform with a minimum power quantity of 5 MW positive or negative for each of the two time slices, primary processing time and secondary processing time.

In contrast to primary balancing power, the price paid for secondary balancing power services consists of a rate per MW and a rate per MWh. The MW-rate takes account the provision of balancing power, while the MWh-rate comprises the de facto delivery of balancing power to the grid.

Table 3: Characteristics of secondary balancing power.

Bidding frequency	Minimum quantity
Weekly	+ / - 5 MW

3.2.3 Minute Reserve Power

In case of long term failures which take longer than 15 minutes, the minute reserve power is utilized. Its complete activation and delivery is compulsory within 15 minutes after the request call. Compared to the other balancing power types, minute reserve power has the lowest value and the longest possible time period of balancing power delivery. As a consequence, the duration of balancing power supply can take several hours. The compensation for the supply of minute reserve power consists of a demand rate and a MWh rate similar to the secondary balancing power. Regarding the limited battery capacity of electric vehicles, it is very unlikely that one vehicle will be able to deliver minute reserve power for several hours.

Table 4: Characteristics of minute reserve power.

Bidding frequency	Minimum quantity
Daily	+ / - 5 MW

4 OPTIMIZATION MODEL

In order to understand the optimization model, the aggregator´s planning process for the supply of balancing power is described in Figure 1.

At first, the aggregator has to be informed about the probable availability of its electric vehicles

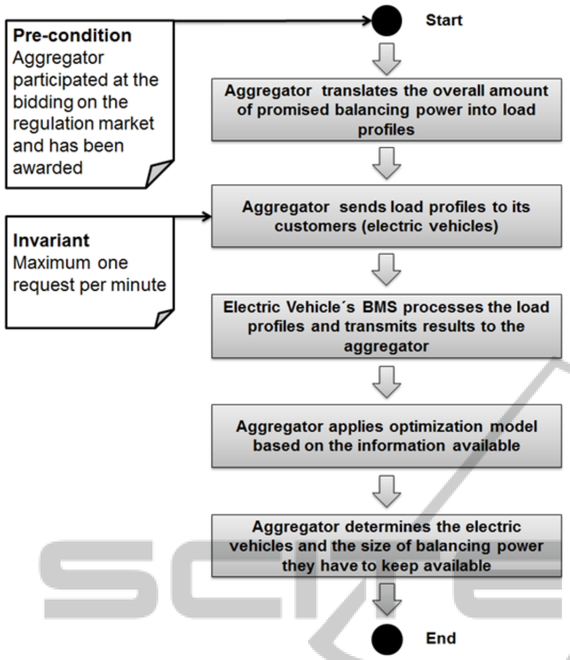

Figure 1: Flow chart of the aggregator´s planning process for supply of balancing power.

within its vehicle pool at least for the following day, since it wants to participate for the bidding of minute balancing power and up to a whole week as for primary and secondary balancing power biddings. As soon as a vehicle determined the amount of balancing power it is willing to offer, it can participate (assuming prior pre-qualification) in the biddings. After being awarded to supply balancing power by the transmission network operator´s bidding, the actual optimization starts. The aggregator translates the requested balancing power into three predefined load profiles. The balancing power ranges to minimum 1 MW up to several MW and is dependent on the number of electric vehicles available in the pool. A load profile consists of a power dimension (kW) and a time dimension (seconds).

As a function of available and suitable electric vehicles, the overall balancing power is split in to partial balancing power amounts for each of the three load profiles. One request consists of up to three load profiles and is sent to each electric vehicle BMS which is connected by the aggregator to the pool's ICT systems. For that, the load profiles have to be initially translated to a BMS proprietary format. In this way, every load profile´s power and time dimension is encoded in a CAN message of 8 bytes which is interpretable by the BMS. The BMS´ of the electric vehicles then process the request and send the aggregator the predicted degradations as a change of the battery´s state of health (deltaSOH) for every load profile received. The new state of health of the battery is calculated according to equation (1):

$$SOH_{new} = SOH_{actual} - deltaSOH \qquad (1)$$

By this, the aggregator has up to three different deltaSOH values with associated balancing power amounts for each electric vehicle. At this point, the aggregator concentrates all the information of each connected electric vehicle, e.g. availability, the battery´s state of charge, capacity, value, deltaSOH etc. Then in the first step of optimization model´s algorithm all vehicles with the lowest costs (€ per kWh) are added to the bulk of selected electric vehicles for balancing power services as long as the required overall balancing power is achieved. In case the required overall power is not achieved and, all available vehicles are already selected, the algorithm deselects the electric vehicles which do not supply their maximum balancing power possible yet. Thereafter, the electric vehicle with the minimum costs in € per kWh is selected with the restriction that the selected load profiles amount of balancing power has to be higher than the amount of the previously selected one. This procedure is repeated until the required overall power is finally achieved. The aggregators profit (G) is the difference between the earnings (e) and the costs (c) for the balancing power services of every electric vehicle (index k) and the load profile (index i) selected according to equation (2):

$$G_{i,k} = \max\left(\sum_{k=1}^{K} e_{i,k} - \sum_{k}^{K} c_{i,k}\right), \qquad \forall\, i \qquad (2)$$

The aggregators profit is the difference between the earnings and the costs for the balancing power services of every electric vehicle selected according to equation (2): The supply of negative balancing power is exceedingly interesting for an aggregator especially during the times where its electric vehicles need to be charged e.g. overnight or when the price is under the regular rate for electricity from the grid. This optimization model is currently implemented in a test environment of a lab including a real BMS and its degradation. The aggregator side and its vehicle pool were simulated via Matlab.

5 SUMMARY AND CONCLUSION

The optimization model developed can be adapted for a variety of business models in principle. The critical success factors and conditions are considered in the modelling of boundary scenarios and their impact on business success.

Since the future of electric vehicles depends to a great extent on the profitability of developed solutions, the selected and specified business model "aggregator of electric vehicles“ addresses initially in particular large fleet operators with hundreds or thousands of vehicles. Only in this magnitude, reliability for balancing services can be guaranteed if some vehicles are not available. Moreover, only then needed scaling effects can be reached. On the other side, the potential revenues from sales of balancing power could lead to an additional incentive for the electrification of vehicles and thus, represent an appropriate leverage and multiplier for further distribution and market acceptance of electric vehicles in general.

Furthermore, the model is also of interest for energy utilities and transmission system operators, since it is a new source for the supply of balancing power.

ACKNOWLEDGEMENTS

The authors wish to thank all project partners for their support. This work was partly funded by the Federal Ministry of Education and Research, based on a decision of the German Bundestag (Li-Mobility: Grant 03X4614B).

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