A Virtual Power Plant Management Model Based on Electric Vehicle Charging Infrastructure Distribution

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Abstract—The exploitation of distributed generation based on intermittent renewable energy sources (RES) has increased the load and generation profile variability. The resort to distributed energy storage systems (DESSs) is usually proposed to compensate the volatility introduced by RES. In particular, plug-in electric vehicles (EVs) are considered one of the most interesting solutions for providing DESSs with the aim of exploiting RES production and matching the distributed electrical generation to the local demand. The aim of this paper is to analyze the impact of vehicle-to-grid technology on an weakly interconnected Virtual Power Plant (VPP) in order to evaluate the effects that distribution and availability of EVs charging structures can have on VPP total cost. A novel mathematical modeling of the mobility system is firstly developed to calculate the probabilistic distribution of parking places. Thereafter, the economic impact on a VPP has been evaluated for different plug-in ratio and charging station scenarios.


I. INTRODUCTION

The growing diffusion of renewable energy sources (RES) in the European countries is supported by many government energy and climate policies with the target of providing 20% of final energy consumption from RES by 2020. Therefore the growth of non-programmable RES, like Wind and Photovoltaic (PV), is expected to further increase in the next years. The integration of such distributed generators (DGs) into the electric grid will drastically change its typical top-down structure. In order to support the diffusion and the integration of RES and to manage this transformation, the system operators are planning to adopt active control strategies for the electricity distribution network. In this framework Virtual Power Plant (VPP) structures are one of the most interesting solutions proposed in the technical literature to guarantee the system reliability in presence of a fast exploitation of RES [1]-[3]. A VPP is an electric system cluster composed of an aggregation of distributed generators, controllable loads and energy storage systems (ESS). The heart of a VPP is the energy management system (EMS) which coordinates the energy flows into the cluster taking into account the power demand and electrical production profiles and storage capacity [3]. In particular, the ESS are the key components of a VPP because allow to introduce a degree of freedom into the instantaneous energy balance condition, permitting both a partial shift in time and compensation of instantaneous energy unbalance. Moreover, the storage devices allow to mitigate the intermittence of non-dispatchable or stochastic generators, e.g. wind turbines and PV plants, especially in weak networks [2].

Plug-in Electric Vehicles (EVs) offer a new possibility for energy storage purpose. According to the Vehicle-to-Grid (V2G) concept, EVs could be seen both as electricity consumers and as electricity suppliers. Several studies have analyzed V2G as a promising option for providing ancillary services [4]-[6]. Most studies identify economic benefits for electric vehicles owners and great technical advantages for network operators when EVs provide extra power supply, peak load shaving, load shifting, spinning reserve and frequency regulation services [5]-[6]. Different methodologies have been developed for taking into account the mobility needs of the EVs owners. Although the reference studies on V2G considered only average mobility behavior values [5], [7], the impact of driving habits on the V2G capability has been recently investigated and evaluated by means stochastic models [8]-[11]. Nevertheless, besides the mobility requirements of an EV user, the availability of charging infrastructures plays an important role in defining the EV’s battery capacity available for V2G services. Therefore the main purpose of this study is to investigate the effects of accessibility of charging points on the economies of a VPP where an EVs fleet works as a DESS.

The paper is organized as follows. Firstly the mathematical model of the mobility system have been described and its key elements (such as number of trips traveled each day, mean of transportation, travel distance and time per day, and purpose of trips) have been presented. In Section III and IV, the main characteristics of the proposed VPP and the economic assumptions used for calculating the VPP cost functions have been explained. Section V illustrates in detail the model used for defining the EVs batteries state of charge (SoC) and the EMS V2G management strategy which aims to determine the amount of energy storage capacity available for V2G services.
hour by hour. The adopted optimization problem have been described in Section VI. The comparative analysis of two scenarios characterized by different parking places distributions have been proposed and economically evaluated in Section VII. Finally, the last section summaries the contributions and the main results of this paper.

II. MATHEMATICAL MODEL

A. Mobility Behavior

In order to determine the EVs plug-in availability, the data from the survey “Mobility in Germany” (MID 2008) [12] have been considered. These data have been filtered out according to several criteria: number of trips traveled each day, mean of transportation, travel distance and time per day, and purpose of trips. Six different modes of transport have been examined: passenger car driver, car passenger, bike, on foot and public transport. Moreover the travel motives have been classified in seven groups: leisure, work, education, private business, shopping (daily needs) and accompanying. Afterwards the data of [12] have been employed for calculating the hourly percentage of cars en-route. The Fig.1 shows the statistical time distribution of cars on the road in Germany for an average week. In addition for each trip purpose the percentage of trips traveled by car has been evaluated and used as input for the proposed modeling. The data are reported in Table I.

A deeper analysis has highlighted the main destinations for leisure and private business journeys. The results are depicted in Fig. 2. It can be observed that the prevalent destinations are places where a charging station could not be available. As a consequence the V2G mobility model has to take into account both the mobility behavior (vehicle on the road or parked) and the statistical time distribution of destinations with the aim of evaluating the available access points. In fact this data is fundamental for the real time estimation of EVs capacity usable for applying V2G services. Basis on these considerations a novel mobility model devoted to calculate hour by hour plug-in EVs connectivity is proposed.

B. Plug-in EVs Availability Model

In order to carry out the distribution of parked EVs according to motives and destinations of trips, a hourly model for an average week is proposed. The calculations have been performed with the following equations:

\[ V_{pt(t)} = 1 - V_{rt(t)} \]  

(1)

where \( t \) is the time step, \( V_{pt(t)} \) indicates the EVs parked at time \( t \) and \( V_{rt(t)} \) represents the EVs on the road at the same time.

The EVs connected to the grid \( V_c \) have been determined as follows:

\[ V_c(t) = V_{c(t-1)} + \left[ V_{r(t-1)} \cdot \sum_i D_i(t-1) \cdot p_i \right] + \left[ V_{r(t)} \cdot \sum_i C_i(t) \cdot p_i \right] \]  

(2)

where \( D_i(t-1) \) is the share of EVs en-route in the hour \( t-1 \), differentiated by travel destinations \( i \); \( p_i \) represents the share of parked EVs that are connected (plug-in ratio) for each destination \( i \); \( C_i(t) \) is the share of EVs on the road in the hour \( t \) which are coming back home, starting their homeward journey from the position \( i \).

In Germany, as stated in [12], the trip distance driven by about 87% of vehicles is less than 25 km and the driven time does not exceed 30 minutes in about 77% of car trips. For

<table>
<thead>
<tr>
<th>Trip purpose</th>
<th>Percentage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leisure</td>
<td>21.9</td>
</tr>
<tr>
<td>Work</td>
<td>20.7</td>
</tr>
<tr>
<td>Education</td>
<td>1.1</td>
</tr>
<tr>
<td>Private Business</td>
<td>12.2</td>
</tr>
<tr>
<td>Shopping (daily needs)</td>
<td>21.6</td>
</tr>
<tr>
<td>Accompanying</td>
<td>9.2</td>
</tr>
</tbody>
</table>

TABLE I

PERCENTAGE OF TRIPS BY CAR ACCORDING TO TRIP PURPOSE

Fig. 1. Statistical time mobility behavior of car users for an average week [9], [12].

Fig. 2. Percentage of trips differentiated in travel destinations for: private business (top) and leisure (bottom) purposes.
these reasons in the simulation it has been assumed that trips starting in hour \( t \) last less than one hour. As a consequence in the hour \( t+1 \) such EVs will be parked and available for V2G, according to their destinations and charging structures accessibility.

C. Storage System

The simulation of the EV battery storage system is based on the model proposed in [13]. Several tests were carried out on a LiFePO\(_4\) battery and charging and discharging models were developed. The obtained results confirmed a good matching between the simulations and the experimental tests. The model has been used to develop the charging and discharging process simulations of a LiFePO\(_4\) battery used in a commercial EV, characterized by the technical parameters reported in Table II. The developed battery model allows to simulate the time evolution of energy, voltage and SoC for an EV LiFePO\(_4\) battery. The results obtained have then been used to perform the V2G simulations in the VPP model. More details about the LiFePO\(_4\) battery model and simulations can be found in [13].

III. VIRTUAL POWER PLANT MODEL

The proposed VPP is schematically reported in Fig. 3. It is supposed to be geographically sited in Germany and characterized by a weakly interconnection to the main grid. The VPP is basically composed of three power plants (a CHP plant, a wind park and a PV farm), an industrial zone and a city district, characterized by the power capacities and demands reported in Table III. A gas turbine, which burns natural gas, is considered as the prime mover of the CHP plant. Additionally, it is supposed that the CHP is heat driven and the heat to power ratio is set to be one. An external boiler is assigned to the CHP plant, in order to avoid excess electrical production during heat demand peak.

The city is considered to have 20,000 habitants. The car fleet of the overall energy district is characterized by 11,000 vehicles, equal to about 550 passenger cars per 1,000 inhabitants [14]. The total share of annual wind and photovoltaic energy production is equal to 20% of the annual district electrical energy demand, respecting the EU goal and reducing the energy dependence from fossil fuel plants. To evaluate the wind and PV annual production, generation profiles of German wind and PV farms have been used. The hour profile of the city electricity demand has been modeled referring to yearly measured data of German power networks. Contrariwise, the thermal and electrical behavior of the industrial zone has been evaluated employing data found in the scientific literature.

An EMS coordinates the energy production depending on weather conditions, storage capacity and availability, and load demand. The EMS is modeled in Matlab environment as a real time management system, which works on time hour base. Moreover the developed algorithm allows to carry out an annual energetic analysis for the proposed VPP. The EMS task is the achievement of energy balance conditions between the hourly local energy generation and the hourly consumption.

IV. ANNUAL VPP COST ANALYSIS

This work aims to analyze the impact of accessibility of EVs charging points on the economies of the proposed VPP. To make this possible, the EMS:

- controls the CHP and external boiler energy production with an active regulation;
- manages the RES production, reducing the power coming from wind plant and PV farm in case of high production;
- regulates the industrial load demand with a Demand Side Management (DSM) control which allows to avoid or decrease peak load;
- coordinates the charge and discharge cycles of the battery storage systems in order to exploit the RES electrical production and to support the system during peak load.

In the developed model an EVs fleet is introduced. In order to be able to charge and discharge according to EMS signals, providing V2G services and exploiting their batteries as DESSs, the vehicles have been supposed to be equipped with bidirectional power connection and adequate meter and communication systems [15].
by the evaluation of the Total Cost (TC) function. The VPP TC calculation has been integrated into the EMS algorithm and determined on an annual basis, according to (3).

$$TC = \frac{8760}{t=1} \sum_i G_{i,t} + S_t + E_t + C_{D,t}$$

being:

- $G_{i,t}$ the generation cost of the power plant $i$
- $S_t$ the storage costs
- $E_t$ the cost associated to RES power production curtailment
- $C_{D,t}$ the DSM costs

The energy generation costs have been evaluated by means of the Levelized Unit Energy Costs (LUEC) approach [16]. The costs afforded by the system for funding the purchase of EVs and for developing adequate meter and communication infrastructures make up the storage costs, which have been also levelized during the EV life time. The costs associated to wind and PV power production curtailment have been estimated by adopting the external cost concept. In particular, in this study the external costs associated to the electricity natural gas power plant generation, which range between 10 and 40 €/MWh [17], have been considered. The average value of 20 €/MWh has been employed to determine $E_t$. The peak load deficit has been economically introduced to the Value of Lost Load (VoLL) which represents the cost caused by the disconnection of industrial loads in the period of energy deficit. In this work the VoLL value has been set equal to 1,000 €/MWh. More detailed information on the economic assumptions used for calculating the VPP TC have been summarized in Table IV.

In [13], the economic advantages obtained with the introduction of EVs as DESS in an autonomous VPP were already evaluated. Nevertheless, in [13] a static analysis of EVs fleet, based on the average mobility behavior, was carried out. In the proposed study, these shortcomings have been overcome by employing a dynamic hourly simulation and considering plug-in ratio dependence, according to the EVs mobility model described in Section II.

V. Plug-in Electric Vehicles Capacity Model and Management Strategy

In this paper the battery of each EV and its SoC is considered as part of a virtual aggregated battery. Therefore the proposed management strategy aims to define hour by hour the SoC of the equivalent big battery and the hourly power which could be charged or discharged according to the control signals sent by the EMS at each time step. For these reasons a Vehicle-to-Grid algorithm has been integrated into the EMS procedure. Moreover, the dynamic time evolution of mobility and charging infrastructure distribution, deducted by [12] and exposed in Section II, has been implemented in the proposed EMS algorithm in order to determine hour by hour the EVs aggregated battery capacity available for V2G services. The hourly stored energy ($E_t$) has been evaluated as follows:

$$E_{st-1} = E_{st-2} + \left( \frac{k_d}{2} \cdot C_{ev} \cdot V_{r(t-1)} \cdot \sum D_{i(t-1)} \cdot \rho_i \cdot n_{EV} \right)$$

Equation (4) consists of three terms. The first one evaluates the share of energy at the time $t$ referring to the stored energy at the previous step $E_{st-1}$. From this quantity the capacity subtracted by the EVs which start their trips at the time $t$ from the location $i$, characterized by a plug-in ratio $\rho_i$, has been deducted. $H_{i(t)}$ represents the share of EVs en-route in the hour $t$, differentiated by departure places $i$. The second term is a further additive component which takes into account the energy added by the EVs arrived and plugged in their destinations $i$ at the time $t$, which were en-route in the previous step $t-1$ and parked and connected at the time $t-2$. The third term takes into account the energy consumption of batteries of EVs on the road at the time $t-1$, bound for the destination $i$, occurred during driving. The parameter $k_r$ refers to the daily driven distance for an EV and its value is reported in Table V. The initial aggregated battery SoC has been defined as 50% ([9], [11]) of the maximum battery storage capacity $E_{max}$ equal to the sum of all individual batteries of plugged EVs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment cost of the CHP¹</td>
<td>(€/kWth)</td>
<td>1,117</td>
</tr>
<tr>
<td>O&amp;M fix cost of the CHP¹</td>
<td>(€/year)</td>
<td>14,896</td>
</tr>
<tr>
<td>O&amp;M variable cost of the CHP¹</td>
<td>(€/kWh)</td>
<td>0.006</td>
</tr>
<tr>
<td>Life time of the CHP</td>
<td>(years)</td>
<td>25</td>
</tr>
<tr>
<td>Investment cost of the boiler²</td>
<td>(€/kWa)</td>
<td>141.51</td>
</tr>
<tr>
<td>O&amp;M fix cost of the boiler²</td>
<td>(€/year)</td>
<td>29,304</td>
</tr>
<tr>
<td>O&amp;M variable cost of the boiler²</td>
<td>(€/kWha)</td>
<td>0.0075</td>
</tr>
<tr>
<td>Life time of the boiler</td>
<td>(years)</td>
<td>30</td>
</tr>
<tr>
<td>Fuel price (natural gas)²</td>
<td>(€/MWh)</td>
<td>17</td>
</tr>
<tr>
<td>Investment cost of the wind park²</td>
<td>(€/kW)</td>
<td>1,000</td>
</tr>
<tr>
<td>O&amp;M cost of the wind farm²</td>
<td>(€/kW)</td>
<td>38</td>
</tr>
<tr>
<td>Life time wind farm</td>
<td>(years)</td>
<td>20</td>
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<tr>
<td>Investment cost of the PV²</td>
<td>(€/kW)²</td>
<td>2,500</td>
</tr>
<tr>
<td>O&amp;M cost of the PV²</td>
<td>(€/kW)</td>
<td>29.4</td>
</tr>
<tr>
<td>Life time PV plant</td>
<td>(years)</td>
<td>20</td>
</tr>
<tr>
<td>Discount rate</td>
<td>(%)</td>
<td>6</td>
</tr>
<tr>
<td>Investment cost for EVs</td>
<td>(€/vehicle)</td>
<td>15,000</td>
</tr>
<tr>
<td>EV battery lifespan</td>
<td>(years)</td>
<td>15</td>
</tr>
<tr>
<td>External costs</td>
<td>(€/MWh)</td>
<td>20</td>
</tr>
<tr>
<td>$\text{VOLL}$</td>
<td>(€/MWh)</td>
<td>1,000</td>
</tr>
</tbody>
</table>

¹[16] ²[18] ³[9]
TABLE V

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average day distance</td>
<td>k_d</td>
<td>km</td>
<td>30</td>
</tr>
<tr>
<td>Distance buffer</td>
<td>k_b</td>
<td>km</td>
<td>75</td>
</tr>
</tbody>
</table>

For each hour the EMS algorithm synthesizes the control signals according to the following hierarchical strategy.

In presence of an excess of electricity production \((E_{urb})\), the EMS firstly recharges the batteries of plugged EVs in order to avoid the reduction of CHP production and fully exploit the RES energy generation. Then, the EMS algorithm evaluates again the VPP electric energy unbalance and the aggregated battery SoC and manages the remaining part of the overproduction by means of the reduction of the thermo-electric CHP energy production. Finally, the EMS reduces the RES generation. The energy charged in the EVs batteries in one hour cannot be more than \(E_{\max}\), which represents the maximum battery capacity available at that time step. Moreover the limitations of the hourly power capacity of EVs connected \((P_{ch})\) have to be taken into account. The hourly energy charged was calculated referring to EV specifications reported in Table II and implementing in the V2G control algorithm the LiFePO4 battery model described in Section II, considering a 3.3 kW charging station rating power. Thus the amount of charged energy is the minimum of these three values:

\[
E_{\text{ch}}(t) = \min \left\{ E_{\text{sur}}(t) - E_{\max}(t) \cdot P_{\text{ch}}(t) \right\}
\]

(5)

In case of deficit \((E_{\text{def}})\), the EMS first action is the discharging of the energy stored in the plugged EVs in order to provide ancillary services to the grid and cover the deficit. Then, if the electric underproduction has not been balanced, the EMS increases the CHP thermal production and, as last energy balance control action, shutdowns some industrial loads. The energy delivered by the aggregated battery has been determined according to (6):

\[
E_{\text{dis}}(t) = \min \left\{ E_{\text{def}}(t) - E_{\min}(t) \cdot P_{\text{dis}}(t) \right\}
\]

(6)

In this situation the hourly amount of discharged energy is limited by the maximum hourly inverse power flow \((P_{\text{dis}})\) allowed from the power connection. The energy supplied to the grid is also limited by the energy \((E_{\min})\) necessary for driving a preset kilometer range buffer \((k_b)\), see Table V. The introduction of the \(k_b\) parameter ensures that the driver could still use his car for 75 km (three times the average trip distance reported in Section II), preserving the EVs users mobility requirements. Additionally, as it can be observed in Table II, the EV battery SoC is limited within 20%-95% in order to avoid battery damage and preserve the battery life.

VI. OPTIMIZATION METHOD

The main purpose of the proposed study is to find the influence of charging structure availability on the economies of a weakly interconnected VPP. A Matlab algorithm has been developed to calculate the optimal number of EVs \((n_{EV})\) which minimize the VPP total costs, depending on plug-in ratio parameters for each trip parking place.

The optimization problem is defined according to (7) being:

\[
P_i \quad \text{the electrical power generated by the generator } i
\]

\[
P_j \quad \text{the electrical power demanded by the load } j
\]

\[
Q_i \quad \text{the thermal power generated by the power plant } i
\]

\[
Q_j \quad \text{the thermal power demanded by the load } j
\]

The first two equality constraints, (8) and (9), represent the electrical balance (i.e. hourly power produced by power plants and delivered by ESS must equal to hourly power demanded by loads and absorbed by storage systems) and the thermal balance respectively. The third equality constraint (10) indicates that RES annual energy production must cover the 20% of the annual energy demand of the VPP loads.

To validate the influence of mobility behavior and plug-in capability on the economies and technical feasibility of the proposed power system, two main scenarios have been evaluated and compared.

VII. SIMULATIONS RESULTS

The first scenario is the reference one. The vector \(p_i\) has been set equal to 1 for each parking destination \(i\). It means that at each time step all parked EVs are connected to the grid and participate to the V2G regulation. In this case the number of EVs has been calculated by means the implementation of the optimization problem in the Matlab algorithm with the aim of evaluating iteratively the objective function (7), emulating the annual EMS procedure at each iteration step.

The optimal number of EVs for the reference case is 500, equal to 4.5% of the total car fleet. This result is referred to the condition of plug-in rated power of 3.3 kW. A summary of reference scenario results referred to the annual energetic analysis has been reported in Table VI.

In the second scenario the vector \(p_i\) has been considered to be composed as reported in Table VII. Considering an EVs fleet constituted of 500 units (i.e. the optimal solution found in the first scenario), an increase in VPP total costs (2.4% respect to the first case) has been found. The second scenario economical results have been summarized in Table VI as well. In particular, it is possible to observe that the introduction of plug-in ratio parameters, which take into account different probabilities of finding a charging point at the parking places, has increased the cost connected to VoLL of 76%, respect to
TABLE VI
SCENARIOS RELEVANT RESULTS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1st</th>
<th>2nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>nEV</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Production Cost (M€)</td>
<td>11.427</td>
<td>12.775</td>
</tr>
<tr>
<td>EV annual Cost (M€)</td>
<td>0.654</td>
<td>0.654</td>
</tr>
<tr>
<td>Deficit Cost (M€)</td>
<td>0.378</td>
<td>0.666</td>
</tr>
<tr>
<td>Total Cost (M€)</td>
<td>12.475</td>
<td>12.631</td>
</tr>
</tbody>
</table>

TABLE VII
PLUG-IN RATIO PARAMETERS

<table>
<thead>
<tr>
<th>Parking Place</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
<td>p_w</td>
<td>0.5</td>
</tr>
<tr>
<td>School/Educational Building</td>
<td>p_e</td>
<td>0.3</td>
</tr>
<tr>
<td>Supermarket/Shopping Centre</td>
<td>p_s</td>
<td>0.4</td>
</tr>
<tr>
<td>Private Business (Doctor, Church…)</td>
<td>p_p</td>
<td>0.1</td>
</tr>
<tr>
<td>Free Time (Pub, Theater, Cinema)</td>
<td>p_f</td>
<td>0.2</td>
</tr>
<tr>
<td>Home</td>
<td>p_h</td>
<td>0.7</td>
</tr>
</tbody>
</table>

![Fig. 4. Hourly evolution of the aggregated battery SoC for the two scenarios.](image)

The hourly evolutions of the aggregated battery SoC obtained in the two scenarios are shown in Fig. 4 for an average week. It can be noticed that, in the first case, all the energy capacity of the parked EVs batteries is exploited, resulting in a high level of V2G energy used for regulation services. On the contrary, in the second case, the aggregated battery available as DESS is drastically reduced.

The yearly frequency distribution of plug-in ratio for the second scenario has been depicted in Fig. 5. It’s worth noting that the average plug-in ratio registered during the year is equal to 0.676. This result is justified by the much more high relevance of p_h with respect to the plug-in ratio parameters of the other parking places.

The impact of the plug-in parameters can be properly evaluated by observing Fig. 6, where the total cost function evolution referred to p_w and p_h has been reported. The obtained results show the highest influence of p_h on the VPP overall costs, as expected. These outcomes confirm the statement reported in [8], according to which home parking location offers the highest percentage of permanent parking at any given time step.

For example, even when the lowest share of parking EVs is recorded, i.e. at workdays between 11 a.m. and 3 p.m. (see Fig. 1), more than 25% of all EVs are parked at home. Therefore the availability of EVs batteries capacity as DESSs is mainly influenced by the presence at home of a parking place with the required charging infrastructure. Consequently, the VPP could economic benefit from investments in access points at the house parking locations.

A further relevant sensitivity analysis considers different plug-in rated powers for each parking location. Nevertheless the investigation of this aspect is besides the purpose of this study and it has been neglected in the presented simulations. A future work will be accomplished in order to examine in detail this important facet.

VIII. CONCLUSIONS

In this paper, a novel VPP management model has been proposed. Particularly this work analyzes the impact of Vehicle-to-Grid technology on the distribution system of a weakly interconnected VPP based on probabilistic distribution and availability of EVs charging infrastructures. A novel mathematical modeling of the mobility system has been firstly developed and its key elements have been presented. The model have been then employed for calculating the probabilistic distribution of parking places in order to estimate, hour by hour, the amount of EVs batteries capacity...
available for V2G purposes. Thereafter, the economic impact on the proposed VPP has been evaluated. The model effectiveness has been properly validated by means the comparison of two simulation scenarios which consider different plug-in ratios and charging stations distributions. In the first one, all parked EVs are connected to the grid at each time step and participate to the V2G regulation. Contrariwise in the second scenario different share of connected EVs are taken into account, according to the EVs parking locations. The simulation results highlight that only an adequate charging infrastructure allow to actually exploit the potential of EVs as DESSs. In addition, the results show as the availability of charging points at the house parking places is a mandatory requirement for applying V2G services, emphasizing the need of investments in developing EVs access points at home parking spaces, as roadside, garages and multi-storey car parks.

IX. REFERENCES


X. BIOGRAPHIES

Maura Musio studied electrical engineering at the Università di Cagliari, Italy. She graduated in 2010 at the same university with the degree M.Sc. She joins Sardegna Ricerche, the Regional Sardinian Research Centre, for the development of a novel concentrator PV system.

Alfonso Damiano (M’12) received the degree in electrical engineering from the Department of Electrical Engineering, University of Cagliari, Cagliari, Italy, in 1992. In 1994, he joined the Department of Electrical and Electronics Engineering, University of Cagliari, where he was an Assistant Professor. Since 2001 he has been Associate Professor of Electrical Energy Management and of Electrical Machines. His current research interests include control of variable-speed ac drives, electrical drives, energy management, especially for electric vehicle and renewable energy system applications. He is a member of the IEEE Industry Applications Society (IAS) and the IEEE Power Engineering Society (PES)