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doi:10.15199/48.2019.10.12

Analysis of the possibilities of using V2G technology for power system balancing

***Abstract**. The paper is an attempt to analyse the possibilities of power system balancing using technology electric vehicles compatible with V2G, which enables bidirectional power flow between EVs and power grid. The analysis was carried out on example of Polish Power System (KSE).*

***Streszczenie.** W pracy podjęto próbę analizy możliwości bilansowania systemu elektroenergetycznego przy wykorzystaniu pojazdów elektrycznych wyposażonych w technologię V2G, umożliwiającą dwukierunkową wymianę energii pomiędzy pojazdem elektrycznym a systemem elektroenergetycznym. Analiza została przeprowadzona na przykładzie Krajowego Systemu Elektroenergetycznego. (**Analiza możliwości wykorzystania technologii V2G do bilansowania systemu elektroenergetycznego**).*

Keywords: V2G technology, power system, power system balancing.
Słowa kluczowe: technologia V2G, system elektroenergetyczny, bilansowanie systemu elektroenergetycznego.

Introduction

Rising number of electric vehicles (EVs), in particular plug-in electric vehicles (PEVs), which can be recharged from the power grid, is not without significance for the functioning of power systems on a local, regional or even national scale. In 2017 less than 150 000 cars of this type were registered in Europe. Nevertheless, it is expected that by 2030 the number of electric vehicles will be oscillating around 125 million cars worldwide, which will put an additional load on existing power systems [1]. On the assumption that 15% of all cars registered in European Union are electric, electricity demand will increase by 95 TWh per year, which will be equal to around 3% of total electricity consumption in all EU countries [2]. On the other hand, every electric vehicle is equipped with battery, which can be used as an energy storage system, capable of sending power back to the grid during peak demand periods and storing energy when demand is low [3].

First concepts of using energy stored in EVs batteries for power system balancing were presented in 1997 [4] and the results of preliminary research confirmed that this idea is feasible and viable for both power system operator and vehicle owner [5]. The technology was called Vehicle-to-Grid, usually shortened to V2G [6]. V2G is a system of bidirectional power flow and communication between EVs and power grid. There are several requirements which need to be satisfied in order to make it attainable, including power flow management systems and communication infrastructure [7].

As mentioned before, growing number of plug-in electric vehicles can considerably affect power systems by increasing electrical energy demand [8]. However, reasonably managed EVs fleets – compatible with V2G – could have positive effects on the grid. Potential benefits include peak load levelling, providing spinning reserves and regulation services [9], improving power quality, reducing harmonic content [10, 11], compensating reactive power [12] and working as an emergency power source for households or street lights during power outages [13].

In this paper, the possibilities of using V2G technology for power system balancing by suitable EVs management are analysed. This feature is beneficial for power systems on both local and global scale. Storing electrical energy generated locally by renewable energy sources is also a remarkable aspect of V2G systems. The number of wind and solar power plants is constantly increasing, due to the rise of prosumer micro systems. This way, the negative effects of unexpected intermittencies of renewable generation would be significantly reduced [9].

There are several pilot programs executed currently in Europe, which are focused on testing Smart Grid with V2G systems opportunities. The most noteworthy of them are presently conducted in London (Great Britain) [14], Denmark [15], Amsterdam (Holland) [16] and Hagen (Germany) [17]. V2G technology is a contemporary prospective solution for power system balancing. In such circumstances, the following question arises: what is the number of electric vehicles in V2G system to have a substantial effect on power system balancing? The analysis will be carried out on the example of Polish Power System (KSE).

Assumptions

Before the analysis was conducted, initial assumptions were made. Existing pilot programs are still in its nascent stage, functioning only on the scale of local power systems. The problem with obtaining load profiles from power system operators prompted authors to choose Polish Power System (KSE) as a basis for the analysis. The year 2018 was chosen as a reference period.

Based on the data collected from the website of Polish Power System Operator, which is Polskie Sieci Elektroenergetyczne S.A., two typical working days – accordingly the winter and the summer one – were selected. 17th January 2018 was picked as a typical winter working day, subsequently 18th July 2018 – as a typical summer working day. Figure 1 shows the KSE power demand for selected days.

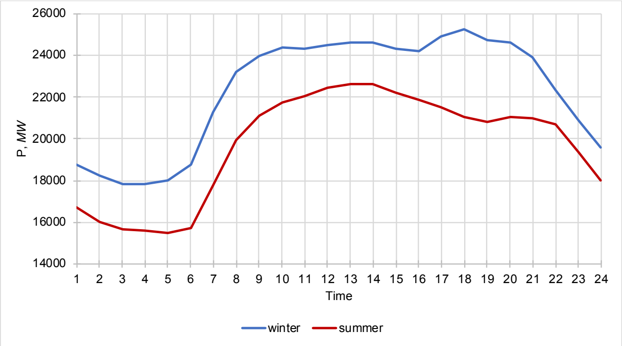

Fig.1. KSE power demand for selected days

For the analysis, the total number of EVs functioning in V2G system, ready for bidirectional energy flow between them and the power grid, was assumed to vary from 50 thousand to 200 thousand, increasing by 50 thousand every 5 years. The average battery capacity was estimated to be

40 kWh, what is a typical property of modern battery electric vehicles (BEVs). Such battery is a component of, for instance, Nissan Leaf 2018, which currently is one of a few models fully compatible with V2G. Furthermore, batteries state of charge was assumed to equal 80%.

Conducted research [18] indicates that at any given time 95% of cars are parked. During this time, EVs are able to operate in V2G system, on condition of being connected to a bidirectional charger. It has been assumed that 80% of all V2G compatible cars are connected to the grid at any moment and actively participate in V2G system. 10 kW was assumed as the average charging and discharging power, what is a nominal power of most of the commercially available V2G chargers, suitable for single-family house, garage or workplace installation.

One of the most significant assumption concerns the usage patterns of electric vehicles. It has been assumed that EVs are being charged for 4 hours per day during the time of lowest power demand. Going further, vehicles are being discharged for 3 hours, sending power back to the grid when power demand is high. Analysing the load profiles of KSE, the most suitable time for V2G operations for selected days was determined:

- EVs charging:
  - summer day: 1:00-5:00,
  - winter day: 2:00-6:00,
- EVs discharging:
  - summer day: 16:00-19:00,
  - winter day: 11:00-14:00.

Analysis of the possibilities of using V2G technology for power system balancing

Considering the assumptions above along with the number of 100 thousand EV on roads, from which 80% (80 thousand) participates in V2G system, electrical energy stored in batteries of EVs connected to the grid E_t is equal to:

(1) $$E_t = n_{EV} \cdot E_{EV} \cdot SOC_{EV}$$

where: n_{EV} – number of EVs connected to grid, E_{EV} – battery capacity of a single EV, kWh, SOC_{EV} – average battery state of charge, %.

For the assumptions made, theoretical electrical energy stored in EVs batteries is equal to E_t = 2 560 MWh. Power capacity of parked electric vehicles P_t was calculated as:

(2) $$P_t = n_{EV} \cdot P_{EV}$$

where: P_{EV} – power capacity of a single EV, kW.

Power capacity of a single EV was assumed to be the power of a bidirectional charger. Thus, calculated power capacity of all EVs equals to P_t = 800 MW. Equation 3 defines the relation between energy stored in EVs batteries E_t and their power capacity P_t:

(3) $$E_t = P_t \cdot t_t$$

where: t_t – time of EVs discharging, h.

Transforming equation 3, time of EVs discharging t_t was obtained:

(4) $$t_t = \frac{E_t}{P_t}$$

Using the parameters set out before, time of discharging is equal to t_t = 3,2 h.

Analysing the results, it can be established that EVs are capable of sending power to the grid for the time of 3,2 h. Considering the fact that deep discharging can affect lithium-ion batteries longevity and make unexpected mobility need completely impossible, this idea is not possible for implementation. Therefore, for further calculations it has been assumed that V2G system needs to guarantee a minimum state of charge, discharging EVs for at most t_t = 3 h per day. Using equation 3 and assumed time t_t, calculated electrical energy, which can be returned to the grid, is equal to E_{td} = 2 400 MWh.

Average distance driven by a single car per day was assumed to be 50 km. Energy consumption of the example BEV – Nissan Leaf 2018 – is around 14 kWh/100 km. Thus, every vehicle participating in V2G system needs to be supplied with additional 7 kWh from the grid each day.

Charging vehicles at night would be helpful for load balancing, reducing the negative effects of load valley. EVs are assumed to be charged during night hours with the amount of energy sent back to the grid during peak hours increased by energy consumed for mobility purposes. Electrical energy used for EVs mobility E_{tm} is given by:

(5) $$E_{tm} = n_{EV} \cdot E_{EVm}$$

where: E_{EVm} – energy used for mobility purposes of a single EV, kWh.

Calculated energy for mobility needs is equal to E_{tm} = 560 MWh. Total electrical energy $E_{tc,}$ absorbed by EVs during night, is calculated as a sum of energy returned to the grid during day E_{td} and energy consumed for mobility purposes E_{tm}:

(6) $$E_{tc} = E_{td} + E_{tm}$$

The result of calculation amounts to E_{tc} = 2 960 MWh. Time of EVs charging has been assumed to be 4 hours. Total power of EVs charging is equal to:

(7) $$P_{tc} = \frac{E_{tc}}{t_{tc}}$$

where: t_{tc} – time of EVs charging, h.

Obtained power of EVs charging equals to P_{tc} = 740 MW. Parameters calculated before are essential for the analysis of V2G technology impact on KSE power demand profiles. Analysis is carried out for selected typical working days, based on the data collected from the website of Polskie Sieci Elektroenergetyczne S.A.

Proposed scheme of charging and discharging is advantageous for load shifting. By charging vehicles at night, it is possible to realize load valley filling, while discharging vehicles is beneficial for peak shaving: on a winter day an evening peak is levelled off whereas on a summer day it affects a morning peak. Based on carried out calculations, power demand is increased by P_{tc} = 740 MW when EVs are being charged. On the contrary, sending power back to the grid is decreasing load by P_t = 800 MW, what would normally needed to be balanced by conventional power plants. Using this information, for selected days the graph of KSE power demand supported by V2G technology – for 100 thousand EVs – was plotted (Fig. 2).

For the assumed number of V2G compatible vehicles, power capacity and stored energy are comparable to the corresponding parameters of the Poland's largest pumped-storage power plant, located in Żarnowiec. This power plant is characterised by installed capacity of 713 MW, while its upper reservoir can store up energy to 3 600 MWh [19].
Increasing the number of EVs to 200 thousand in the following years, combined with proper fleets management, V2G impact on KSE demand profiles could be even more significant, what shows figure 3.

The analysis above does not consider projected increase of KSE power demand in the following years [20]. Table 1 shows the forecast of KSE peak power demand up to 2035.

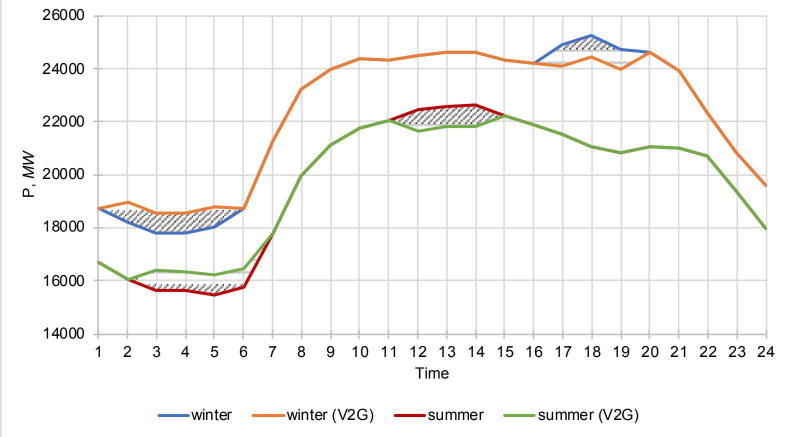

Fig.2. KSE power demand supported by V2G (100 thousand EVs)

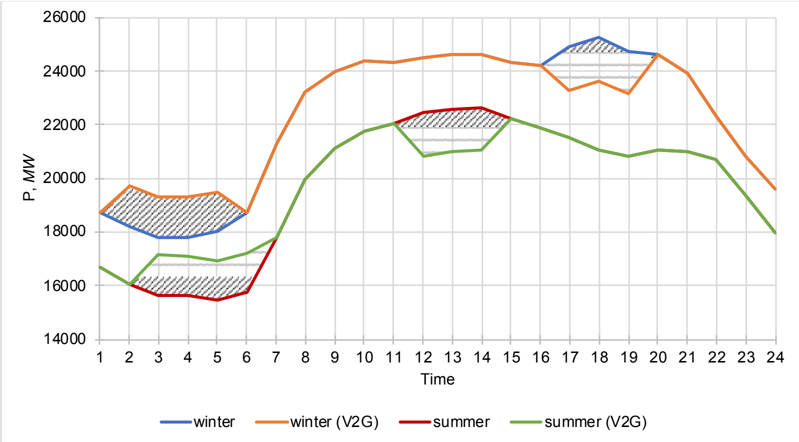

Fig.3. KSE power demand supported by V2G (200 thousand EVs)

Table 1. Forecast of KSE peak power demand up to 2035 [20]

Year	Winter peak [GW]	Summer peak [GW]
2016	26,2	22,7
2020	28,0	24,8
2025	30,3	27,5
2030	32,7	30,1
2035	35,2	32,7

Table 2. Forecast of KSE power shortages compiled with EVs capacity up to 2035 [20]

Year	Number of EVs [thousand]	Power shortage – winter peak [GW]	Power shortage – summer peak [GW]	Theoretical EVs capacity
2020	50	–	–	0,4
2025	100	2,2	0,3	0,8
2030	150	6,8	4,8	1,2
2035	200	15,2	13,4	1,6

After 2020 power shortages in KSE are expected to occur because of the slow pace of new power plants development. What is more, old generation units are highly exploited and require renovation or decommission. Depending on a chosen scenario, in 2035 power shortages will amount to 13 000 MW or – in the worst-case scenario – even 20 000 MW. For the analysis, the modernisation scenario was taken into consideration, according to which power shortages will occur from 2020 to the end of the analysis period [20]. In this manner, given the expanding power shortages, electric vehicles could play an essential role in power system balancing. Table 2 shows the projected power shortages compiled with theoretical EVs capacity.

As presented in table 2, sufficient number of EVs participating in V2G system could partly cover expected KSE power shortages, however the expansion of electromobility has to be closely associated with the investments in new generation units. Otherwise, discrepancies between electricity demand and generation capacity of existing power plants will have to be balanced by importing energy from the neighbouring countries.

Conclusion

The above analysis indicates that plug-in electric vehicles and V2G technology could significantly affect the shape of power demand profiles. The more EVs participating in V2G system, the more substantial their impact on power system is. The development of this technology is strictly conditioned by the technical aspects, such as expansion of bidirectional charging stations, adaptation of existing grid for delivering at least 10 kW power as well as batteries degradation and expensive replacement of them. Nevertheless, social factors appear to have the biggest impact on V2G spread. EV owner, who agrees for participating in bidirectional energy exchange, needs to be aware of some limitations on car usage, for instance not being able to drive EV during the time of charging or discharging [7]. Moreover, being part of V2G system may require changes in drivers' habits, such as matching driving hours with V2G operations time.

Nonetheless, appropriate encouragement – mainly financial incentives – could convince EVs users to support power gird with their cars. Legal regulations are also a vital element to provide the development of this concept. Another important factor associated with balancing power system is uneven distribution of electric vehicles across the country. For that reason, it is recommended to implement V2G on a local scale at the outset.

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