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V2G—An Economic Gamechanger in E-Mobility?

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Abstract: The Vehicle-2-grid (V2G) technology enabling bidirectional charging between electric vehicles and the energy grid system for frequency regulation and load balancing has the potential of significantly improving the financial viability of electric mobility. This paper has identified that the introduction of V2G offers a plethora of potentially beneficial business models, which primarily focus on providing stability services to the energy grid and optimizing the economic benefits of owning an EV. Within these overarching categories, it is likely that several niche business models will emerge, as the current V2G concepts include the integration of intermittent renewable energy into the grid, reduction of peak load, charging optimization, and regulation of participating capacity. Most important is the balancing of the five market factors in order to create a profitable business case, as this is what makes V2G move from a potential revenue generator to a profitable business.

Keywords: Vehicle-2-grid (V2G); V2G deployment criteria; V2G business model; V2G market potential; smart grid; electric vehicles (EVs); Aggregation of EVs

1. Introduction

The production and distribution of energy are continuously being improved with the installation of an increasing amount of renewable energy sources, which are constantly pushing the boundaries for energy efficiency. However, as no one is capable of determining when the wind blows and sun shines, or has found an effective way of storing excess energy, the European production of energy is still highly reliant on nonrenewable energy sources. A proposed strategy to accommodate this apparent energy waste is to integrate vehicle-2-grid (V2G) technology into the energy system, and take advantage of the energy storing capacities of electric vehicles.

As electric vehicles are used for transportation purposes for only 12.1% of an average day, they are available for load balancing and frequency regulation [1], which can be beneficial both for the energy system and EV owner, who potentially will be able to generate a profit by taking advantage of the price elasticity of electricity over the course of the day or providing services to the electric grid. However, in order to make the energy grid system ready for the integration of V2G charging and ensuring a positive business case for the vehicle owner, different aspects must be considered. The full-scale deployment and exploitation of V2G technology require an intelligent smart grid system, an integrated communication network, and feasible business models, which take the complexity of the energy distribution network into consideration.

The full potential of the V2G technology depends on a technological development as well, since deployment of EVs in specific markets is key to achieving a critical mass for providing services. V2G is not a business for an individual but for a collaboration between many EV owners. This paper will therefore evaluate different V2G business models, and the market potential of V2G.

2. Technology Overview

V2G technology essentially represents an application enabling a bidirectional flow of energy to and from an EV, building a large capacity of instantly available energy storage devices, which can be used for load balancing, peak shaving, and frequency regulation [2].

2.1. Central Actors in the Energy System

Aggregators will become central actors in the future energy system, as they can accumulate electric energy from several vehicle fleets for delivery to the distribution responsible (DSO), balance responsible (BRP), and/or overall system responsible (TSO). There is already a market for balancing of instabilities of the electrical grid in most European markets, hence the V2G technology will have to adapt to existing market structures there. One of the most important requirements is a minimum bid size for up- and downregulation, since this causes the electric vehicle owner not to be able to deliver power back to the system without an aggregator, who will become a key player in the future energy system [3]. On the local low voltage distribution level, responsibility for grid stability resides at the DSO, who utilizes their monopoly to make long term investments in copper and new transformer stations instead of investing in intelligent solutions. Due to this, no market structure exists for buying and selling services to this type of organization.

2.2. V2G Technology

The V2G technology consists of several elements that need to be aligned before V2G can take place; the connecting element making it possible is the communication and charging protocol. They define whether signals can be sent from an aggregator to the charging infrastructure and further to the car, allowing the battery to discharge.

Currently, four different communication and charging protocols are being used in the market for EVs:

1. CCS–IEN 15 118 (DC fast charging mainly used by American and European producers)
2. CHAdeMO (DC fast charging mainly used by Japanese producers)
3. AC Fast Charging (Used only by Renault)
4. Tesla Superchargers (Used only by Tesla)

Of these four protocols, currently only CHAdeMO supports V2G, however, the IEN 15,118 has the opportunity integrated into the protocol, but no car utilizes it to the fullest. The vehicles currently in the European market that can be considered V2G-ready can be summarized:

- Mitsubishi iMiev
- Mitsubishi Outlander
- Nissan Leaf 2. Zero
- Nissan eNV200/Evalia
- Kia Soul Electric

As with the EVs, the EVSE (Electric Vehicle Supply Equipment) needs to comply with the charging protocol and also be constructed in a way that allows for bi-directional current to flow. The amount of available chargers complying with this is still to be mapped, however, in the Parker Project [4], the chargers are supplied by Italian energy company ENEL.

3. V2G Business Models

For reaping the economic benefits of V2G technology, it is necessary to develop and deploy viable business models taking factors such as minimum bid size, participating capacity, state-of-charge (SOC), etc. into consideration [3,5]. In order to create a profitable business model within this area, it is important that the service providers create value for the three main stakeholders—grid,

aggregator, and EV owner. The following section outlines two V2G business models which comply with these measures.

3.1. Frequency Regulation

As noted by several studies, "a shallow charge/discharge cycling instead of deep depth of discharge (DoD)" is more suitable for V2G-enabled BEVs, as it can prevent fast battery degradation [6]. Frequency regulation, therefore, represents an ideal V2G business model, as it will have a less negative impact on the battery cycle lifetime without compromising the potential economic benefits that can be generated by engaging in frequency regulation [6]. Essentially, a frequency regulation strategy comprises the aggregator dispatching the bi-directional charging according to the grid frequency deviation [5]. This market already exists and the major payment for servicing this market is granted for availability and not supply of the actual service. This type of service is also hard for existing thermal generators to provide as it demands a fast response time which suits the batteries of EVs well. The limited amount of energy supplied in this type of service also supports the interests of the EV owner, who will have limited risk of experiencing the situation of wanting to use the car with insufficient SOC.

Services connected with frequency regulation thereby have the potential of creating benefits for all important stakeholders, however, for the aggregator, the challenge lies in forecasting when the service will be needed and when capacity will be available.

3.2. Reduction of Peak Load

The large-scale integration of EVs into the energy grid will increase load, which could cause system overload during peak periods. V2G operators could therefore develop a business model dispatching intelligent signals that regulate when different EVs charge to reduce peak load [5]. If the system is built appropriately, it might be possible to reduce the dimension of the energy distribution network, which could be very economically viable. As described in Section 2.1, no marketplace for DSO exists in most European countries, which is a barrier towards providing this service, as is the strategy by DSOs of making long term investments in grid expansions in order to absorb larger peaks. Due to there being no previous cases of selling this service to DSOs, no pricing indications exist on this type of service, which makes the market potential highly uncertain. For the EV owner, providing a peak shaving service will result in a displaced charge session, leaving the EV less usable for the peak period.

Services connected with reduction of peak load have the potential to create a benefit for the DSO as an alternative to creating long term investments in grid infrastructure, and for the aggregator there will be a higher predictability as the energy consumption patterns are of a well-defined size, however for the EV owner, there may be challenges associated with the availability and SOC of the EV.

4. Market Potential

The market potential of V2G technology seems to be dependent on the specific case and a range of decisive variables, as different studies have yielded significantly different results [6–8]. For instance, a recent study [7] concluded that "the current price levels in Germany do not incentivize the use of EVs to provide grid-stabilizing services", whereas another [6] concluded that a Nissan Leaf with a battery capacity of 24 kWh can generate a yearly profit between $318 and $454.26. However, despite this difference among scientists, the emergence of V2G technology opens up a whole new field of business models with new market actors [5]. As V2G technology involves several complex variables, it is likely that the market will see different business models focusing on aspects such as participating capacity, frequency regulation, load balancing, etc. [5]. Moreover, with the structure of the V2G market, it is likely that new market actors and business models will emerge, as OEMs, charging infrastructure owners, and parking garage operators likely will develop innovative concepts with which they can offer ancillary energy services [1,5–8].

5. V2G Market Factors

In order to apply the new business models in the field of V2G, the importance of knowing the market place will be the defining factor between success and failure. These new markets will be distinguished by geography, market rules, and EV adoption. Already, five central factors that will define the role of the aggregator, the pricing of the bid, and the construction of a positive business case can be identified.

5.1. Battery Effect

A central element that has been mentioned often as a barrier towards the implementation of V2G is the potential effect on the battery. Both arguments about longer and shorter lifetime have been placed by parties involved in the development of the services, and recent research has concluded both that it has a negative impact on battery degradation [9] and that it prolongs the lifetime of the battery [10]. The difference between the two research papers connect to the application of the technology, which supports the conclusion that the aggregator will play a vital role in creating a balanced business case across the value system. From the business evaluation point of view, this specific factor can be translated into perceived risk for the individual EV owner and should therefore be represented in the compensation payment the EV owner receives for being a part of the value system. As no clear conclusion exists on the topic of V2G effect on battery degradation, several claims and compensation schemes can be made to secure acceptance from the EV owner including direct payment, warranty offers, and service contracts. This factor can be considered as C_{EVower} and contains all costs associated with securing satisfaction for the EV owner to make them apply their EV to a given aggregator. This will be the same factor that will be included in the TCO calculation for the EV owner.

5.2. Value System

The core of the concept of V2G is to utilize a balancing opportunity without making large investments in batteries [1]. This concept should make it possible for an aggregator to offer the energy from the batteries for grid services at a competitive price. The potential economy should, however, be considered in the context of the value system, where several actors are to share the economic revenue generated by the services. The number of involved parties are, as seen in Figure 1, three levels of stakeholders, including the BRP, the aggregator, and the prosumer. Other relevant groups could include sub-aggregators, charging point operators, and vehicle OEM's, who all have an interest in the system's performance. Some countries, e.g., Finland, are experimenting with allowing the Aggregator to act as a BRP, hence reducing the number of stakeholders in the value chain, increasing the potential revenue for the aggregator. The split between the parties in the value system will be defined by individual offerings of aggregators and BRPs and happen on market terms.

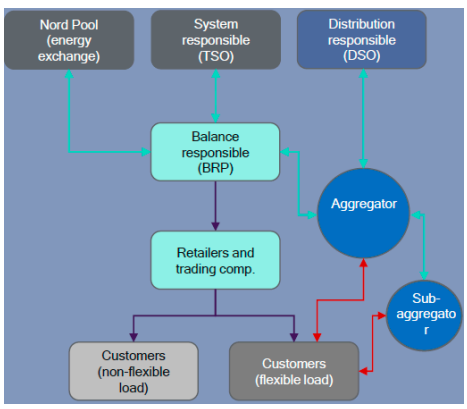

Figure 1. Central actors in the electricity market.

Previous calculations on the economy have primarily focused on the potential revenue generated [5,11], where interesting levels have been identified, however, the distribution of the revenue between the different actors in the value system has not yet been discussed. This topic will, however, be a central point to address in order to create a positive balance between costs and income. The combined cost associated with partners in the value system is considered as the factor $C_{ValueSystem}$.

5.3. Services

The commonly mentioned market, when referring to the largest V2G potential, is frequency regulation, see Section 3.1, where the battery can supply quick, high power, and low energy support. Further to this, a large group of potential services for V2G have been identified [12]. Especially the distribution system will be challenged in the future by the combined implementation of photovoltaics and EVs, which will put stress on the low voltage grid at different times of the day. The balancing of the grid on this level will be a potential new market place that will develop with the increase of EVs in larger scale in local areas. This is a relevant topic to consider as a rapid increase in EVs and aggregators will cause market saturation of the frequency regulation market.

5.4. Energy

Energy used for providing V2G services will need to be re-bought, in order to charge the battery, which causes for a simple, yet important, calculation to be done before applying the energy from the battery to the designated service chosen by the aggregator.

$$\sum I_{services} > C_{energy}$$

The sum of potential income (I) from the services provided should surpass the cost (C) needed to refill the battery for all the services delivered. Although a simple equation, this is an element that often has been overlooked, but is critical to take into consideration, especially for the EV owner, who will be the entity to whom this expenditure applies.

Previous analyses have shown that in Denmark [11], a potential in buying energy at low prices utilizing it for Vehicle-2-Home can provide a potential saving of 70€ pr. Year/Vehicle and that smart charging can create savings of 60€ pr. Year/Vehicle. The limited size of the potential savings is partly a result of the low deviation in Danish energy prices and partly caused by the fact that the Danish energy taxation system is fixed priced and not a percentage of the energy price and make out a very high percentage of the retail price. When transferring this into a V2G context it is important to consider that energy sold from a vehicle is provided at production price, but the supplementary energy needed after providing a service is bought with taxes.

5.5. Market Variables

The market structure for balancing services creates a framework that defines the potential for applying V2G as a technology for grid services. A market structure can be defined by seven variables, which are to be considered when applying V2G and creating bids into the market place [13], see Figure 2.

The individual variables are important to consider when structuring a bid as they each will set limitations or open opportunities for applying a competitive bid. For example, the bid size could delimit V2G aggregators from bidding into the market in the time where available EVs are low, thereby causing the available power to be equally low, whereas the frequency and timing of the bid could cause high insecurity in the bid if these are to be applied by a week's notice.

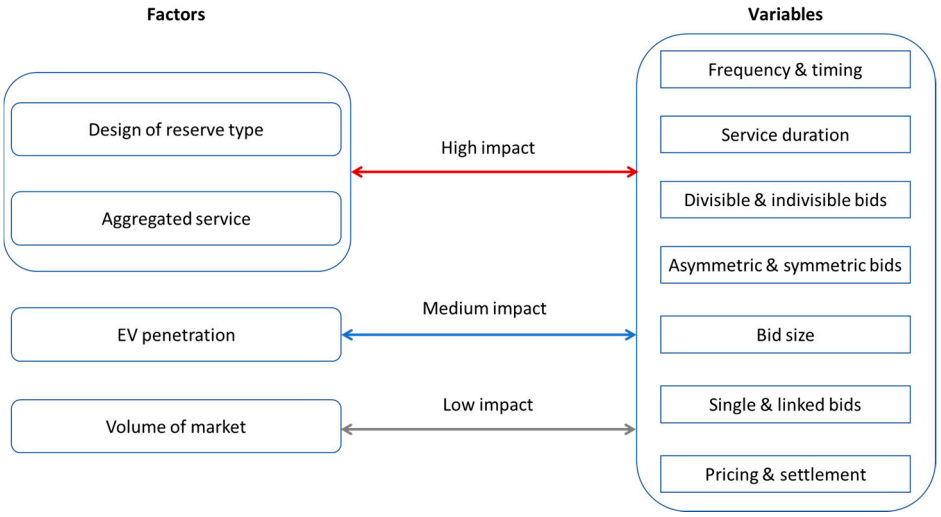

Figure 2. Impact factors and levels for FCR variables.

6. Conclusions

The philosophy of applying the V2G technology as a means to balance the grid on the DSO and TSO level is a logical approach when considering the future smart grid and that in some locations, the technology is already being tested in real-life conditions.

When going through the available research on the area, conclusions on the viability of the technology are inconclusive as the market place and application of the technology will differ from aggregator to aggregator. Analyses show it being a cost bearing system with up to 45,426$ in revenue pr. Vehicle.

The paper has identified and described five central market factors to take into consideration when doing the business case study on V2G in a given market. These are:

1. Battery effect
2. Value System
3. Services
4. Energy
5. Market variables

These can be accumulated into the following equation that on an overall level defines whether or not V2G will be an economic game changer for EVs in the future.

$$\sum I_{services} > C_{energy} + C_{EVowner} + C_{ValueSystem}$$

As these factors are still only considered on a theoretical level, but for companies considering this as a market potential, several scenarios should be considered with different versions of the factors in order to create a full overview of the potential futures the system will be applied to.

At the same time, it is important to understand regulations and market variables in the target country in order to be able to evaluate the potential of the business model and business case.

V2G still has potential to become an economic game changer for EVs, but the potential differs widely from country to country and will rely on more companies utilizing the potential.

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