Virtual Power Plants with Electric Vehicles

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Abstract

The benefits of integrating aggregated Electric Vehicles (EV) within the Virtual Power Plant (VPP) concept, are addressed. Two types of EV aggregators are identified: i) Electric Vehicle Residential Aggregator (EVRA), which is responsible for the management of dispersed and clustered EVs in a residential area and ii) Electric Vehicle Commercial Aggregator (EVCA), which is responsible for the management of EVs clustered in a single car park. A case study of a workplace EVCA is presented, providing an insight on its operation and service capabilities.

I. Introduction

High penetration of Distributed Energy Resources (DER) will pose significant challenges in traditional system operation [1]. The Virtual Power Plant concept is a solution presented in the literature, to overcome the challenges of DER integration and enable their market participation. Several European projects have explored the challenges and potential benefits of the VPP, with a combined output of field tests and simulation results [1, 2]. A VPP is described as the aggregation of DER, controlled and managed as a single entity, operating as a controllable generation power plant [1]. Through the VPP, distributed energy resources become visible to System Operators (SO). Moreover, the financial risks of individual DER market participation are reduced [1]. Therefore, a maximisation of the benefits for DER owners and system operators is expected [3].

The EV uptake is expected to grow in the forthcoming years [4]. The high EV associated load that would need to be accommodated by the system, without any form of control, could overload the distribution transformers and cables, and modify the voltage profile of distribution feeders [5]. Controlling the EV battery charging may lead to the accommodation of higher EV utilisation within system technical constraints [6] and reduce the need of new generation plants to cover the battery charging needs [7].

Several studies have identified the potential of EVs to participate in electricity markets [8, 9]. Individual EVs have small power capabilities; therefore their participation in electricity markets will require a new entity: the EV aggregator; which will serve as an intermediary between large number of EVs and market players and/or system operators [9]. Integration of EVs with Vehicle to Grid (V2G) capability, which is the ability to inject power to the grid [8], will increase the market participation opportunities of EV aggregators.The role of the EV aggregator would be to cluster dispersed EVs, and manage their generation and demand portfolio as a single entity.

II. Opportunities for EV aggregators and VPPs

The integration of electric vehicle aggregators within the VPP concept offers benefits to both parties. This section discusses the benefits offered from a VPP to EV aggregators (EVA) and the EV aggregator benefits offered to the VPP. The prerequisite for the integration of EVAs in a VPP, is the VPP capability to monitor and/or control the EV aggregators.

a) VPP benefits to EV aggregators

Irrespectively of the EV aggregator size and location, the virtual power plant offers the opportunity to aggregate at an upper level the resources of many EV clusters and create a single portfolio in order to proceed with market negotiations. In addition, the costs and risks of the market negotiations for each aggregator are reduced, similarly to the aggregation of individual generators, as described in [10]. These market negotiations may include wholesale and spot market auctions, as well as ancillary services. Hence, each aggregator is provided with the opportunity to maximise its revenues.

b) EV aggregator benefits to VPPs

The main characteristic of a VPP is the aggregation of many demand and generation profiles creating a single flexible portfolio. The flexibility of this portfolio is increased with the addition of more controllable resources. The EV aggregator may improve the flexibility of a VPP and provide the opportunity to reduce imbalances that may occur after market negotiations. The increase of VPP controllability could contribute to offset the intermittency of Renewable Energy Sources (RES). The advantages that EVs could provide in terms of services to the VPP include: the absence of startup and shutdown costs, a very fast response time, “low standby cost” and high availability factors as cars are parked 92% of their lifetime [8, 11]. Table 1 summarises the benefits of the electric vehicles aggregator as part of a virtual power plant.

Table 1: Benefits of EV aggregator integration into the VPP concept

Benefits for EV Aggregator	Benefits for VPP	Benefits for both parties
Energy market participation	Increase of flexibility	Revenue maximisation
Ancillary services provision	Offset RES output	Reduction of risks and costs from market participation

III. Classification of EV aggregators

Energy suppliers in the UK, have categorised the services they offer to their customers into residential and business (commercial) services. This distinction is adopted to characterise the EV aggregators:

i) The EV Residential Aggregator (EVRA) is responsible for the management of the EV battery charging and discharging regime, of electric vehicles geographically dispersed in a residential area.

ii) The EV Commercial Aggregator (EVCA) is responsible for the management of EV battery charging and discharging regime, of electric vehicles clustered in a specific (physical) car park.

The parking duration and the power rating of the connection will determine the services provision and future control management strategies. Three types of Electric Vehicle Aggregators are identified, regarding the parking duration: short, medium and long duration as presented in Fig. 1.

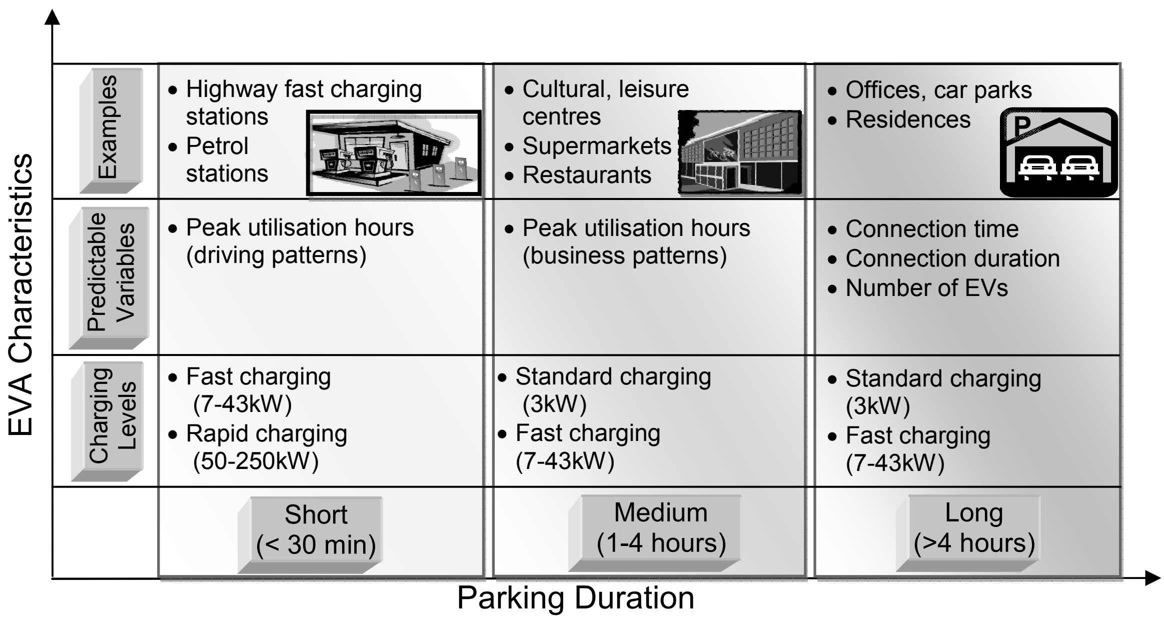

Fig. 1: Classification of EV aggregator types according to the parking duration. Charging rates classification is adopted from [12]

IV. VPP Operation with EV aggregators

A VPP software comprises of various modules, each responsible for different functions. The VPP will hold databases, forecasting tools and communication modules for exchanging information with the external players (Market Operator [MO], Distribution System Operator [DSO], Transmission System Operator [TSO]) and the internal players (aggregators, suppliers and retailers). This paper does not address the function of each module, but it uses only the term VPP to describe the interaction with the EV aggregators. Two timelines of the virtual power plant operation are identified: (i) day-ahead operation and (ii) real time operation. It is assumed that the aggregators and the VPP will be able to forecast the EVs battery charging demand for the next day and proceed with day-ahead market negotiations [13].

a) Day-ahead operation

After the VPP day-ahead market negotiation, the technical feasibility of the planned schedule within the distribution network has to be validated by the DSO [1]. This validation may include changes in the plans or corrective actions required by the DSO [10]. Post validation, the VPP disaggregates the day-ahead demand profiles and distributes them to the electric vehicles aggregators accordingly. These schedules are forecasted, based on the predicted customers' needs and behaviour, as well as the market prices [13].

b) Real time operation

In real time operation, the VPP receives information regarding the connected EVs from the EVA regularly. The VPP will use the EVA flexibility to fine tune its market position or to participate in balancing markets.

V. Case Study

To demonstrate the operation of a workplace EV Commercial Aggregator (EVCA), simulations were performed. The EVCA manages the EVs which are connected in its car park, according to the technical constraints of the local electricity network. At every time step (30 minutes in the study case) the EV commercial aggregator sends to the VPP:

- The number of connected EVs,
- The actual power consumption and
- The programmed schedule for the connected EVs.

In real time operation, the VPP is assumed to have the ability of requesting the EVCA to change the charging schedules of the EVs under its management, reducing the power consumption of the present time step or any future period. If there is a load reduction request from the VPP, the EVCA sends to the VPP:

- The power consumption that can be reduced
- The scheduled profile before the request
- The new profile if the request was accepted

a) Software Tool Description

In order to emulate the above mentioned procedure, a Java based software tool was developed. The tool accepts inputs from the user in order to create charging schedules for a number of EVs, considering the technical constraints and customers needs. A schematic of the tool is given in Fig. 2.

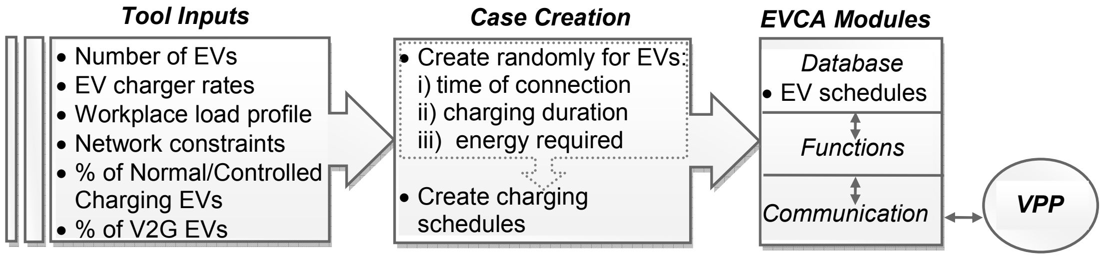

Fig. 2: Schematic of the software tool

The software tool contains a function which can modify the schedule of connected EVs in controlled charging mode by displacing their charging to subsequent time steps. The flowchart of the software tool core is given in Fig. 3.

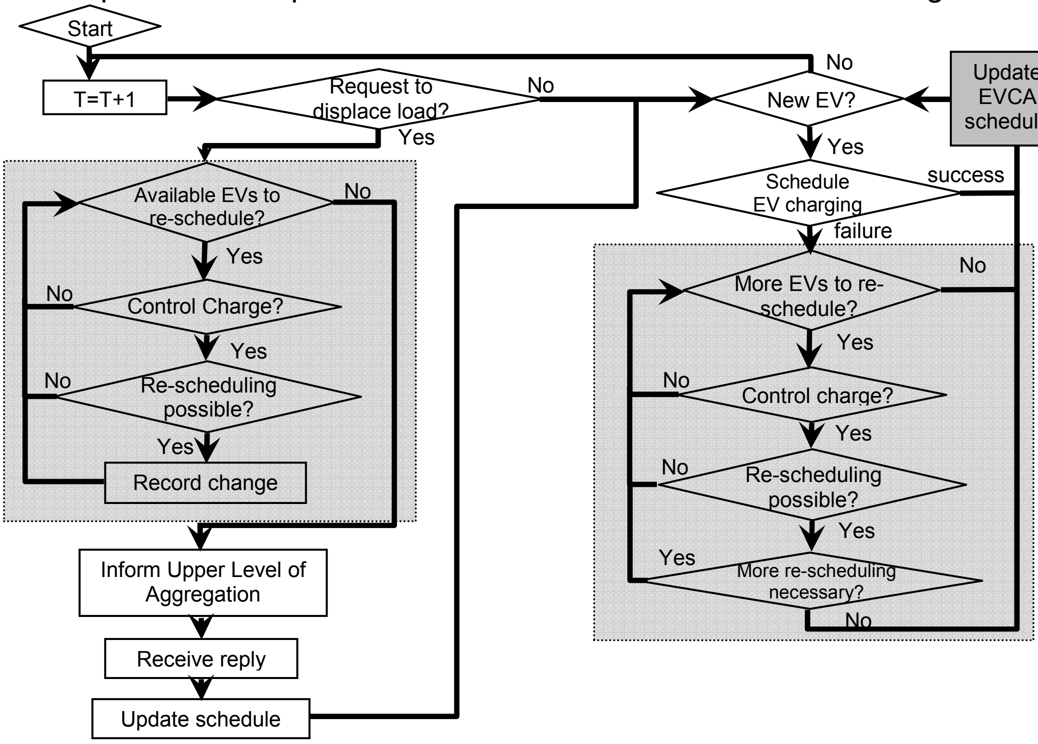

Fig. 3: Software flowchart of the EVCA's functions

The assumptions of the software tool and the EVCA are presented in Table 2. The charging modes listed in Table 2 are defined as follows: in Normal Charging (NC) mode the EV is considered as a non-controllable load. In Controlled Charging (CC) mode, the EVCA can schedule and control the charging of the EVs.

Table 2: Case study Assumptions

Software related assumptions	EVCA related Assumptions
• Two charging modes are available: i) Controlled Charging (CC) ii) Normal Charging (NC)	• Office size : 450 employees • Employees using EV car park: 50 • Employees with Battery Electric Vehicles (BEVs): 12 (25%) [14] • Battery capacity : 35 kWh [4]
• Direct two way communication between the VPP and the EVCA • VPP can request load reduction at every time step • EVCA monitors: i) Office load [15] [16] ii) Connected EVs	• Employees with Plug-in Hybrid Electric Vehicles (PHEVs): 38 (75%) [14] • Battery capacity: 9 kWh [4] • EVs in CC mode: 50% • Workplace peak load: 405 kW [15] [16] • Workplace single load connected to the MV/LV) transformer • Technical constraint: Transformer rating (500 kVA) • Chargers rating: 3kW [12]

b) Simulation results

Fig. 4 shows the EVCA's capability (in kW) to reduce its scheduled load demand at each half hour time step.

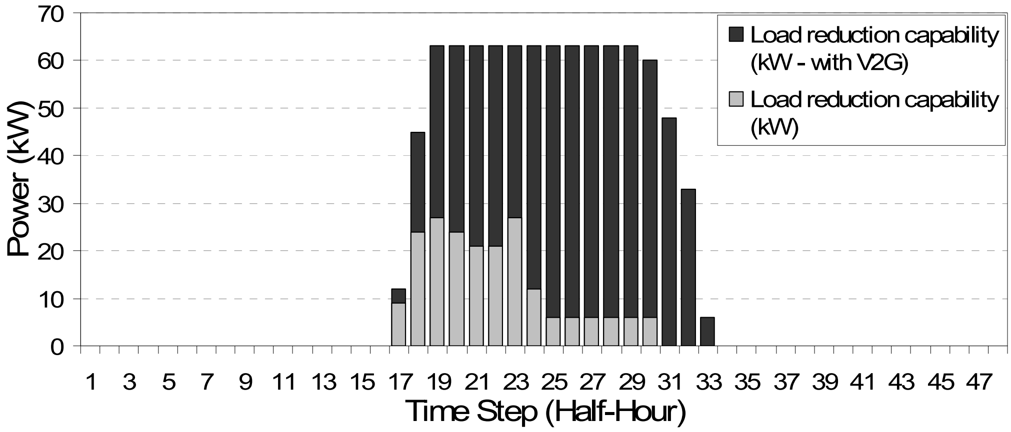

Fig. 4: Load reduction capability of the EVCA with and without V2G EVs

A request was performed at every time step and the available load demand reduction recorded. The grey bars represent the capability of the EVCA to reduce its scheduled load demand at each time step. The black bars represent the demand reduction when all the EVs connected in controlled charging mode are also V2G capable. Fig. 5 shows the information sent by the electric vehicle commercial aggregator at time step 18 after a VPP load reduction request. This information is: (i) the available load reduction, 42kW in this case (black bar), (ii) the scheduled load of the connected EVs at time step 18 prior to the request (grey bars) and (iii) the load displaced at subsequent time steps if the maximum allowable load is reduced (the displacement is noted with the white bars on top of the primary profile).

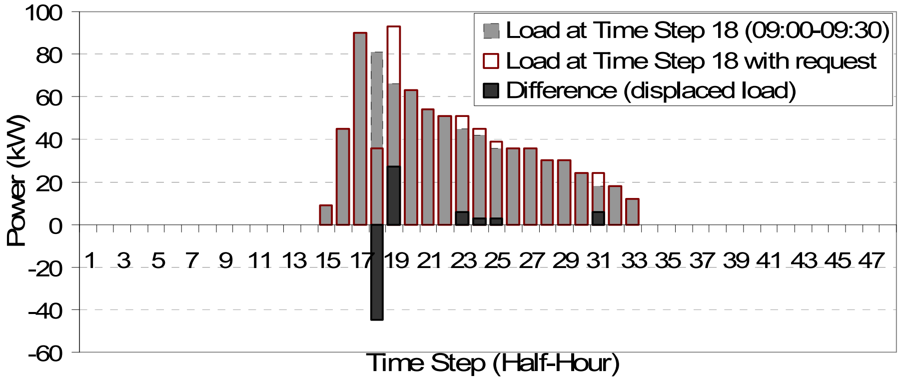

Fig. 5: EVCA load profile with and without a load reduction request

VI. Conclusions

The integration of EVs aggregators within the existent VPP concept was discussed. The benefits of this integration for both parties were identified. Two types of EV aggregators were defined as follows: the EV residential aggregator and the EV commercial aggregator.

A study case considering the operation of an EVCA was described, along with a simulation of its operation. It was identified that the main aim of the EVCA is to increase the VPP controllability, by sending EVs schedule regularly and indicating the available load displacement when requested by the VPP. A Java-based software tool was developed for this purpose and tested. Results from calculations on the power reduction capability of the particular electric vehicle commercial aggregator were presented.

VII. Acknowledgement

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VIII. References

[1] FENIX Project, Available at: http://www.fenix-project.org/ Date accessed: 23 June 2010

[2] European Virtual Fuel Cell Power Plant. Available at: http://ec.europa.eu/energy/res/sectors/doc/polygeneration/euvpp.pdf Date accessed: 20 July 2010

[3] Pudjianto, D., Ramsay, C., and Strbac, G., "Microgrids and virtual power plants: concepts to support the integration of distributed energy resources," Proc. of the IMechE part A: Journal of Power and Energy, vol.222, 2008.

[4] Department for Business Enterprise and Regulatory Reform, Department for Transport, "Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles", 2008.

[5] Papadopoulos, P., Jenkins, N., Cipcigan, L. M., and Grau, I., "Distribution networks with electric vehicles," UPEC 2009, 1-4 September 2009.

[6] Papadopoulos, P., Skarvelis-Kazakos S., Grau, I., Cipcigan, L. M., and Jenkins, N., "Predicting Electric Vehicle Impacts on Residential Distribution Networks with Distributed Generation", 2010.

[7] Papadopoulos P., Akizu O., Cipcigan L. M., Jenkins N., and Zabala E., "Electricity demand with electric cars: Comparing GB and Spain", 2010.

[8] Kempton, W., and Tomic, J., "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue," Journal of Power Sources, 2005.

[9] Brooks, A., and Gage, T., "Integration of electric drive vehicles with the electric power grid—a new value stream", 18th International Electric Vehicle Symposium and Exhibition, Germany, 2001,

[10]. Pudjianto, D., Ramsay, C., and Strbac, G., "Virtual power plant and system integration of distributed energy resources,"Renewable Power Generation,IET, 2007

[11] Sekung, H., Soohee, H., and Sezaki, K., "Development of an Optimal Vehicle-to-Grid Aggregator for Frequency Regulation," Smart Grid, IEEE Transactions, 2010

[12] Greater London Authority, "London´s Electric Vehicle Infrastructure Strategy", December 2009.

[13] Binding, C., Gantenbein, D., Jansen, B. ,Sundström, O., Bach Andersen, P,. Marra, F., Poulsen, B., and Træholt, C., "Electric Vehicle Fleet Integration in the Danish EDISON Project,", 2010.

[14] Grau, I., Skarvelis-Kazakos, S., Papadopoulos, P., Cipcigan L.M., and Jenkins, N., "Electric Vehicles (EV) support for Intentional Islanding. A Prediction for 2030". North American Power Symposium, 2009.

[15] Kilpatrick, R., "Energy Demand Patterns in Non-Domestic Buildings" IEECB'10 Conference, Frankurt, Germany, April 2010.

[16] Locke D., "Guide to the Wiring Regulations" 17th Edition IEE Wiring Regulations (BS 7671: 2008). 2008.