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Electric Vehicles as Electricity Storages in Electric Power Systems

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***Abstract* – Improvements in battery technology make electric vehicles more and more suitable for the use as electricity storages. Many benefits could be achieved by using electric vehicles for storing electricity in their batteries. This paper talks about the idea of electric vehicles as electricity storages in electric power systems. The idea has a great number of supporters, but also a significant part of the professional community believes that is unfeasible. This paper is not classified in either side and strives to give a realistic picture of this idea. For this purpose, findings from papers published in scientific journals are mainly used. There is also some information from websites, mainly for some technical issues. Partly, the opinions of the authors are present. Specificities of EVs and EPSs that enabled the birth of this idea are explained along with proposed concepts through which the idea can be implemented. Keeping with the vehicle to grid concept, issues about the implementation of the idea are considered. Achievements in the practical realization of the idea are also presented.**

***Keywords*: electricity, electric vehicles, storages, V2G**

I. INTRODUCTION

The people's conscience about the importance of a more rational use of energy increases every day. Many efforts are made to find solutions that lead to a higher energy efficiency and to a larger using of renewable energy sources. The main drivers of these changes are consequences of using fossil fuels as energy sources.

Positive changes are happening in the transport sector as well. One of the mirrors of these changes is a significant awakening of the production and using of electric vehicles (EVs). They are largely driven by achievements in EVs technology and various subsidies. Achievements in EVs technology made EVs more competitive and more appealing as products. Besides traditional good characteristics (high energy efficiency, low maintenance costs, and not emitting exhaust fumes), EVs today have a significantly lower price and a larger autonomy. However, the price and the autonomy are still main obstacles to a wider use of EVs. Affordable EVs (up to EUR 30,000) have the autonomy of less than 200 miles (about 320 km) [1]. These obstacles keep the number of EVs at only about 3.2 million [2]. It is about 0.25% of world vehicle population. Thus, a help of EVs for a rational use of energy in the transport sector is still negligible.

The main cause of the small use of EVs lies in the storing of electricity, i.e. in batteries. The price of battery in the total price of an EV participates in the highest percentage and an EV autonomy depends on the battery's capacity. One of the solutions that could mitigate the high cost of EVs batteries can be their use for other purposes, not just for driving. Stems from the fact that EVs are most of the time in a standby mode and their batteries can store a significant amount of electricity. Therefore, EVs can be significant electricity storage resources. A few concepts are proposed, within which this opportunity can be exploited. One of the most comprehensive concepts is the Vehicle To Grid (V2G) concept. This concept enables sending electricity from EVs battery into the grid and vice versa. V2G concept was created by Kempton and Letendre in 1997. [3].

The introduction of EVs as storage resources in electric power systems (EPSs) could open the door to many benefits. EPSs could obtain storage capacities on their disposal, which could help them be more efficient and greener in the production and distribution of electricity. It could also help them transform their grid into smart grids and integrate a larger amount of electricity from renewable sources. The production of renewable sources is a highly variable and unpredictable, and require recourses for stabilization. On the other hand, owners of EVs could benefit from making EVs available for using as electricity storages in electric-power systems. That would reduce costs of buying EVs and increase the number of EVs in use. In the end, it would result in a more efficient and greener transport sector.

Because of such great potential, the idea of EVs as electricity storages in EPSs is the topic of this paper. We explain this idea and give an overview of the findings of other authors about the idea, from the time it was originally occurred to date. In addition, the development of this idea in practice is followed. The paper is organized as follows. The second chapter contains the background of this idea, i.e. the facts about EPSs and EVs. The third chapter explains the concepts that include the use of EVs as electricity storages. The fourth chapter presents the idea of EVs aggregation. The fifth and sixth chapter presents opportunities and threats to the realization of the idea of EVs as electricity storages through the V2G concept. The seventh chapter presents pilot projects dedicated to the realization of this idea. The concluding observations are discussed in the last chapter.

II. BACKGROUND

A. *EPS*

EPS is a system within which electricity is produced, bought, sold, distributed and consumed. Because electricity cannot be easily stored, the electricity supply must continually match the demand in an EPS. Otherwise, an EPS cannot operate. The complexity of EPS is further increased by introducing of the deregulation in EPSs. Productions, transmission, distributions, and regulation are divided between separate entities in a deregulated EPS. Instead of one subject who govern with all these activities, there are few of them. In a deregulated EPS, electricity distribution companies (EDCs) meet demand for electricity in the system, i.e. sell the electricity to consumers. Producers of electricity produce and sell electricity to EDCs, on a wholesale market. Regulator concerns about the stability and reliability of an EPS.

Generally, all entities in an EPS (EDCs, regulator, electricity producers) are involved in the alignment of electricity supply and demand. This is a process that is started by electricity producers, continued by EDCs and ended by a regulator. Usually, EDCs firstly buy power that should meet the estimated minimum demand of their customers (base load) over 24 hours or longer. This power (base load power) is purchased well before the delivery and from the power plants that have low production costs (thermal, hydro and nuclear power plants). The purchase and the sale of base load power are realized through bilateral agreements, on the wholesale market. If it happens that the base-load is less than the estimated, an EDC must get rid of power surpluses. On the other hand, to benefit later it may happen that an EDC deliberately orders more power for base load than it is estimated to be needed.

The alignment process continues during the peak period. One part of the demand in this period, an EDC can cover much sooner and with a cheaper power. Surpluses of such procured power, the EDC can sell on the day-ahead and hour-ahead market. The second part of the demand in the peak period, the EDC covers by procuring power on the day-ahead market. The mismatch occurs afterward, the EDC addresses through buying or selling power on the hour-ahead market. The resulting mismatch is addressed by the regulator, through providing ancillary services. The alignment process presented by now is shown in the figure given in [4].

The regulator continues to align supply and demand in many ways. Among them are actions known as load following and regulation. Load following is matching of supply and demand on the interval of 5 to 15 minutes length. Aims at reducing the difference between the average supply during the one-hour interval (formed after the hour ahead alignment) and the demand in the observed interval (e.g. in an interval of 10 min long). Load following includes calculating the difference between supplied energy and the realized demand them for the previous 10 min, and accordingly adjusting production of generators for the next 10 min. The regulator adjusts (reduces or increases) the production of certain generators which are scheduled for production, within the observed hour. These generators need to have the adequate ramping rate, i.e. the rate of change of power that is supplied. In that way, the regulator attempts to follow a trend in power consumption during one-hour intervals.

After applying the load following action, matching of production and demand is still needed. To put their mismatch in allowed boundaries, the regulator matches them on intervals of a smaller length. It is called regulation. The mismatch of supply and demand is now observed after each 2-4 seconds, through the area control error (ACE) [5]. ACE represents the difference between the scheduled power generation and the realized demand in the observed interval. Based on ACE, generation of certain generators are automatically adjusted (decrease or increase) every 2-4 seconds. However, their responses are much slower. These adjustments of generators are carried out within the system of automatic generation control (AGC). To participate in the AGC system, generators need to have the right equipment and satisfy certain requirements in terms of ramping rates and capacity. To carry out regulation, generators also need to be scheduled for production during a day- or hourly- ahead alignment. Given the technical requirements, for regulation are suitable gas power plants and special hydro power plants. Regulation and load following are usually provided by generators that are on the margin of the economical electricity production [6].

Therefore, regulation is used to correct the current mismatch. Load following is used to correct the estimated mismatch of electricity supply and demand. Load following represents a slower, whereas regulation represent faster alignment [6]. However, they are directly connected. The larger interval for load following is used, the larger mismatch needs to be corrected with regulation and vice versa [7]. Hence, systems without load following are also possible. Mismatches that still exist after the regulation must be within the prescribed boundaries. Load following action and regulation action are graphically presented in [8].

The regulator is also responsible for addressing the mismatch between supply and demand which occurs as a result of an unexpected reduction in supply. More precisely, in situations when unexpected events caused failures on a generator or on equipment. The regulator addresses this type of mismatch by using various types of reserves. Hence, the reliability of an EPS is directly dependent on the capacity of these reserves. Among the necessary reserves are spinning reserve. Spinning reserve represents the unused production capacity of the generators that are scheduled for production, i.e. which are connected to the grid. These generators meet also appropriate requirements in terms of ramping rates.

All three mentioned actions (load following, regulation and spinning reserve) require keeping a certain amount of production capacity at scheduled generators on standby. More precisely, at generators that are connected to the grid in the observed hour and meet certain technical requirements for these actions. Primarily, these requirements are referred to the ramping rate, up- and down-capacity. The difference between the scheduled level of a generator's production and its minimum allowable production represents generator's down-capacity at some moment. The difference between the maximum level and the scheduled level of a generator's production is up-capacity of the generator. Ramp rate and generator' capacities are graphically given in [8].

It is clear that for spinning reserve is only important the up-capacity. When there is no enough unused capacity at generators, the capacity can be provided through direct load control (DLC). DLC allows the generator to reduce the consumption of consumers who participate in DLC program. By using DLC, the regulator practically obtains a generator with a capacity equal to the possible energy reduction.

In a deregulated EPS, the regulator cannot order to generators to leave a certain amount of unused capacity. Instead of that, the regulator needs to provide the adequate compensation to generators for the left capacity. Regulator covers these costs by charging EDCs for provided actions. Regulator's actions which lead to the matching electricity supply and demand and generally to the stabilizing EPS are called ancillary services. For each of the services, the regulator forms the market where generators compete to participate in providing these services.

This competition for load following and regulation services is realized in the form of auction. Auctions are held after the end of trading on the day- and hour- ahead market, because only the generators which are scheduled in the given hour can compete for providing these services. Generators bid price for a capacity and for a price for supplied electricity. The selection of the generator is carried out by the method of clearing prices. All generators selected on auction, receive the agreed payment for the provided capacity (price times capacity times time) by the regulator. The payment for supplied electricity depends on a supplied electricity during providing services. Putting aside a part of the capacity required for these services (instead of using it for energy production), may cause opportunity costs at the generators which provide these services.

The required amount of capacity for each of these operator's actions can be defined in a system. The required capacities are defined in relation to the maximum estimated loads during the day, the experience from the previous day/hour, etc. The graphical example of the schedule of a generator's capacity for some actions is given in [8].

What services are counted in ancillary services, depends on the EPS. In addition to the above described, Kirby [9] as important lists also non-spinning reserve, supplemental or replacement reserve, voltage support and black start. For this paper, primarily is important to understand how the base-load power, power during a peak of consumption, load following and regulation are provided. It is important to say that here described way of providing them is not universal. It is more or less different from EPS to EPS. The here presented way is the closest to the way of providing them in EPSs in the United States. In Europe, there are counterparts to the regulation and load following in the form of the first, the second and the third control. More about the functioning of EPSs in Europe can be found in [10].

B. EVs

Plug-In Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs) are considered as EVs in this paper. Both types can be connected to the electrical grid (grid). Unlike BEVs that use only electricity from batteries, PHEVs have the possibility of using fossil fuels as well. However, the average capacity of BVs batteries is higher compared to PHEVs batteries. The batteries of EVs are usually lithium-ion. To a lesser extent are present also NiMH (more often in PHEVs). Lithium-ion batteries have an advantage over the others types of battery because of its low weight, high energy density and low environmental impact (almost all parts can be recycled). Because of all these advantages, lithium-ion batteries also cost more than other batteries [11].

In addition to the battery, EVs also need chargers. The main role of charges is to convert AC power to DC [12]. Today, most EVs comes with chargers customized to the home charging (max 16A with 230V, according to the European standard of household plugs). Hence, their connection capacity is about 3.3 kW [13]. In this case, the estimated charge time of 22 kWh battery is approximately 8 hours. A faster charging with the standard residential installation can be achieved with the three-phase current. For that propose, an onboard or off-board three-phase charger is needed. The connected capacity and the speed of charging are then three times larger than in the previous case.

For a faster charging of above mentioned, it is necessary to have electricity with a higher amperage or a higher voltage, or both. This can be achieved in industrial plants or by installing special charging stations at home or at public places. Such stations usually include a suitable battery charger. Faster chargers are not part of EVs due to their size and mass, which are larger in the case of a larger charging capacity. Currently, the fastest charging is achievable at charging stations of Tesla Motors Company (according to the statements of this company). Connection capacity at their stations is 120 kW [14].

Chargers are adjusted to the standards that regulate charging EVs batteries at some market. These standards prescribe the possible ways of charging (connection voltage and amperage) and technical and security settings for each of ways. In the United States, three different ways (levels) of charging are defined through the standard SAE J1772. This standard prescribes the required equipment for EV, Electric Vehicle Supply Equipment (EVSE), connectors, charger ratings and safety [15]. In the EU the standard IEC 62196 is used for that purpose. It defines three modes of charging (Table 1).

Table 1. IEC 62196 EV Charging Modes [16]

Charging Mode	Ratings	Status
Mode 1 (Standard AC sockets)	250 VAC, 4 kW @ 16 amp 480 VAC, 7.7 kW @ 16 amp	Established
Mode 2 (Standard AC sockets)	250 VAC, 8 kW @ 32 amp 480 VAC, 15.4 kW @ 32 amp	Established
Mode 3 (dedicated AC EVSE)	250 VAC, 8-62.5 kW @ 32 to 250 amp 480 VAC, 15-80+ kW @ 32 to 250 amp (with communication wire)	Established
Mode 4 (dedicated DC EVSE)	250-480 VDC, 80+ kW @ up to 400 amp (with communication wire)	Established

The rate of the battery charging depends on how much the battery is already charged, i.e. on the battery's SOC (state of charge). As the battery's SOC is increased, the rate of charging drops. When SOC exceeds 50%, the rate is significantly reduced. When SOC is over 80%, the rate is significantly smaller. Hence, the charging over 80% of SOC is not recommended. Some chagrining stations interrupt charging at 80% coverage, by themselves [17].

A characteristic of a battery that is of particular importance for users is the battery lifetime. From the day of production, battery lifetime is spent. That process is commonly referred to as degradation. Li-ion batteries are deemed to be at the end of their life, i.e. to be completely degraded when they max SOC drops below the 80% [18]. The degradation of the battery is primarily a consequence of battery charging and discharging. This is an irreversible chemical reaction in which the internal resistance of the battery increases and thus the useful battery capacity is also reduced [19]. The battery lifetime is also affected by a high level of SOC, depth of discharge (DoD), temperature, voltage, and by the time [20].

The guaranteed lifetime of EV batteries can be expressed in a number of charge-discharge cycles, a number of kilometers or years. However, for all types of batteries is common to express the life in the number of charge and discharge cycles (cycles). As it is not clearly defined what constitutes a charging-discharging cycle, the guaranteed number of cycles are given for a certain average DoD [21]. The majority of EV batteries are guaranteed to 8-10 years or 160 000 km of use [22]. Because of the rapid technological progress, their lifetime is increased rapidly. For example, Thunder Sky Energy Group offers batteries having a lifetime of 5000 charge cycles at an average DoD of 80% or 7000 charge cycles at an average DoD of 70% [23]. It is 2000 cycles more than in batteries they produced in 2007. The strong guarantee has 85 kWh battery of Tesla S model, which is 8 years and an unlimited number of kilometers [24].

C. The Integration of EVs in EPS

The introduction of a large number of EVs in EPS as consumers would lead to significant problems in electricity supply and for a longer period would not be sustainable. The UK Department of Transport and the Royal Academy of Engineering estimated in 2007 that if the UK replaces all traditional vehicles with EVs, the demand for electricity is increased by 16%. In the USA, that increase is 15% for the same situation [25].

However, a bigger number of EVs does not necessarily require the increase of electricity production and distribution capacity (up to a certain number of EVs). It can be avoided by smart managing of EVs batteries charging. The introduction of an EV in the Danish EPS costs 263 EUR/ year in free charge mode, whereas in a smart plan only 36 EUR/ year [26]. The simplest way of smart managing of the battery charging is to charge the battery overnight. By battery charging within a demand side management, the owners of EVs and EPS can achieve even greater benefits. EV owners obtain a more affordable electricity supply; EPS obtains a resource with a certain up-capacity.

The essence of the existing programs, which enable a smart management of EVs battery charging is to provide a cheaper electricity supply to users and a lesser load during peak hours for EDCs. Therefore, they see EVs as any other appliances. However, there are concepts which provide for the integration of EVs in EPSs as resources. These concepts provided for even greater benefits for the EDCs and for owners of EVs. They are based on utilization of the possibility of storing a larger amount of electrical energy in batteries of EVs.

III. CONCEPTS OF INTEGRATION EVS AS ELECTRICITY STORAGES IN EPSS

The use of EVs as electricity storages in EPSs can be ensured through several concepts. Some of the most important are V2G, Vehicle To Home (V2H), Vehicle To Building (V2B) and Grid To Vehicle (G2V).

3.1 V2H

V2H concept involves the use of electricity from the battery EVs for supplying household electric appliances. More precisely, using electricity from EVs that is not needed for driving and at the time when EV is at home. The main benefit of this concept lies in achieving cost savings for EV owner. The owner of EV has the opportunity to store electricity in EV battery in the period when electricity is cheap and used in periods when electricity is expensive. In addition, it allows the owner of EV to increase the security of its electricity supplying. If there is an interruption in electricity supplying, electricity from EV battery can be used for supplying household electric appliances. A 24 kWh (100-mile range) EV battery can provide an individual household with electricity for 2 hours [27].

A special benefit of this concept may have the owners of EVs that also own a renewable energy source. As these sources are mostly PV panels on roofs, EV battery can be used for storing a surplus of electricity that comes from the PV panels. This stored energy can provide significant cost savings if it is used when production of the panels is decreased or during the evening peak hours. V2H concept can be implemented through the concept of smart homes. It can help a concept of smart homes face one of main challenge – providing a storage for electricity.

Among the first companies that entered the V2H business are Mitsubishi with MiEV Power Box and Nissan with the Leaf-2-Home energy station [27]. Both products are launched in Japan in 2012. The total power of electricity which can provide MiEV Power Box is 1.5 kW, and Leaf-2-Home can provide the power of 6 kW [28, 29]. Many companies from other fields, also invest in R&D with the aim of making EVs batteries more suitable for non-driving purposes. Among them are manufacturers of batteries, manufactures of EVs and etc.

V2H concept allows the use of electricity near its source. This makes V2H concept efficient because there are no large losses caused by the electricity transmission. Realization of V2H concept does not require much of electric and communication equipment. In the case of a smart house, a central controller manages EV battery using. Therefore, human activity in the realization of V2H concept is almost negligible [30]. Managing with EV battery from the home is a significant advantage of this concept [27]. Mainly, because the need for direct interfaces between EVs and the grid is avoided. Further, the regulation of property rights and the legalization of such electrical supplying is facilitated.

3.2 V2B

As in the case of a home, EVs can be used for electricity supplying of business buildings. This concept is known as V2B concept. However, there are some differences between V2H and V2B concept. V2B concept involves a larger number of vehicles, i.e. requires management of charging and discharging a larger number of vehicles at the same time. EVs involved in V2B concepts can be the property of the same owner as the building. This is the case of companies with EVs in their fleets. Another option is that EVs involved in V2B concept are a property of natural persons. In that case, the owners of EVs participate in V2B concepts of buildings in which they work, study, do shopping, resting, etc.

This concept can be economically feasible in the electric power markets where medium and large organizations are encouraged to subscribe to a certain amount of energy [31]. In this case, EVs can be extremely useful when the organization needs more energy than it ordered from EDC. By using EVs in these situations, an organization avoids high penalties for using an additional electricity. Cost savings are not the main reason for the implementation of V2B concept [30]. Before them, it is ensuring a basic functioning of a building during a period of unexpected interruption in the electricity supply.

Similar to V2H, many believe that it is more realistic to expect from V2B concept to become a reality before the V2G concept. The main reason is a lower implementation costs of V2B concept, compared to the implementation costs of V2G concept. As far as the authors of this papers known, this concept is still not present in practice. Though, Nissan successfully tested V2B concept in 2013. In that experiment, six Nissan Leaf vehicles supplied the Office of the Nissan Advanced Technology Center in Atsugi City, Japan [32].

3.3 G2V

Viewed broadly, G2V concept (unidirectional V2G) is nothing more than charging batteries with electricity from the grid. However, it actually represents smart storing electricity from the grid to batteries of EVs. Such storing provides benefits to EDCs and EVs owners. First of all, G2V concept implies charging batteries during periods of a lower load (e.g. overnight). In this sense, corresponds to DLC program. However, the load following, regulation and spinning reserve services can also be provided through G2V concept. Sending power to the grid (up-capacity) is simulated by reduction of the amount of electricity that EVs use during charging batteries [33]. Furthermore, G2V concept enables participating in the process of valley filling.

This concept does not require upgrading the existing electro infrastructure, except installing communication equipment. Hence, implementing of G2V concept may be the first step towards the establishment of V2G concept [34]. It can help discovering challenges that operating of V2G concept bears. G2V concept does not imply a degradation of the battery caused by an additional cycling and can be implemented within the standard J1772 [35]. On the other hand, G2V concept does not exploit all possibilities of EVs as electricity storages. As it enables only the one direction flow of electricity, capacity for providing ancillary services through this concept is significantly lower.

3.4 V2G

V2G concept enables the biggest utilization of opportunities that EVs as electricity storages in EPSs can provide. First of all, this is due to the possibility of driving electricity from EVs batteries to the grid that this concept ensures. Kempton and Letendre [3] first indicate this possibility. Later, Kempton et al. [36] introduce the term V2G in 2001 (to the best known to the authors of this paper). They define V2G as "using the electric storage and/or generation capacity of battery, hybrid and fuel cell vehicles to send power to the grid."

By introducing the concept of V2G, Kempton et al. [36] also define what is feasible to do within that concept. They point out as feasible providing peak power, regulation, and spinning reserve. A similar opinion is valid these days. Hence, when the application of this concept is considered it primary includes peak power, regulation, and spinning reserve. There is a dilemma about the feasibility of providing the peak power. Providing the base-load power is still consider as unfeasible, because of the low prices for this power on the market. The feasibility of providing regulation and spinning reserve is a consequence of obtaining payment for being available, i.e. for a providing capacity (in addition to the payment for delivered kWh) [36].

Providing load following service trough V2G concept is not considered in the literature, as far as the authors of this paper known. Authors of V2G concept mention it in [37], as a service that overlaps or complements regulation service by a slower adjusting of electricity generation. They state that although it may be feasible to provide that service, they do not consider it. An exception in the literature may be made in [10]. Authors of that paper consider the feasibility of EVs for providing the second and third frequency control, which can be identified as load following. Papers mainly discuss the feasibility of using EVs for providing base-load power, peak power, regulation, and spinning reserve.

V2G concept was not so much present in the literature until recent years. The development of batteries and drop off their prices increased the chance of realizing V2G concept, and also the interest of researchers. On a practical level, first steps towards the realization of V2G concept began to happen. By now, they are in the form of V2G pilot projects. Nevertheless, the cost of equipment (primarily bidirectional charger), communications issues and degradation of the battery are still significant obstacles to the realization of this concept in practice.

Among negative opinions about the feasibility of V2G concept is the opinion of Tesla Motors' first man for car batteries, from August 2016. He claims that V2G concept is unfeasible because of the cost of battery degradation and interconnection costs [38]. It may also happen that because of the rapid growth of EVs participating in V2G concept prices of services provided through V2G concept are quickly reduced [35]. As a result, it may happen that the investment in equipment for V2G do not repay. On the other hand, there is a significant number of papers that speak in favor of the feasibility of this idea [33, 39, 40].

Therefore, a general opinion about the feasibility of V2G concept does not exist. The assessment of profits of participation in the markets of different services through the V2G concept range from negative 300 to positive 4600 $/vehicle/year and more [40]. The most common range is from 100-300 $/vehicle/year. These or those results depend on the way they are calculated. Results also depend on characteristics of EVs batteries, services provided through the concept, the growth rate of the V2G market, whether V2G is realized through aggregators or each EV participate separately, and many other issues.

IV. AGGREGATION

How EVs will participate in electric power market is an especially important issue for the success of the idea EVs as electricity storages in EPSs. Overall, there are two main options in the literature. The first involves a self-participation (directly) and the second involves the participation through an aggregator (indirectly).

Self-participation means that each owner of EV makes an agreement for providing services on the market separately. If EV owner provides regulation or spinning reserve, then he/she makes an agreement with a system operator. The system operator controls the charging and discharging of each EVs separately, in accordance with the agreement with EV owner. In the case of existing an aggregator, it represents more EVs on the market and makes agreements about providing services. The aggregator also makes agreements with EVs owners, and manage with chagrining and discharging of EVs batteries. The aggregator is responsible for providing the agreed services to customers (operators, EDs), but also has the responsibility for meeting agreements with EVs owners.

Due to technically difficulties for a system operator to connect with each EV separately and to manage of charging and discharging of such large number of batteries, the option with aggregators is more feasible. The expected reliability and availability are also greater in the case of using aggregator [41]. However, the revenues for EV owners are smaller if they use an aggregator for participation on a market. Though, the option with aggregation is the only one that can satisfy owners of EVs and the system operator at the same time [41].

As far the authors of this paper know, the concept of an aggregator is introduced by Kempton et al. [36]. They point out the aggregator's role as a middleman between an owner of EV and a system operator. The aggregator needs to coordinate charging and discharging of multiple EVs batteries in order to meet commitments to system operator about providing the agreed services and commitments to EVs owners about the agreed level of electricity in EVs batteries during a day. To make it possible, the aggregator needs first gather a sufficient number of EVs.

An aggregator needs to monitor and to record the use of gathered EVs, in order to define a profile of use for each EV [42]. Based on particular profiles, the aggregator can define the profile of its virtual powerplant made by batteries of gathered EVs. With that information, the aggregator can estimate power and capacity that has on disposal at any moment. Based on such formed estimations, the aggregator offers a bid on services' markets. During the realization of services, electricity is taken from EV battery or sent into EV battery. The algorithm in each EV can control the battery SOC, i.e. stop providing certain service from some EV in order to maintain the established profile of use for that EV [42].

Establishment of a computer/communication/control network is crucial for operating an EPS with aggregator (Guille and Gross 2009). That network needs to connect aggregator with EVs, and aggregator with system operators and/or producers of electricity. In that way, an aggregator can track SOC of aggregated EVs, their provision of services, measuring electricity flow into and out of them, and etc. In this regard, the network needs to satisfy requirements in the field of security, reliability, and flexibility. In addition, it needs to be easily expandable and costs of connection on the network need to be negligible compared to the cost of EVs [5].

If it is assumed that there are no technical barriers, there is the question how to persuade the owners of EVs to place their vehicles at the aggregator disposal. Even in the first paper about the V2G concept by Kempton and Letendre [3], there is the idea how to do that. The authors propose that each EV owner is obliged to indicate when they intend to use EV again and how much electricity in EV battery should be at that time. Depends on the time their EVs spent connected to the grid, they get the corresponding revenue. Some stricter variants, propose defining in the contract how long and/or when EV needs to be connected to the grid and/or how much electricity in EV battery needs to be at some time.

However, people are not willing to accept obligations such as a minimum time connected to the grid or having only a guaranteed amount of electricity in the battery. Therefore, a strategy based on hour-by-hour or pay-as-you-go can be used [43]. The first does not imply any obligation for EV owners. EV owner gets revenues depending on the amount of time they put their vehicle is at the aggregator disposal. In the second case, the owner would receive money in advance for the agreed putting EV to aggregator disposal. Aggregator needs to monitor - learn about the behavior of drivers and on that basis make decisions about charging and discharging their EVs [3]. In this case, the driver would be obliged only to announce an unexpected or non-standard trip.

The aggregator has to manage with charging and discharging EVs batteries in order to meet the obligations under the contract with the EVs owners and the system operator. Different proposals (concepts, strategies) can be found for managing of charging and discharging EVs batteries while providing services. Some of the proposals aim at maximizing benefits for the owner of EVs, some for aggregators, some for both and some for the system operator. These proposals are usually supported by different algorithms, mathematical models, and simulation models. Examples of some models for managing of chagrining and discharging EV batteries can be found in reviewed papers [18, 44].

Aggregator function does not have to be performed only by a newly-established company. That can do also be some existing companies, which are in some way connected with what aggregator works, needs of equipment, etc. It could be EDCs, EVs manufacturers, and mobile phone operators [36]. Also, it could be producers or sellers of batteries, EVES, EVs, electricity.

The aggregator could participate in the market directly or through an existing electric entity. To participate in the market of regulation service or spinning reserve service, a participant usually needs to have a capacity of at least 1MW power [33]. That power corresponds to 67 EVs with a battery capacity of 15 kW. As not all vehicles will be available all the time, the required number should be obtained by multiplying with 1.5 [37]. Hence, 100 EVs are needed to have the capacity of 1MW power. If the electricity is sent through the household installations, then about 500 EVs are needed for capacities of 1-2MW [27].

V. OPPORTUNITIES TO REALIZATION THE IDEA OF EVS AS ELECTRICITY STORAGES

The idea of EVs as electricity storages in EPSs has a chance to become a reality also due to the fact that the number of EVs is constantly growing. In that way, a large unused electrical energy resource is creating by EVs batteries. Mechanical power of all vehicles in the US was 19.5 TW in 2004, which is 24 times the greater power than the power of the entire US EPS [45]. If this information is taken along with the estimation that 90-95% of time vehicles are parked, then it is clear what an energy resource is created by switching to EVs. Taking the example of Denmark, it would is enough that just ¼ of vehicles is EVs and only half of them are connected to the grid, and all needs of Denmark for electricity are satisfied [46].

The concrete reasons for belief in the feasibility of this idea arise from the suitability of EVs as storages for providing ancillary services, peak load power (peak shaving), valley filling, and the help in the integration of renewable energy sources in EPS. In this chapter, only regulation and spinning reserve service of ancillary services are considered. Ehsani et al. [47] show that EVs are also suitable for providing reactive regulation and motor starting ancillary services.

5.1 Regulation, spinning reserve, peak shaving, valley filling

Storage resources are extremely useful in stabilizing EPSs, i.e. for aligning of energy supply and demand during the day, hour, minute. However, due to the high cost, they are not present in a significant amount in EPSs. EVs can form a significant electricity storage that can be also affordable. Electric energy sector would practically share the cost of that storage with transportation sector.

While the feasibility of providing valley filling with EVs is unquestionable, the feasibility of providing peak shaving is under suspicion due to an increased wear of batteries. As batteries are improving rapidly, it can be expected that these doubts disappear soon. Charging EVs at night significantly increase the efficiency of existing electricity production systems and also reduce exhaust emissions of fossil fuel power plants [48]. By charging EVs overnight, it is reduced the need for reducing or even shutting down the production overnight. I that way, costs, and emission of gasses caused by increasing or restarting of electricity production are reduced [5].

Existing facilities that provide regulation and spinning reserve, predominantly are in the form of gas and hydropower plants. Looking at the efficiency of gas power plants, in terms of converting thermal energy into electricity, it is quite low. Furthermore, the variation in their output leads to a great wear. Also, gas power plants emit harmful gasses. The efficiency of hydropower plants is quite high, but building of these plants is expensive and not possible in all areas. Due to the high cost of building and an insufficient utilization their capacities during providing these services (due to minimum electricity generation), this resource can be considered as expensive. The reliability and availability of gas turbines for providing regulation is estimated at 93% and 98.9%, whereas in the case of EVs through aggregation they are on 100% [41].

The response of EVs can be measured in milliseconds unlike the existing resources, where the response is measured in minutes (gas plant) and seconds (hydropower plants). This means that EVs can quickly change the amount of energy they send or receive. Existing resources can only provide services by increasing or decreasing their production. The exceptions are special hydro power plants. They can receive (store) electricity by pumping water to higher levels. EVs can send and receive electricity. That gives them a significant advantage over existing resources for providing services on electric power market.

Owing to the possibility of EVs to receive electricity, using EVs for regulation or load following practically enables using resources that do not have significant ramping rates for providing peak power as well. These resources are cheaper, which means that significant savings can be achieved in that way. Compared to existing resources, EVs have less maintenance costs incurred because of the frequent cycling. EVs also have no opportunity costs, which may occur at existing resources [16].

By providing load following and regulation, EVs can provide revenue to owners, almost without driving electricity from the batteries. Especially this is true in the case of regulation, where the level of electrical energy in the battery only varies slightly around the level that was before the provision of this service [36]. Wang et al. [39] measure degradation of EV battery caused by providing regulation/peak shaving. Simulation results indicate that if EVs are used for the regulation/peak shaving each day in the period from 7pm-9pm ten years, then the loss of battery capacity is increased by 3.62% /5.6%.

Costs of wearing of lead acid battery, while providing regulation are 20-60% of the annual income that can be achieved by providing that service [42]. Revenue (income minus costs) of providing peak power is $ 267 (510-243), in the case of spinning reserves it is $ 720 (755-55), and of regulation is 3162 $ (4479-1317) (Kempton et al. 2001b). By discharging EVs during peak periods and by using EVs for providing ancillary services, power plants are able to produce more electricity and thus achieve a higher revenue. This is all reasons to believe that these two services, along with many others ancillary services can significantly help EVs as electricity storages become reality.

5.2 Renewable energy sources

By integration of electricity from renewable energy sources (RES electricity), instability of EPSs is additionally increasing. This is due to the extremely variable and uncertain production of these electricity sources. First of all, this is referred to electricity obtained by renewable sources based on solar and wind power. Because of that, EPSs need additional capacity for providing ancillary services. If the share of RES electricity in the grid exceeds a threshold of 10-30%, it is necessary to introduce new resources for stabilizing power in the grid [51]. Due to the above-mentioned drawback of the existing resources for stabilization, it is searched for better solutions. One of the possible solutions is the use of EVs through V2G concept for these proposals. Moreover, EVs can be used as a buffer for surpluses of RES electricity appearing in certain periods. That electricity can be used after, in periods of the lower production or for driving proposes.

The idea of V2G concept is arisen out of searching for a solution for the increased instability that brings integration RES electricity into EPSs [52]. The support to the integration of RES electricity into EPSs can be the most important role of the V2G concept [37]. The importance of using EVs for this purpose is greater in places where there are no conditions for the building of traditional resources for supporting RES electricity integration (e.g. the hydroelectric power plant) [37]. EVs are a natural resource of demand-and supply-side flexibility that can help reduce the negative effects brought by volatility and uncertainty of RES electricity [53].

Charging at public stations would be increased by 433% if they offer the charging with RES electricity [54]. Charging EVs directly from the PV panel reduce the losses that occur due to transmission of electricity [40]. Also, the losses are reduced because there is no need to switch DC to AC electricity. Using such practice would be also beneficial for EPS, because it would reduce the need for its upgrading due to the appearance of new consumers in the form of EVs. Wang et al. [39] examine loss of battery capacity in the case of using EVs for the load following as a support service to the distribution of electricity from renewable energy sources. Results indicate that the loss of capacity is increased by 22% in the period of ten years if EVs are used for providing the load following during all day.

The synergy of EVs and ERS is almost inevitable for the sustainable growth of both of them. Increasing the number of EVs creates demands for additional production resources which are increasingly based on renewable sources. On the other hand, the introduction of such resources of electricity in the system causes a growing of need for stabilization resources. That need can be met just by the use of EVs through V2G concept.

VI. THREATS TO REALIZATION THE IDEA OF EVS AS ELECTRICITY STORAGES

Threats to the realization of the idea of EVs as electricity storages in EPSs are primarily of a technical nature. These technical threats further mostly imply economic threats, and they cause weaker position in the fight with competitors.

6.1 Technical threats

Threats of a technical nature can be divided into those related to infrastructure, communication, and control (security). Generally, the integration of a large number of EVs brings infrastructural challenges for EPSs. By realization of V2G concept, these challenges are increased. The integration of a large number of EVs would keep a grid at its maximum planned capacity longer than is now case [55]. That could cause cancellations of grid components, and thus reduce the reliability of the electricity supply.

Among all grid's components, the biggest concern is for transformers. Primarily because they represent among the most costly components in the medium and low voltage distribution infrastructure [56]. The increased number of EVs can cause rapid aging of transformers [55, 57]. The transformers in off-peak periods (during the night and between peaks) are cooled. If it is assumed that larger number of EVs are charged overnight (when electricity is cheaper), the time for cooling transformers is significantly reduced. Consequently, their temperature is increased and the aging is accelerated.

Issues such as communication delays, routing protocols, and cyber security are very critical for the reliable and efficient adoption of the V2G transactions framework and the smart grid context [58]. For example, the response to the call for a spinning reserve should be up to 10 seconds. The question is whether it is possible to build such a communications system that can provide timely information from the system operator to all aggregators, and from aggregators to their EVs. A large number of EVs, which are used as resources within EPS would create a great pressure on the communications resources, and even on the GPS [30].

EVs that send electricity into the grid are considered as a distributed energy resources. Hence, they have to adhere to IEEE 1547 in the territory of the United States [15]. This standard defines the criteria and requirements for interconnection of distributed resources and EPSs. Among the most important requirements are the response time to abnormal voltages and frequencies, and current distortion limits [15]. Metering and billing in a case of application of V2G concept have to be also defined. A special problem is how to ensure full battery capacity during winter.

6.2 Economic threats

Investments in infrastructure, primarily in V2G equipment and grid upgrading, are still a big reason for doubts about the feasibility of the idea of EVs as electricity storages. Investments are needed in bi-directional chargers, charging stations, measuring devices, communication equipment and so on. Besides of investments at EVs owners side, investments in the certain equipment and people are needed also at EDCs and aggregators. The big question is who needs to invest in the upgrading of the grid [59].

Costs due to the accelerated degradation of the batteries are too big and make exploitation of EVs as electricity storages through V2G concept unfeasible [60, 61, 62]. The frequency of battery replacement at PHEV is increased from once every two years (at 30% DOD) to once a year (for a larger DOD) [61]. For BEV that increase is from once every three years to once a year (for DOD greater than 30%). EV battery life is reduced from 11.8 to 8.7 years, and the energy throughput is increased from 44.8 MWh to 72.8 MWh for providing ancillary services 2 hours per day [62]. An overview of some other studies that indicate the unprofitability of V2G concept due to degradation of the battery can be found in [60].

The cost of investing in infrastructure and cost of battery wearing can hardly be covered by revenues from the provision of ancillary services [51]. Primarily because the ancillary services are rarely used, i.e. a small amount of energy is delivered by providing them. Hence, the main income came from the provision of capacity. This revenue, however, is not enough to make EVs as a resource economical on the market of ancillary services. Subsidies for supporting the use of EVs as a resource should not be expected, because of the realized investments in existing resources that provide ancillary services [51].

With the increase of EVs and their increased participation on the ancillary market prices of these services can drop. If EVs are used as electricity storages through G2V concept, the price of these services may fall by 70% for 300,000 integrated EVs. If they are used through V2G concept, prices may fall by 69% for 100,000 integrated EVs [35]. The fall in prices may cause that the invested capital in equipment cannot be returned.

6.3 Alternative options

If we look at the present situation, competitors of EVs in providing ancillary services are pumped hydro electric storages (PHSs), conventional hydro power plant and gas power plants. From the others are still expected to make an expansion. Among them are: concentrating solar power systems (CSPSs), dedicated battery banks, flywheel energy storage systems (FESSs), hydrogen storage systems.

More than 99% of the world's total storage capacity for electricity consists of PHSs. They have a high efficiency, between 70-85% [63]. PHSs is a much cheaper option for the storage of electrical energy than EVs [51]. Newer hydroelectric power plants for providing ancillary services does not take up much space and have a high power [63]. Therefore, they do not harm the environment as previous hydro plants. Advantages of PHS is also a very long life time [64].

Gas power plants are generation based technology for supporting grid. They are especially important in places where installation of PHSs is not possible. Their efficiency is low, only about 33% of the energy value of the gas is converted into electricity. However, they are acceptable in EPSs where the main part of electricity is obtained from fossil fuel plants. Because the storing of that electricity during providing ancillary services produce additional losses and make the production of this electricity more inefficient [63]. However, given the growing tendency towards the transition to cleaner technologies, gas power plants should not represent a significant alternative in the future.

CSPS is becoming increasingly attractive electricity storage technology [51]. Tanks with a molten salt mixture can store energy and up to seven days. The representation of this technology is growing from year to year. According to forecasts of the International Energy Agency (IEA), it will continue in the future. Compared to batteries, CSPs with a molten salt is significantly less expensive and electricity storage with longer life [51].

Battery banks resource has excellent efficiency and can be placed at any place [63]. In addition, the rapid progress of technology makes battery banks more and more competitive. Technological advantages compared to V2G are no, because of the same technology in the batteries. However, battery banks can provide benefits to buyers because of buying a larger battery capacity (discount on the amount), self-participating on market (without aggregator) and an unlimited availability for providing services [51].

FESSs have a high efficiency (about 85%), which is particularly high in the provision of regulation service [63]. FESSs are suitable for small and EPS distant of power production. In addition, improved FESS have a high energy density (the amount of energy per unit volume of the system) and small losses during the standby period (over periods of many minutes to several hours). They also have the possibility changing the state of total discharged to the state of fully charged in just a few seconds [65]. Despite the poor efficiency, the interest in hydrogen energy storage is increasing. The reason for this is the greater storage capacity compared to batteries or pumped hydro system [66].

VII. V2G PILOT PROJECTS

Below are given some of the most important pilot projects which endeavor to practical prove the feasibility of the idea of EVs as electricity storages or help its implementation. Information on many similar projects can be found in [67].

7.1 The University of Delaware in 2010 & independent system operator PJM Interconnection

The project is carried out at the University of Delaware in cooperation with power supplier NRG Energy Inc., under professor Kempton supervision. For the purpose of the project, BMW donated 15 Mini E models that are equipped with two-way charger. Batteries in Mini E models are Li-ion with 35 kWh capacity. The charger can send a power of 18kW [52].

EVs together form the Virtual Power Plant (VPP) that can draw electricity from the grid, but also hand over electricity to the grid. They call that plant a short-term mini storage facility and it is being used by PJM Interconnection (the operator of the electricity-transmission system in much of the Eastern U.S.). When there is a surplus of power, PJM uses VPP as a storage for that surpluses and pays for it. PJM ensures that the level of electricity in batteries never falls below the defined level when using electricity from batteries.

Because of the condition that the power plant must have a minimum power of 100 kW to take part in the market, a minimum 9 EVs of the VPP have to always be connected to the grid. VPP participate in PJM market as other conventional power plant (through the auction) but also has the same responsibility as conventional plants. Participating VPP in markets resulting in earnings for each single EV of 5 $/day and about 110 $/month [68].

7.2 DOD V2G Pilot Project

The project is a product of the aspirations of the US Department of Defense to reduce total petroleum consumption of their fleet and exhaust emissions. Also, it is a response to a presidential memorandum from 2011, according to which all new light-duty vehicles purchased or taken on lease by 2015 must be driven by alternative fuels. Accordingly, during 2013, 40 vehicles with electric vehicle service equipment are delivered at the Los Angeles Air Force Base (LA. AFG) within an all-electric fleet pilot. The plan is that EVs participate in the CAISO regulation up and down market. The results of that participation and smart management of this fleet should serve to assess the overall economic feasibility of DOD non-tactical fleet electrification [69].

In the next two phases should have been delivered about 500 medium duty trucks at six military bases, including L A, and in the third phase another about 1500 PEV. The overall program includes V2G activity, which means that the vehicles will be V2G capable. Pentagon deemed that the income of providing the services through the V2G concept can quickly offset the high cost of electric vehicles [70].

However, information on whether the second and third stages of the project are implemented and what are the results of participation in the market of ancillary services are not found by the authors of this paper. The latest pieces of information about this project are from 2015 and are found in [71]. They tell us that 42 EVs are delivered in LA AFB to test V2G concept and that these EVs can produce electricity of power higher than 700 kW when all are plugged in. By that source, that makes this project the largest demonstration of the V2G concept in the world.

7.3 Carmakers and Electric Power Research Institute Project

The project is launched in 2014, in the organization of Electric Power Research Institute (EPRI) and nine car manufacturers (BMW, Chrysler, Ford, Honda, General Motors, Mercedes-Benz, Mitsubishi and Toyota). The aim of the project is to develop a common platform for communicating of these manufacturers' EVs with the grid. Participation in the project is taken by 15 EDCs as well. The project is the result of problems that electricity suppliers have if they want to smart manage charging of EVs. In fact, EDCs need to make a special software for each producer. Some of the producers require sending a signal by power lines, others wirelessly [72]. This open grid integration platform will simplify V2G communication, enabling EVs to provide services to the network and thus increase the overall profitability of EVs [73].

7.4 Nissan and Enel Project

Enel and Nissan joined forces in late 2015 with the aim of developing the innovative V2G system. This system should ensure that EVs operate as "energy hubs" that can be used for supplying household appliances, but also for returning electricity to the grid when there is a surplus of electricity in them [74]. The result of this cooperation will soon be applied in a practice. In May of 2016, Nissan announced that all owners of Nissan electric vehicles will be able to sell electricity from their EVs to EDCs. It will be possible at 100 V2G points around the UK, which are the result of cooperation between Nissan and Enel [75].

7.5 Nissan and Enel Project

Similar to Nissan and Enel, Mitsubishi and V2G developer Nuvve joined forces in V2G pilot project utilizing Outlander PHEVs. Partners in the project are smart charging specialist NewMotion and Dutch grid operator TenneT. The project was implemented in November 2017 in Amsterdam. The aim is to demonstrate V2G potential of Mitsubishi Outlander and opportunity for a new income for their drivers [76].

VIII. CONCLUSION

The idea of EVs as electricity storages in EPSs may be of interest to researchers from many fields. First of all, because it aims to reduce pollution and to achieve a greater energy efficiency. According to the results of survey presented in [77], willingness for participation of EVs drivers in V2G projects might also grow as problems with 'range anxiety' and the 'minimum allowed range' are solved.

By offering a comprehensive overview of this idea, this paper presents a good basis for all researchers who want to start dealing with this idea and further elaborate it. The authors of this paper also intend to further elaborate this idea, through the prism of logistics. The aim is to offer a solution for storing of electricity in EVs that will be useful for owners of EVs and users of their storage capacities, and also simple to implement. That includes the development of solutions for managing of charging and discharging of EVs at public parking lots, with different variants of contracts with EVs owners.

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