ELECTRIC VEHICLES AS AN ELECTRICITY STORAGE IN ELECTRICITY SUPPLY CHAIN

Vlado Popović [a,*], Dejan Dragan [b], Borut Jereb [b]

[a] University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia
[b] University of Maribor, Faculty of Logistics, Slovenia

Abstract: *Electricity supply and demand must match all the time. It is not easy to achieve, because of a highly variable nature of electricity demand and a lack of electricity storing capacities. By introducing electricity from renewable energy sources, a variability occurs on the supply side as well. As electricity demand keeps rising and renewable energy sources become more and more in use, achieving an electricity supply-demand balance becomes more difficult. As one of the results, new resources are needed for dealing with that raised variability on both sides. In this paper, we consider the idea of using batteries of electric vehicles (EVs) as a resource for balancing electricity supply and demand. The idea implies charging and discharging of EVs batteries for keeping electricity supply and demand balanced. We observe batteries of EVs engaged in that process, as an electricity storage in electricity supply chain (ESC). In light of this, we explain the proposed idea, concepts of its realization and its feasibility.*

Keywords: *electric vehicles, storage, supply chain, V2G*

1. INTRODUCTION

Electricity supply chain (ESC) has its own specifics, but there are also many similarities between ESC and supply chains of material goods. ESC includes producers of electricity, distributors, transporters, consumers, and others. However, unlike a supply chain of material goods, supply must match demand in ESC all the time. Hence, the supply needs to be constantly adjusted according to the forecasted demand. By introduction of renewable energy sources, it becomes necessary to forecast and plan the electricity production as well. Therefore, ESC management is a challenging and responsible task.

ESC management would be much easier if the electricity could be stored in larger quantities. Nowadays, alternative ways (pumped hydroelectric storage, hydrogen storage, compressed air energy storage, etc.) are mainly used for the purpose of electricity storing. However, capacities of such resources are insufficient to follow the increasing demand for electricity and the growing demand for the integration of electricity from renewable energy sources. Batteries, as the most efficient way for storing electricity, still do not have a significant capacity. However, a rapid development and an increasing use of electric vehicles (EVs) could change the situation. As the number of EVs is growing, a potential electricity storage made of EVs batteries is growing as well. Knowing that cars spend most of the time in the standby mode, it is clear that EVs can also be used for other purposes.

* vlado.popovic@yahoo.com

The idea of using EVs as an electricity storage in the process of electricity supply is not new. As far as authors of this paper know, it is introduced by Kampton and Letendre (1997). They propose using EVs for storing surpluses of electricity in their batteries, and for driving electricity from their batteries when it is necessary. EVs can achieve the role of storage also by allowing only storing electricity. EVs, as an electricity storage, can be integrated in different parts of ESC (at the producers, distributors and/or at electricity consumers).

The idea of using EVs as a storage of electricity in ESC implies also benefits for owners of EVs. They would acquire certain benefits by making available their EVs for this purpose. In that way, the price of EVs would be reduced, and their number would be increased. The realization of this idea could be particularly important for a greater integration of electricity from renewable energy sources. Using EVs as an electricity storage could help mitigate the problem of the variability of electricity from renewable energy sources. On the other hand, to have EVs as the clean form of transport, EVs need to be supplied by a clean electricity. Hence, the realization of the idea of EVs as a storage of electricity in ESC would connect these two environmentally friendly solutions and enable their growth. Thereby, the whole society could benefit from the realization of this idea.

Because of all these potential benefits, EVs as an electricity storage in ESC is the subject of this paper. The aim of the paper is to describe the place and role of such storage in ESC, and to present the ways of realization of its storing function. The accent is on the realization of storage function of EVs through the Vehicle to Grid (V2G) concept. In accordance with the set aim, the paper is organized as follows. The next chapter discusses ESC management. The third chapter describes concepts that enable realization of the storage function of EVs within ESC. The fourth chapter talks about feasibility of the use of EVs as electricity storage through the V2G concept. The last chapter gives concluding remarks.

2. ESC MANAGEMENT

ESC management, among the other things, has to ensure the electricity supply-demand balance. Generally, ESC management in an electric system is started by producers (suppliers) of electricity, continued by electric distribution companies (EDCs), and ended by the system operator (SO). Producers and suppliers are those which deliver electricity to EDCs. EDCs distribute electricity to consumers. SO monitors the production-consumption imbalance all the time and carries out actions to keep that imbalance within the prescribed limits.

Usually, EDC first purchases an electricity that should meet the forecasted minimal demand (base load). The base load power is purchased much earlier than it is distributed, and in a larger amount. It is purchased in accordance with the forecasted minimal demand of EDC clients. Another type of electricity, which EDC purchases, is the peak power. EDC purchases the peak power in accordance with the forecasted demand, made one day before. The peak power is an additional electricity which covers peaks in demand during the day. If the forecast suggests that demand will be lower than the base load, EDC sales a surplus one day before. A final adjustment in the amount of electricity that is supplied, EDC does according to the forecasted demand an hour before. In this case, an hour before, EDC sales the surplus or buys the additional amount of electricity for the next hour.

ESC management ends with actions of SO aimed at maintaining the electricity supply-demand balance. The most important services of SO are load following, regulation and spinning reserve. Load following is the service of adjusting the supply according to the forecasted demand every 5 to 15 minutes. It implies reducing the difference between the electricity power scheduled for supply an hour before and the forecasted demand in the next interval of 5 to 15 minutes length. Regulation is carried out after the load following action, with the aim of aligning supply and demand in a short interval. It is carried out by calculating the area control error (ACE) every 2 to 4 seconds (Guille and Gross, 2009). Based on ACE, the output power of certain generators is automatically adjusted (reduced or increased) every 2 to 4 seconds. With the regulation action, the final adjustment of supply according to demand is performed.

SO is also responsible for repairing electricity supply-demand imbalances which are the result of an unexpected interruption in the electricity supply. These interruptions occur as the consequence of breakdowns in the infrastructure for electricity supply. SO repairs this type of imbalance, by using various reserves. Among the most important is the spinning reserve. Spinning reserve is an unexploited capacity of generators which are scheduled for the electricity supply in the electric system. These generators differ from other generators because they can quickly increase or decrease their production.

All three mentioned actions require reserving a certain capacity at generators that supply electricity within the electric system. These generators must meet the requirements about the speed at which they change their output power (the ramping rate). Load following and regulation require reservation of the capacity for the power increase and reservation of the capacity for the power reduction. Spinning reserve requires only a capacity for the power reduction. Using the electricity storage made of EVs for providing these actions, could be the most useful function of this storage. Instead of keeping an unused capacity at scheduled generators, an extra amount of electricity can be taken from EVs batteries. Also, instead of reducing the power of generators, the excess amount of electricity can be stored in EVs batteries.

3. CONCEPTS OF THE USE OF EVs AS AN ELECTRICITY STORAGE IN ESC

The use of EVs as an electricity storage in ESC can be achieved through several concepts. Some of the best known are Vehicle To Home (V2H), Vehicle To Building (V2B), Grid To Vehicle (G2V), and Vehicle to Grid (V2G).

V2H involves the use of EVs as a storage of electricity at the end of ESC. Every single EV, as a small storage of electricity, is managed by its owner. Based on this managing, when EV is at home, EV is used for supplying household appliances. The EV owner has the opportunity to store electricity in EV battery when electricity is cheap and use it when electricity is expensive. Also, the owner of EV can use electricity from EV battery when there is an interruption in the electricity supply. According to Weiller and Neely (2014), a 24 kW EV battery can provide an individual household with electricity for 2 hours. A special benefit through this concept can achieve the EV owners who own solar panels or wind turbines. Thanks to the electricity storage in the form of EV battery, they can store the excess electricity from their power plants and use it when the production of these power plants is insufficient. Among the first companies who started a V2H business are Mitsubishi with MiEV Power Box and Nissan with the Leaf-2-Home Energy Station (Weiller and Neely, 2014). In parallel, these two companies offered their products on the Japanese market in 2012. The maximum power supply that MiEV Power Box can provide for a home is 1.5 kW. Leaf-2-Home Energy Station can provide the power of 6 kW.

Like in case of V2H, in the V2B concept EVs batteries are used as a storage at the end of ESC. However, unlike V2H, the V2B concept implies using multiple EVs for storing electricity by a client of EDC. Hence, management of charging and discharging EVs batteries is more complex. EVs that participate in this concept can be owned by the owner of building or privately owned. In the first case, it is about buildings of companies that have fleets with EVs. In the second case, it is about buildings where people come with their private cars (office buildings, shopping centers, schools, etc.). As far as authors of this paper know, this concept has not yet been used for a commercial purpose. Though, Nissan successfully tested the V2B concept in 2013. In this experiment, six Nissan Leaf cars supplied the Office of the Nissan Advanced Technology Center in Atsugi City, Japan (Nissan Motor Corporation, 2013).

The G2V concept involves using EVs, only for storing electricity in their batteries. However, load following, regulation and spinning reserve services may be provided through this concept. It is achieved by reducing the electricity for charging EVs, which is equal to sending a new electricity into the grid. Also, the G2V concept enables participating in the valley filling process (the process of increasing demand). The G2V concept has the advantage over the other because it does not cause an excessive degradation of the EV battery. Also, it requires no special upgrade of the current electric system. On the other hand, because of the one-way flow, the G2V concept does not enable the utilization of all potentials of EVs as a storage resource in ESC.

The V2G concept allows for the greatest utilization of EVs as a storage of electricity in ESC. According to this concept, EVs as storage of electricity can be used for storing and supplying electricity. This storage is integrated into the middle of EDC. Kempton et al. (2001) first introduced the term V2G in 2001, to the best knowledge of this paper authors. They defined V2G as "using the electric storage and/or generation capacity of battery, hybrid and fuel cell vehicles to send power to the grid."

There are two dominant proposals for the implementation of the V2G concept. The first one implies that a new entity (aggregator) executes aggregation of EVs. Aggregator would manage the storage of aggregated batteries of EVs and sell storage services on the market. In practice, managing this storage would be carried out through aggregator's managing of charging and discharging of each EV battery in accordance with the contract made with each EV owner. The owners of EVs would receive compensations for making available EVs to the aggregator. Under the second proposal, each EV owner would participate separately in the electricity storage market. EV owner would negotiate the provision of storage services directly with some of the existing entities (EDCs, SO, producers, etc.). The first proposal with the aggregator seems to be a more realistic option. It is hard to expect that one of the existing subjects would connect and manage with each of EVs. However, the application of the second proposal would bring higher revenues to EVs owners.

4. FEASIBILITY OF THE USE OF EVs AS AN ELECTRICITY STORAGE THROUGH THE V2G CONCEPT

By introducing the V2G concept, Kempton et al. (2001) pointed out that it is feasible to use EVs for providing peak power, regulation, and spinning reserve services. Regulation and spinning reserve are feasible to provide with EVs because they are paid per a delivered energy and per a capacity placed at SO disposal. Supply of the peak power in some situations may be feasible, but not in the others. Other authors evaluate the feasibility of the V2G concept as well. Richardson (2013) reviewed several papers that assess the profit of providing services for supporting the supply of electricity through the V2G concept. He points out that estimates of the profit range from the negative 300 $ to the positive 4,600 $/vehicle/year and more. The most common range is 100-300 $/vehicle/year.

There are also totally negative opinions about the feasibility of the V2G concept. One of them is the opinion of Tesla Motors' first man for car batteries. He argues that this concept is unfeasible because of the cost of battery degradation and connection costs (Shahan, 2016). Costs of degradation and cost of infrastructure are also reasons of many other negative opinions. Because of that, it is interesting to consider results of Wang et al. (2016). They examine how much degradation of EV battery occurs by providing various services for supporting electricity supply through the V2G concept. Simulation results indicate that if EVs are used for the regulation/peak shaving each day in the period from 7 p.m. to 9 p.m. during ten years, then the loss of battery capacity is increased by 3.62% and 5.6%, respectively.

In case of using EVs for the load following during the distribution of electricity from renewable energy sources, the loss of capacity is increased by 22% in the period of ten years. In this case, EVs are used for providing the load following during all day. Although the results of Wang et al.

(2016) are encouraging, the feasibility of V2G concept may come into question because of another reason. According to Sortomme and El-Sharkawi (2012), if batteries are improved and the number of EVs is increased, then prices of services (regulation, load following, etc.) could be quickly reduced by increasing the number of EVs participating in V2G. In that way, the use of EVs for providing these services may become unfeasible as well as the V2G concept. If it comes to that, it may also happen that investments in equipment and infrastructure for V2G do not pay off.

Therefore, a general assessment of the feasibility of the V2G concept does not exist. The results about the V2G feasibility depend on the way of calculation and set assumptions. Though, on a practical level, the first steps towards the realization of V2G concept are made. They are still in the form of pilot projects. Some of the most famous V2G projects are V2G project of University of Delaware, V2G project of US Department of Defence, V2G project of carmakers and Electric Power Research Institute, and V2G project of Nissan and Enel. The V2G project of Nissan and Enel is particularly interesting. It implies installation of 100 V2G points in the UK (Campbell, 2016). However, equipment costs (primarily the costs of bidirectional chargers) and connection costs (costs of infrastructure) are still significant obstacles for a bigger practical implementation of this idea.

5. CONCLUSION

Using EVs, as a storage of electricity in ESC could bring many benefits. Existing electricity producers would reduce the provision of services for supporting the supply of electricity, such as load following and regulation. That will help them operate at the full capacity longer, and ensure new quantities of electricity for the supply, without building new power plants. The costs of wear, at these power plants, would also be reduced. Providing services for supporting the supply of electricity cause wearing of power plants, because of permanent change of the output power of generators. The pollution, which also occurs because of changes in the output power of generators, would be also reduced.

Using EVs for supporting the integration of electricity from renewable sources has a particular importance. Hence, authors of this paper will examine the idea of using EVs as a resource for providing the load following service during distribution of the electricity from PV panels. As far as authors of this paper know, this idea is poorly considered in the literature. Kempton and Tomic (2005) mention load following as the activity where EVs could be engaged. However, they state that although it might be feasibly to use EVs for this purpose, they do not considered that option. On the other hand, Wang et al. (2016) have already calculated the cost of EV batteries degradation caused by the use of EVs for load following during distribution of electricity from renewable energy sources. Thus, authors of this paper will attempt to calculate the benefits that can be achieved with the use of EVs for load following during the distribution of electricity from PV panels.

REFERENCES

[1] Campbell, P. (2016, May 10) Electric car drivers to sell power back to National Grid. Financial Times. Retrieved from https://www.ft.com/content/7e75b7d2-169c-11e6-b197-a4af20d5575e

[2] Guille, C., Gross, G., (2009). A conceptual framework for the vehicle-to-grid (V2G) implementation. Energy Policy, 37:4379–4390.

[3] Kempton, W., Letendre, S.E., (1997). Electric vehicles as a new power source for electric utilities. Transportation Research Part D: Transport and Environment; 2:157–175.

[4] Kempton, W., Tomic, J., (2005). Vehicle-to-grid power fundamentals: calculating capacity and net revenue. Journal of Power Sources, 144, 268–279.

[5] Kempton, W., Tomic, J., Letendre, S.E., Brooks, A., Lipman, T., (2001). Vehicle to grid power: battery, hybrid, and fuel cell vehicles as resources for distributed electric power in California. Working Paper Series ECD-ITS-RR-01-03, UC Davis Institute for Transportation Studies. Available at: http://escholarship.org/uc/item/5cc9g0jp

[6] Nissan Motor Corporation, (2013, November 29). Nissan Leafs can now power Office, as well as the Home. Retrived from http://www.nissan-global.com/EN/NEWS/2013/_STORY/131129-01-e.html

[7] Richardson, D. B., (2013). Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. Renewable & Sustainable Energy, 19, 247–254.

[8] Shahan, Z., (2016, August 22). Tesla CTO JB Straubel On Why EVs Selling Electricity To The Grid Is Not As Swell As It Sounds. Cleantechnica. Retrieved from: http://cleantechnica.com/2016/08/22/vehicle-to-grid-used-ev-batteries-grid-storage/

[9] Sortomme E., El-Sharkawi, M.A., (2012). Optimal combined bidding of vehicle-to-grid ancillary services, IEEE Trans. Smart Grid, 3(1), 70-79.

[10] Wang, D., Coignard, J., Zeng, T., Zhang, C., Saxena, S., (2016). Quantifying electric vehicle battery degradation from driving vs vehicle-to-grid service, Journal of Power Sources, 332, 193-203.

[11] Weiller, C., Neely, R., (2014). The Role of Plug-In Electric Vehicles with Renewable Resources in Electricity Systems. Revue d'économie industrielle, 148, 291-316.