Estimation of electric vehicles with V2G capabilities potential for market participation

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***Abstract*— In this paper we estimate flexibility potential of selected use case of parking lot with 10 aggregated EVs. Flexibility of EVs can be procured by the aggregator on local flexibility market or on balancing market regarding services. Selected use case corresponds to the Slovenian demonstrator of EV4EU project. For the selected use case we estimate negative and positive flexibility potential that aggregated EVs can provide in terms of energy and time. We conclude that EVs could have 880 kWh of negative and positive flexibility potential in one day. Considering charging station specifications potential is 550 kWh. Based on the results of potential flexibility of EVs we estimate the ability of the selected use case for the participation in the frequency services by providing negative and positive balancing energy in the scope of the balancing market. In regard to the work beyond the project on the Slovenian demonstrator we also estimate how energy self-sufficient parking lots can be, if charging is provided with energy from local PV and how this can help secure and stabilize distribution grid by participating in different flexibility services.**

Keywords—EV, V2G, V2X, VGI, flexibility, energy market, PV, energy self-sufficiency,

I. Introduction

The drive to mitigate climate change requires drastic changes. One of them is the electrification of transport, the aim of which is to reduce greenhouse gas emissions and thus improve the quality of life (QoL). However, with the wider use of electric vehicles (EVs), problems with grid congestion are arising that require appropriate solutions for vehicle to grid integration (VGI) [1].

After two decades, the concept of two-way power exchange between EVs and the energy grid is moving from theory to practice as Vehicle-to-Grid (V2G) [2]. We can observe that major car original equipment manufacturers (OEMs) have already committed to it. V2G technology, or the broader term Vehicle-to-Everything (V2X), is also a central part of the Horizon Europe EV4EU project investigating the impact of the mass introduction of e-mobility with an emphasis on V2G technologies and new business models [3].

In principle, V2G facilitates the integration of a larger number of EVs into the grid, as it enables not only the dynamic charging of EVs, but also their discharging, i.e. sending energy from EVs batteries back into the grid [2], [4]. And therefore, it enables EVs to participate in the energy market as a flexibility asset.

In the scope of this research, we investigate a use case representing 10 aggregated EVs plugged in during working hours. Similar situation corresponds to the Slovenian demonstrator of the EV4EU project [5]. Flexibility of EVs can be procured by the aggregator on local flexibility market or on balancing market, regarding services [4], [5]. For the selected use case, we estimate the potential negative and positive flexibility that aggregated EVs can provide in terms of energy and time. Based on the results of potential flexibility we estimate the ability of the aggregated EVs for the participation in the frequency services by providing negative and positive balancing energy in the scope of the balancing market. In regard to the work beyond the project on the Slovenian demonstrator, we also estimate how energy self-sufficient parking lots can be, if charging is provided with local PV. This estimation also shows how EVs charging with local PV production can help secure and stabilize distribution grid by participating in services such as voltage control, congestion management [6].

II. V2G and Slovenian demonstrator

A. Electric vehicles aggregation and market participation concept with V2G

V2G technology is part of the broader concept of V2X, which encompasses all types of vehicle communication with other entities such as other vehicles, infrastructure, houses, etc. [2].

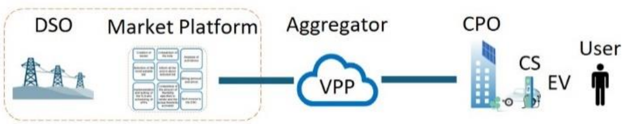

Figure 1. Actors for the market participation of aggregated EVs with V2G technology. Visuals used with permission from EV4EU [3]

Figure 1 presents the actors for the market participation of aggregated EVs with V2G technology. The key elements are an EV that supports V2G technology and a bidirectional charger that can charge and discharge the EVs battery. An aggregator and the establishment of an energy market and the market platform are also very important for the ability of aggregated EVs to participate in the energy markets [4].

An aggregator is a market participant, whether a physical or legal person, that aggregates the consumption or production of several energy grid assets, with the aim of selling, buying or participating in the energy market [7]. Aggregator can participate in services on balancing market such as Frequency Containment Reserve (FCR), Automatic Frequency Restoration Reserve (aFRR), Manual Frequency Restoration Reserve (mFRR). It can also help the local grid, help distribution system operator (DSO), by participating in services such as voltage control, congestion management etc. [4], [5], [6]. The aggregator represents the connection between several EVs, or the charge point operator (CPO) and the energy market and the energy grid represented by the transmission system operator (TSO) or (DSO).

The aggregated EVs or charging stations (CSs) by aggregator are connected into a virtual power plant (VPP) [8], which it uses to manage various distributed energy sources. The CPO, which is responsible for managing the CSs, plays an ever-increasing role, which is why it is the intermediate link between EVs, CSs and the aggregator [4].

The aggregator procures and activates its flexibility on the energy market, more precisely on the market platform (Figure 1). When an aggregator participates in the energy market, it must also take into the observation requirements in relation to the EVs and create an optimal scheduling for EVs charging and discharging (Figure 1Figure 2), which is crucial for VPP functionality development [9].

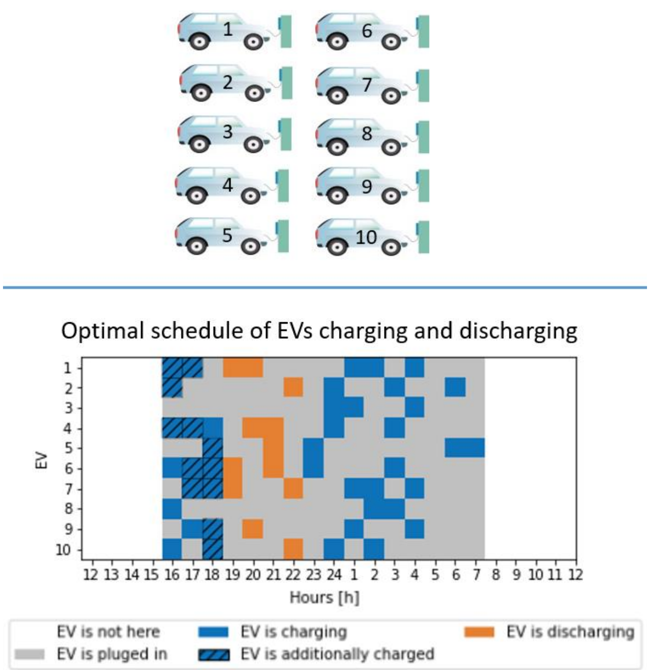

Figure 2: Optimal scheduling of EV charging and discharging for ten aggregated EVs [10]

The aggregator thus participates in the energy market and as a result, ensures greater stability of the energy grid, while at the same time the EVs are charged to the desired state of charge (SOC) [4], [10].

The TSOs and DSOs which manage the grid at national or local levels procure negative and positive flexibility on the energy market based on data on the state of the grid [11].

B. Slovenian demonstrator

EV4EU Slovenian demonstrator is planned at the office building of GEN-I in Krško. In the future, it could offer its services to a wider range of users after it has been tested and updated in the framework of this project to achieve an optimal outcome for all stakeholders, both the VPP and the EV users or owners.

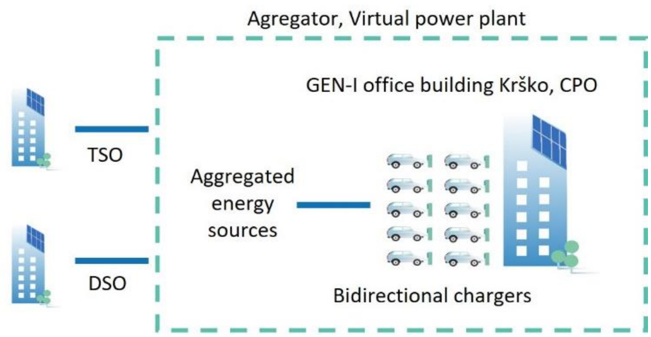

Figure 3. Slovenian demonstrator of the EV4EU project. Visuals used with permission from EV4EU [3]

The setup of the Slovenian demonstrator in the scope of EV4EU project is outlined in Figure 3 [5]. The office building has a rooftop PV system with 100 kWp peak power. For the project, an office building will be equipped with 10 CS that are compatible with V2G (Figure 3). In the Slovenian demonstrator, the market platform will be developed [6]. In a demonstration, the V2X and consequently the V2G management by VPP, is going to be tested.

For the Slovenian demonstrator, three business models (BMs) have been developed within the EV4EU project, but only two of them will be tested in practise. Namely VPP with aggregated EVs and flexibility services managed by DSO. In the Slovenian demonstrator, we will also test two business use cases (BUC), of which you can read more in [5].

III. Selected use case

For the selected use-case, we investigate flexibility potential of EV fleet, estimate its ability for the participation in the frequency services in balancing market and we also estimate how energy self-sufficient parking lots can be and how this can help secure and stabilize distribution grid. Calculations are based on average parameters regarding Slovenian EVs and Slovenian workdays (TABLE 1).

In the selected use case, we have 10 EVs connected on 10 CSs with 11 kW maximum power for charging and discharging. Every EV has battery capacity of 70 kWh, which is around average battery capacity of EVs based on [12].

The EVs are connected to the CS between 8h and 16h, which often corresponds to the Slovenian working day, other EV user profiles can be assessed in future research [13]. We have set the SOC of the EVs to 50% when EV is plugged in. From [14] we calculated the average EV consumption during a workday, of 8.5 kWh, which corresponds to the energy needed to be charged when EV is plugged in.

TABLE 1. PARAMETERS OF SELECTED USE CASE

Description of parameter	**Value**
Number of EVs	10
EVs plug-in	8 h
EVs plug-out	16 h
EV average battery capacity	70 kWh
EV average daily consumption	8.5 kWh
SOC of EVs at plug-in	50 %
SOC range for participation in flexibility services	20-80 %
Maximum power of CS	11 kW

For the participation of the EVs in flexibility services we set the battery SOC range of 20 to 80%, inside which the EVs can participate in the flexibility. The reason is that usage of EV battery in these range minimizes battery degradation [15]. The selected use case presented in this chapter is taken into account in all the estimations in the following chapters.

IV. ESTIMATION OF FLEXIBILITY POTENTIAL

EVs connected to CSs can be a very potential flexibility asset in the energy system. In this context, it is important that the aggregator, which aggregates a certain number of CSs, can estimate what kind of flexibility certain CSs in conjunction with EVs could provide during the day. As part of our research, we have estimated what kind of positive and negative flexibility potential related to energy and time the use case presented in Chapter III. can have.

A. Positive and negative flexibility

As already mentioned, we estimate the positive and negative flexibility potential of the selected use case (Chapter III.). Negative flexibility means that the technical unit draws energy from the grid, while positive flexibility means that energy is fed into the grid [16]. Regarding EVs, negative flexibility is associated with EV charging and positive flexibility with EVs discharging, which is enabled by V2G technology. The flexibility of EVs is only available during the time the EVs are connected to the CSs.

In Figure 4 the estimation of flexibility potential of EVs for selected use case is given. The blue line presents the negative flexibility potential, EVs could have in selected use case, as the orange line presents the positive flexibility potential of EVs (presented with negative values of energy). The estimation considers the EV battery SOC range of 20-80% that is available for the participation of EVs in flexibility services.

The potential flexibility of the selected use case is available from 8 am to 4 pm, which was to be expected as the EVs are plugged in at 8 am and unplugged at 4 pm. From Figure 4, we can observe that the potential negative flexibility decreases over time. While same can be observed for positive flexibility, we have to have in mind that lower or more negative values for positive flexibility mean bigger flexibility potential.

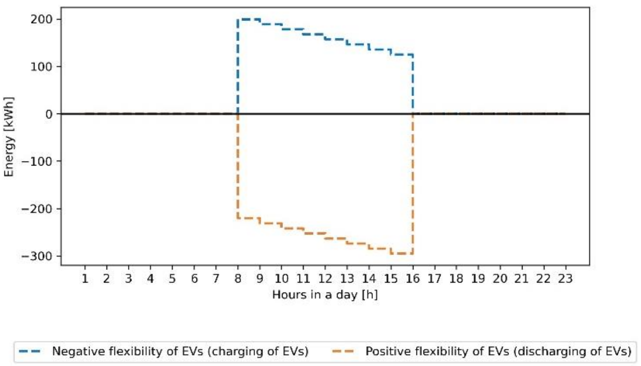

Figure 4. Estimation of flexibility potential of EVs for selected use case

The reason for the decrease in potential negative flexibility is that the EVs needs to be charged in the hours they are plugged in to reach the desired SOC when unplugged. As the batteries of the EVs are getting charged, the available capacity for charging decreases in terms of providing flexibility. When SOC of the EVs batteries increases during the plugged time with regard to EV charging, the potential energy for discharging in the grid increases. This reflects in an increase of the potential positive flexibility of EVs, as shown in Figure 4.

Figure 5 shows the scope of potential flexibility if we also take in to the consideration CS specifications. In the selected use case, we have specified the CS with a maximum of 11 kW charging and discharging power.

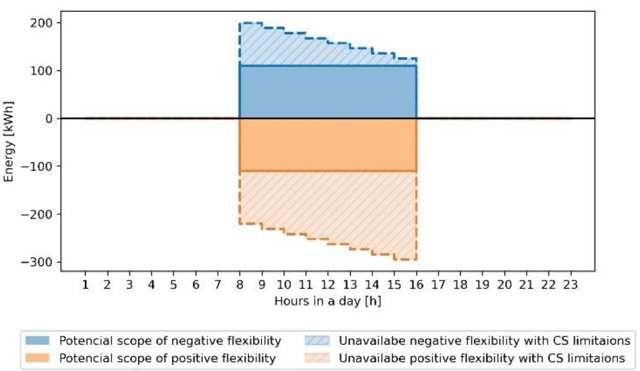

Figure 5. Flexibility potential of EVs for selected use case, considering CSs limitations

Figure 5 shows the available negative and positive potential flexibility of EVs considering the CSs limitations. It also shows the unavailable flexibility of EVs due to CS constraints. From Figure 5, we can see that the selected use case has 110 kWh of negative and positive flexibility potential of EVs every hour from 8 am to 4 pm. Based on the estimation we can also assume that the aggregator can provide constant positive and negative flexibility for the selected use case during the entire time the EVs are plugged. Figure 5 shows us that the specifications of the CSs limit the utilisation of the full flexibility potential of the EVs. This means that development of powerful CSs is just as important as development of EVs that are compatible with V2G technology.

The amount of energy that the selected use case can provide through flexibility during a working day is in TABLE 2. We can observe that the potential negative flexibility of EVs for the selected use case on a working day quals to 880 kWh. The amount of potential positive flexibility of EVs is the same.

The amount of unavailable potential flexibility of EVs in our selected case with respect to the specifications of CSs is given in TABLE 2. The amount of unavailable energy is lower for negative flexibility than for positive flexibility. The reason for this is that the EVs need to be charged during the plugged time to ensure the required SOC at plug-out. The case for potential positive flexibility, is opposite as the available flexibility increases due to the higher charged capacity of the EVs batteries.

TABLE 2. POTENTIAL AMOUNT OF FLEXIBILITY IN A DAY

	Potential amount of flexibility in a day
Potential negative flexibility	880 kWh
Potential positive flexibility	880 kWh
Unavailable negative flexibility because of CSs limitations	417.5 kWh
Unavailable positive flexibility because of CSs limitations	1182.5 kWh

We have also estimated that the utilisation of the negative and positive flexibility potential of EVs in the selected use case is 52.38 %. This means that with that kind of the parameters set in our use case, the aggregator can utilise around half of all the potential flexibility EVs can offer.

B. *Flexibility regarding time*

In this chapter, we estimate the time flexibility of each EV for the participation in energy market in relation to the selected use case.

The estimation of time flexibility is based on a similar procedure as in [17]. From the required time for charging of each EV to reach the required SOC at plug-out and from the time period each EV is plugged in, we calculated time flexibility. The results of our estimation regarding time flexibility of EVs in selected use case are in TABLE 3.

TABLE 3. ESTIMATED FLEXIBILITY IN RELATION TO TIME

Each EV's hours needed for charging	0.77 h
Time flexibility of each EV for participation in services	7.23 h
Hours of each EV plugged in	8 h
Hours of EVs needed for charging	7.7 h
Time flexibility of EVs for participation in services	72.3 h
Hours of EVs plugged in	80 h

TABLE 3 shows that we estimate that each EV must be charged for at least 0.77 hours if we assume that it is charged with a maximum CS power of 11 kW. Based on this estimate and plugged time of the EV, we have assessed that each EV could have 7.23 hours of time flexibility for the participation in flexibility services and the flexibility market. All 10 EVs in our use case could have a time flexibility of 72.3 hours, which corresponds to 90.37 % of plugged time of all 10 EVs.

V. ESTIMATION OF THE ABILITY FOR PARTICIPATION IN BALANCING MARKET

With results from Chapter IV., we estimate the potential aggregator in the selected use case could have for the participation in the services such as FCR, aFRR and mFRR [4], [6]. As mentioned in introductory chapters, aggregator can also participate in local market, but this is not in the scope of this chapter [5], [6]. In our hypothetical case we estimate the ability of the selected use case for the participation in the frequency services by providing negative and positive balancing energy in the scope of the balancing market.

The estimation is based on real historical data (year 2022), from the Slovenian balancing market [18]. The dataset contains requests for the primary service, FCR, the secondary service, the aFRR and the tertiary service, the mFRR. Both positive and negative balancing energy and prices are displayed in 15-minute intervals. In our estimation, we assume that the ability of the aggregated EVs to participate in the balancing market services is in the time frame in which the number of procured services for negative and positive balancing energy is above average. The hours in which the number of procurements for negative balancing energy is above average (based on historical data) are shown in Figure 6. The hours in which the number of procurements for positive balancing energy is above average are also shown in Figure 6.

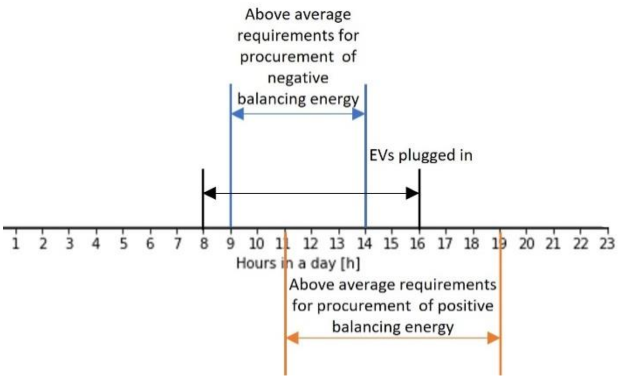

Figure 6 Hours at which number of procurements for negative and positive balancing energy are above average

The hours that relate to our use case (hours that match EVs plugged time) and have above average requirements on the market for the procurement of negative balancing energy are between 9 am and 2 pm. Hours where requirements on the market for the procurement of positive balancing energy are above average are between 11 am and 7 pm or, which is relevant for our use case, until 4 pm, which is the same as plug-out time of EVs.

As part of the estimation, we also calculated that 87.5 % of the time aggregated EVs have the ability for the participation in the services on the balancing market compared to the plugged hours of EVs in the selected use case. This shows that each aggregated EV has the ability for the participation in the flexibility market in 7 out of 8 hours.

Based on the hours in which requirements for the procurement of negative and positive balancing energy on the market are above average, we have estimated the potential energy that EVs could provide with their flexibility within these hours. The estimation is shown in TABLE 4, where is also estimated the amount of unavailable potential flexibility that EVs cannot provide due to the specifications of the CSs.

From TABLE 4 we can assess that aggregated EVs in selected use case could provide 550 kWh of negative and positive flexibility through services on the balancing market during working day. Based on the energy EVs could procure on flexibility market from Table 4, we estimate the potential profit aggregator could have if all the assessed energy will be procured on the market in one day. Based on the historical prices for procurement and activation of services on the Slovenian balancing market for year 2022, we have calculated the average price for the procurement of negative and positive balancing energy. We estimated that the aggregator can realize an income per day of 89.86 EUR for the procurement of negative balancing energy (550 kWh). For the procurement of positive balancing energy on the market (550 kWh), the aggregator could have daily income of 160.67 EUR.

TABLE 4 POTENTIAL AMOUNT OF FLEXIBILITY FOR PARTICIPATION ON FLEXIBILITY MARKET

Type of flexibility service	Potential energy of EVs that can be used for participation in flexibility market	Unavailable potential energy of EVs that can be used for participation in flexibility market
negative	550 kWh	287.5 kWh
positive	550 kWh	818.75 kWh

VI. EV CHARGING WITH PV

Production from PV can have a negative effect on stability of local grids and their substations as stated in [19]. That is one of the reasons that solutions for local grid are needed. One of the solutions is procurement of services as voltage control and congestion management which helps the DSO to balance the production and consumption in its grid. In our case we estimate energy self-sufficiency with local PV, which can also be procured on local flexibility market for the participation in services such as voltage control [5], [6].

With regard to the future work on the Slovenian demonstrator, we wanted to estimate how much energy self-sufficiency we could achieve in relation to the selected use case and local PV. We estimate energy self-sufficiency for the PV system with rated power of 100 kWp, which is related to Slovenian demonstrator (Chapter II.). As alternative case we assessed energy self-sufficiency if we cover all 10 parking lots of EVs with PV. Calculations for energy self-sufficiency are done for a day in the months of July and December.

In our estimation we determine that each PV canopy represent PV with rated power of 2.5 kWp as stated in [20]. This means that we could have a PV system with rated power of 25 kWp if all 10 parking lots were covered with PV. A PV system with rated power of 25 kWp can also be realized with roof top PV, local PV, etc..

For average PV production in location Krško, Slovenia we used PVGIS tool. Energy self-sufficiency in our estimation for the selected use case was assessed based on the ability to charge EVs with energy produced from PV. We also wanted to assess what type of PV is needed to achieve 100 % energy self-sufficiency throughout the year.

Figure 7 presents average daily production of 25 kWp PV at Krško in Slovenia for months July and December. It is visible that PV production in July is approximately three times higher than in December, which was expected as July is the month with maximum production and December with the minimum, for location of Krško.

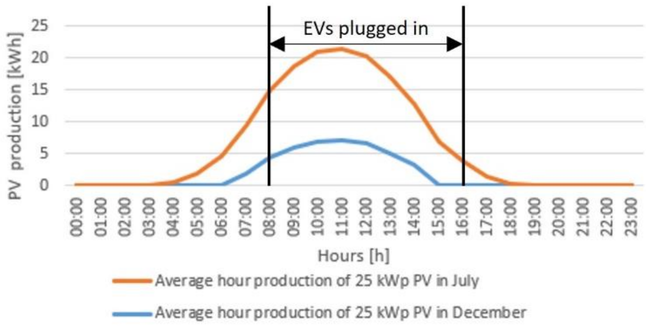

Figure 7 Average production of 25 kWp PV in Krško, Slovenia for months July and December, and correspondence of selected use case

How our selected use case, regarding EVs plugged time, corresponds with average PV production with the aim of energy self-sufficiency is shown on Figure 7. It can be seen that in our case we lose some energy from PV production in the morning hours because the EVs are not plugged in until 8 am. As expected, the morning energy loss is greater in the month of July. This loss means that not all the energy from PV production can be utilized to ensure energy self-sufficiency in the selected use case. For the month of July, is visible that PV still produces energy after EVs plug-out. This means that even after 4 pm, some of the energy from PV production is lost for ensuring higher energy self-sufficiency, which is not the case in December.

Results of our estimation regarding percentage of energy self-sufficiency for selected use case with 25 kWp PV are presented in TABLE 5. It is evident that 25 kWp PV can assure 100 % energy self-sufficiency on a day of month July for selected use case. This means that EVs are 100 % charged with energy produced from PV. This is not the case for the month of December. Based on our calculations selected use case can achieve 45 % energy self-sufficiency, with 25 kWp PV in the month of December. We have found that energy self-sufficiency is about one times greater in July than in December.

From TABLE 5 is evident that PV with rated power of 57.5 kWp could assure 100 % energy self-sufficiency for the selected use case even on a day in December. This means that with 57.5 kWp PV, 100 % charging of the EVs with the energy produced by the PV could be assured all year round. A PV system with rated power of 57.5 kWp corresponds to 23 covered parking lots or an area of 291 m^2 of PV.

TABLE 5 ESTIMATED ENERGY SELF-SUFFICIENCY FOR SELECTED USE CASE WITH PV

Peak power of PV	**Energy *self-sufficiency [%]***	
	Day *in* July	Day *in* December
25 kWp	**107**	45
57.5 kWp	248	**103**
100 kWp	431	180

As mentioned in Chapter II, a PV system with rated power of 100 kWp is also linked to the Slovenian demonstrator. In this context, we also wanted to estimate what kind of energy self-sufficiency can be achieved for the selected use case with a 100 kWp PV. Table 5 shows that a 100 kWp PV produces about 4 times more energy in July than is needed for charging of EVs in the selected use case and about 1.8 times more in December. This means that this type of PV can also be used to achieve energy self-sufficiency besides charging of 10 EVs for other energy consumers or more EVs. It is visible from TABLE 5 that PV with rated power higher than 25 kWp will produce surplus energy in the summer months. The excess PV production can be used for the charging of other EVs, or it can be stored in battery storages or EVs with V2G technology with the aim for later use.

VII. Conclusion

In the scope of this research we estimate flexibility potential of selected use case of parking lot with 10 aggregated EVs. Selected use case corresponds to the Slovenian demonstrator of EV4EU project [5]. For the selected use case we estimate negative and positive flexibility potential that aggregated EVs can provide in terms of energy and time. We conclude that EVs could have 880 kWh of negative and positive flexibility potential in one day. Considering charging station specifications potential is 550 kWh. Based on the results of potential flexibility of EVs we estimated the ability of the selected use case for the participation in the frequency services by providing negative and positive balancing energy in the scope of the balancing market. We concluded that aggregator for selected use case can potentially procure 550 kWh of negative and positive balancing energy. In regard to the work beyond the project on the Slovenian demonstrator we also estimate how energy self sufficient parking lots can be, if charging is provided with energy from local PV and how this can help secure and stabilize distribution grid by participating in different flexibility services. Changing the parameters of the selected use case and analyzing the results and observing differences according to the results in this paper can serve as a starting point for new research. Utilization of surplus PV production in terms of V2G compatible EVs and battery storage systems can also be a part of future research. In addition, these results can serve as a basis for the development of algorithms for the integration of EVs via V2X in VPPs, to develop strategies for aggregators or CPOs participating in markets etc. [9].

Acknowledgment

The research is financed by the HE EV4EU project under contract 101056765.

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