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Citation for the original published paper (version of record):
Gazioğlu, İ., Pillai, J., Le, A. (2023). Real-life demonstration of flexibility provision by smart charging of EVs and stationary
battery storage. 2023 IEEE Asia Meeting on Environment and Electrical Engineering (EEE-AM).
http://dx.doi.org/10.1109/EEE-AM58328.2023.10394850

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Real-life demonstration of flexibility provision by smart charging of EVs and stationary battery storage

İbrahim Gazioğlu
Smart Systems, R&D
Osmangazi Electricity Distribution Company
Eskisehir, Turkey
ibrahim.gazioglu@oedas.com.tr

Jaikrishnan R Pillai
Bovlabs SAS
Aix-en-Provence, France
jk.pillai@bovlabs.com

Le Anh Tuan
Department of Electrical Engineering
Chalmers University of Technology
Gothenburg, Sweden
tuan.le@chalmers.se

***Abstract*—The main aim of the work is to demonstrate in real-life the possibility to manage the flexible demand-side resources, including DC fast EV charger, V2G EV charger and batteries, in a smart manner to mitigate potential grid congestion problems. For this purpose, an intelligent "EV management platform" has been developed and used in the demonstration. Through this platform, the DSO can determine a threshold level for loading of the transformer based on historical loading data of the transformer and can determine the charge/discharge profiles for the equipment for the designated time, considering the charging preferences of electric vehicle users. The results from the demonstration showed that the demand-side resources can be dispatched automatically to satisfy the users' needs while effectively preventing the local grid congestion problems.**

Keywords—grid flexibility, electric vehicle, EV chargers, battery storage system, smart charging, V1G, V2G, load balancing, grid congestion

I. INTRODUCTION

Tradionally, when the standard power flow in the distribution networks is examined, it can be said that the energy flow is uni-directional, i.e., from energy production to distribution to end-users. However, with the increase in distributed energy sources and Vehicle to Grid (V2G) compatible electric vehicles (EVs) (V2G technology allows EV to supply electricity to the grid by discharging from its battery) connected to the distribution grids, it can be said that this uni-directional flow will turn into a bi-directional flow, especially at certain points [1]. Although this situation has the potential to create new problems for DSOs in terms of network operation, such as high power during peak periods and unpredictability [2], the intelligent management of asset's flexibility potential can be utilized to turn possible disadvantages into advantages.

Management of the controllable and flexible loads with the "smart charging" concept can provide flexibility options to the grid [3-4] and may prevent additional grid investments, at least for the short term. There are several different solutions for flexibility services that can be applied according to the need of the grid. Sperstad et al. [5] classified flexible resources into the three groups, including: i) Demand Response (DR) which includes load-based resources; ii) Energy Storage Systems (ESS); and iii) EVs that cover mobile energy systems.

The work leading to this paper was part of the FlexiGrid project (https://flexigrid.org/) which has received funding from the European Union's Horizon 2020 Framework Programme under Grant Agreement No 864048.

According to [6], ESS can be used as an additional capacity for the grid when the demand reaches its peaks. Also, peak shifting can be used for shifting the peak load to lower load periods to avoid grid problems. Also, EVs will have huge effect especially on some local distribution grids. Studies have shown that even at low levels of EV penetration, overloading problems may occur in some regional transformers [7]. Even this increasing demand causes electricity supply issues, EVs can also add an opportunity to the DSOs with V1G, i.e., grid-to-vehicle, and V2G charging. Gonzalez et al. [8] have divided flexibility potentials of EVs for flexibility services into four groups for DSOs, including: i) Local congestion management; ii) Voltage regulation; iii) Phase balancing; and iv) Peak shaving/Valley filling.

As described above, there are large potentials for flexibility provision from the demand-side resources. However, it is still challenging to turn this potential into a reality. Due to the immaturity of the flexibility market mechanism and limitations related to the operation of EV charging stations (DSOs are not allowed to commercially operate charging stations by current regulations), the demonstration study could not be conducted with real users. Therefore, the flexibility delivery process was only demonstrated to prove the feasibility of the technology with real assets and systems.

The demonstration project FlexiGrid [9] has addressed the above challenges by demonstrating the flexibility provision by flexible assets at one of its demo-sites in Turkey provided by OEDAS, a Turkish DSO. The main contributions of this paper include:

i) Preparation of demonstration site to enable flexibility provision;
ii) Implementation of the intelligent EV Management Platform and its interface to the DSO's SCADA system for data-exchange and enhanced control functionality;
iii) Demonstration and evaluation of flexibility provision from EV chargers and a stationary battery storage system for managing local grid congestion.

The organization of the rest of the paper is as follows: Section II presents the demonstration preparation and details of demonstration site; Section III presents functionalities of the developed EV management platform and smart charging services; Section IV presents demonstration results and Section V presents the key findings from the demonstration activities.

II. Preparation and Demonstration Site Description

A. Equipment Installation

Within the scope of the study, OEDAS demonstrated the provision of flexibility to the distribution grid through the smart charging process of EVs and battery storage systems. To this end, the DC fast EV charging station (50 kW charging), V2G bi-directional EV charging station (10 kW charging/discharging) and a stationary battery storage system (10 kW charging/discharging) were installed and integrated with the local energy management system, called "EV Management Platform", which is described in Section III.

B. General Architecture

The devices and systems in the demo area of OEDAS communicate with the central energy management systems and platforms through different communication protocols. In general, *MODBUS TCP protocol*[1] is used for the communication of the battery storage system and power analysers with the battery management system. The communication of the battery management system with SCADA is provided by the *104 protocol*. *OCPP 1.6 protocol*[2] is used for communication and control of charging stations. Charging point management system (CPMS), the sub-module of the EV management platform, undertakes the integration process of charging stations through *OCPP 1.6*. In addition, since the charging and discharging processes of the battery storage system will be controlled by the optimization algorithms on the backend side of the EV management platform, *MODBUS TCP protocol* is used to provide an integration between two platforms. Hereby, control signals can be sent from the EV management platform to battery management system using *Modbus TCP*. Main communication architecture and also the basic single line diagram of the system are presented in Figure 1.

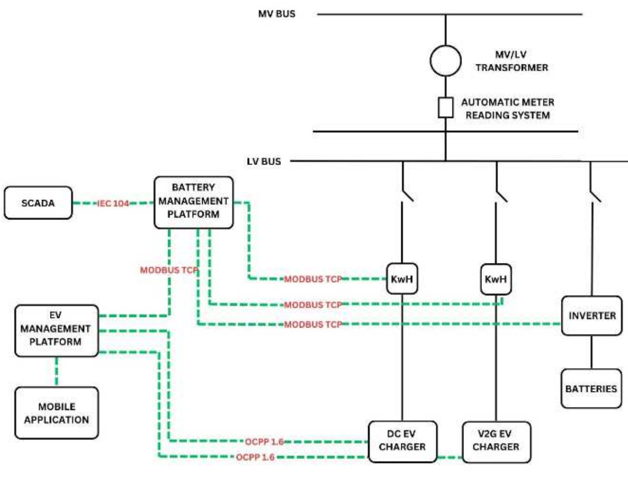

Fig. 1. Communication architecture of OEDAS pilot site.

III. EV Management Platform (EVMP)

The "EV Management Platform (EMVP)" was used to manage the charging sessions with the smart charging algorithms. In general, a charging process is started via the mobile application (QR code or RFID) and the management and optimization processes will be carried out on the backend of the EVMP. The main aim of using this platform is to manage the load of the local transformer with optimum charging/discharging slots. The structure of the EVMP can be seen in Figure 2.

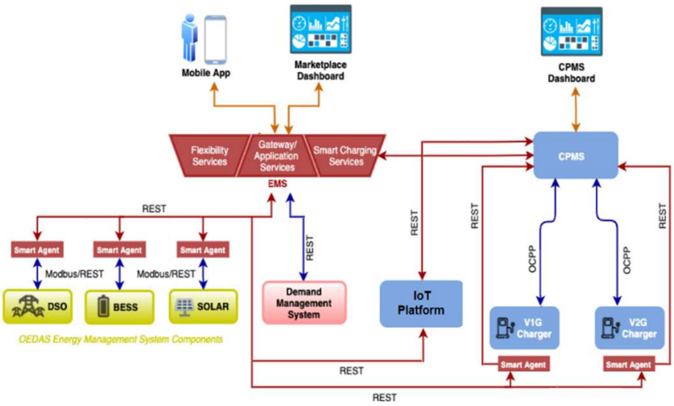

Fig. 2. Architecture of EVMP.

The EVMP can communicate with flexible devices (EV chargers and batteries) and grid assets. In this context, the grid data such as transformer loading level and battery state of charge (SoC) are collected, and the load based charging/discharging optimization is performed with users' inputs. The smart charging module in the central EMS calculates the charging and discharging profiles based on inputs received from relevant devices and users. The smart charging algorithms and process are as described in Figure 3.

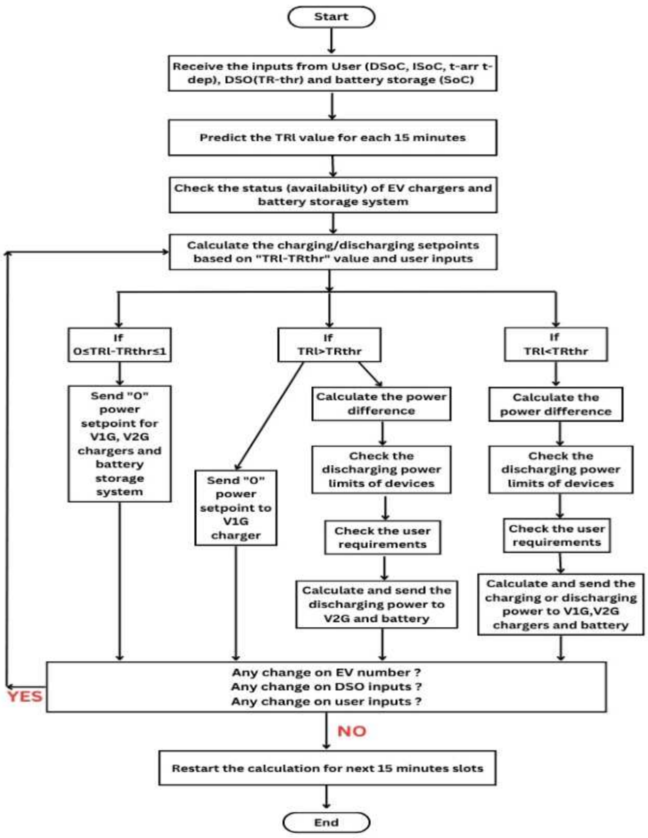

Fig. 3. Flow chart of the smart charging process

The basic criteria for this calculation are:

- Transformer loading (TRl) is predicted using historical load by checking on the average loading over a period of one month for every 15 mins slots.

1) https://www.modbus.org/
2) https://www.openchargealliance.org/

- Parking utilization is based on analysis of number of vehicles connected to the charging stations over a period of time.

For every vehicle, from the user input, the following are derived:

- Arrival (t-arr) and departure time (t-dep);
- Desired state of charge at departure time (DSOC) normally 100%;
- Current state of charge (SOC);

For each of the connected vehicle, the following are derived using the users' input:

- For V2G compliant vehicles offering flexibility, the energy required to achieve the desired state of charge (DSOC).
  - If DSOC is less than 100%, then the difference between DSOC to Full charge is treated as flexibility.
  - If DSOC is 100%, then a pre-configured percentage (20%) of the vehicle's maximum capacity would be considered as flexibility.

The utilization of the flexibility has to consider the departure time of the vehicle and will be different in each slot based on grid conditions. The goal here is to charge the vehicle up to DSOC based on the disconnect time interval while utilising the flexibility offered until then.

- For V1G vehicles or V2G (opt-out option selected)
  - Calculate the respective energy required to achieve DSOC and assign blocks considering the departure time of the vehicle.

The load balancing-based profile calculation is mainly based on the peak and off-peak thresholds determined by the DSO through the platform. The peak threshold indicates the threshold value that the transformer load should not exceed during peak times, while the off-peak threshold indicates the loading value taken into account outside of peak times. Information on how the algorithm performs calculations during peak and off-peak times can be found below.

During the **Peak slot**:

- The EV would never be charged unless the load is below a configurable peak threshold in which case, they would be slow charged.
- In case of V2G, the EV would discharge at a maximum rate for every 15 mins slot (if the charging station is 10 kW capacity it would be discharged at the maximum: 10 kW);

During the **Off-Peak slot**:

- There is a configurable off-peak threshold (TRthr) the charging algorithm always uses to determine the number of cars charged during 15 mins;
- If for some reason the real time loading of the transformer goes above the threshold then V2G would trigger discharging;
- All V2G car would be charged up-to threshold until it gets to the 100%;
- All V1G car would be charged at slow or fast rate depending on the departure of the car and transformer loading threshold value determined by DSO.
- For V2G, any discharge during the peak would be re-charged at off-peak to the same level so the car is always ready for flexibility at the next peak.

IV. Demonstration Results and Discussions

A. *Description of the test-case*

In this test, a pilot study was conducted to demonstrate the potential flexibility of the entire system when operated simultaneously. The primary objective of the test case is to determine the optimal charging and discharging profiles for the equipment, based on user and DSO (Distribution System Operator) requirements, using the smart charging algorithm.

According to the scenario, EV user comes to the charging stations (see Figure 4) and initiate the charging process by entering their charging request through a mobile application. In parallel, the DSO determines the loading threshold values for the transformer during the operational hours, based on the load curve of the current transformer. The smart charging algorithm then determines the charge and discharge profiles for the equipments (EV chargers and stationary battery), based on this threshold value and EV user inputs.

Fig. 4. Simultaneous testing of V2G and V1G compatible vehicles.

As can be seen from the Figure 5, the V2G user (left in Figure 5) delivers his vehicle with a 40% state of charge (SoC) and commits to staying at the station for 5 hours, requesting to receive the vehicle with a 70% SoC. On the other hand, the V1G (right in Figure 6) vehicle user delivers their vehicle with a 20% SoC and requests to receive it with a 97% SoC within 1 hour. Battery storage system was also used during the charging period of V2G charger (5 hours) to provide load support.

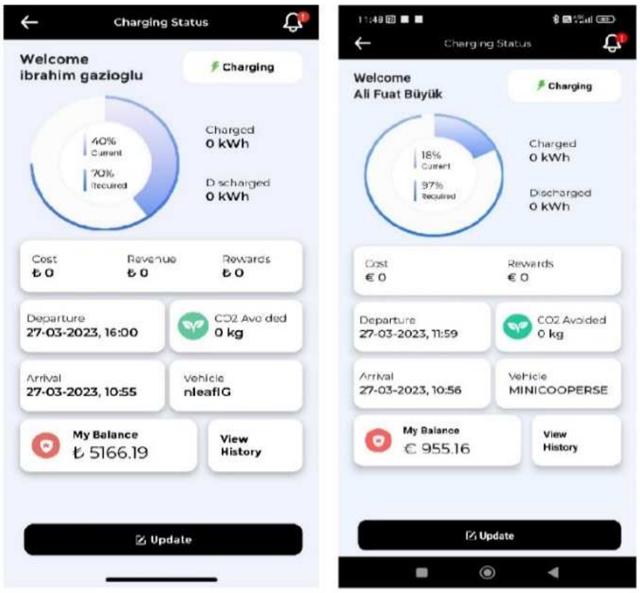

Fig. 5. V2G (left) and V1G (right) user inputs.

To this end, the DSO has established the transformer load threshold values for the relevant study, as illustrated in Table I.

B. Test results

Proposed scenario has been run with the devices and calculated setpoints for each asset can be seen in Table I.

TABLE I. TRANSFORMER LOAD THRESHOLD VALUES AND CALCULATED SETPOINTS DURING STUDY

Time	TR Base Load (kW)	TR Load Threshold (kW)	Setpoints (kW)			TR Final Load (kW)
			DC Charger	*Battery*	*V2G Charger*	
11:00-11:15	155.74	185	24.5	-10	10	180.24
11:15-11:30	152.17	185	37.8	-10	5	184.97
11:30-11:45	144.25	175	35.7	-10	5	174.95
11:45-12:00	147.78	175	32.2	-10	5	174.98
12:00-12:15	148.5	165	-	6.5	10	165
12:15-12:30	164.2	165	-	-9.2	10	165
12:30-12:45	146.98	165	-	10	8	164.98
12:45-13:00	153.1	165	-	0	10	163.1
13:00-13:15	146.27	130	-	-10	-6	130.27
13:15-13:30	153.44	130	-	-10	-10	133.44
13:30-13:45	142.18	130	-	-10	-2.5	129.68
13:45-14:00	146.69	130	-	-10	-6.5	130.19
14:00-14:15	139.06	140	-	0	0	139.06
14:15-14:30*	146.27	DR	-	0	-10	136.27
14:30-14:45	130.18	140	-	5	5	140.18
14:45-15:00	132.21	140	-	4	4	140.21
15:00-15:15	134.52	140	-	0	6	140.52
15:15-15:30	145.92	140	-	-9	4	140.92
15:30-15:45	125.54	140	-	4.5	10	140.04
15:45-16:00	145.38	140	-	-10	4.5	139.88

As can be understood from Table I, a V1G charging session for a DC EV was carried out with one EV user between 11:00 and 12:00. During this time interval, the charging powers of the EV were determined by the algorithm in such a way that the thresholds set by the DSO (185 kW and 175 kW) were not exceeded. Finally, a profiling was defined to reach the desired charging level of the EV user.

There is a decrease in actual charging power when the SoC level of the EV, especially due to its own BMS, exceeds the 80% level. Although the power level is determined according to the threshold level, the power received by the vehicle during these charging intervals is different. The main reason for this situation is that EVs have a Battery Management System (BMS) that does not provide external control capability and adjusts the charging power based on the State of Charge (SoC) and battery temperature of the vehicle This situation is shown in Table II.

TABLE II. CALCULATED AND ACTUAL CHARGING POWER DURING DC EV CHARGING PROCESS

Time	Smart Charging - DC	
	Smart Charging Command (kW)	*Actual Power (Average -kW)*
11:00-11:15	24.5	24.07
11:15-11:30	37.8	37.19
11:30-11:45	35.7	27.49
11:45-12:00	32.2	13.57

Again, as seen in Table I, when the DC EV charging process started, the V2G vehicle began its charging session. At the same time, the stationary battery storage system was also in operation. According to the V1G user's departure time data, the algorithm gives priority to the DC charging station for the threshold level, but the V2G vehicle has also started charging. (According to the algorithm design, the discharge process is not started before the V2G vehicle reaches the desired SoC value set by the user.) Therefore, to prevent the threshold level from being exceeded during the relevant interval, the battery storage system is discharging itself at full power (10 kW). At 12:00 pm, charging process at the DC charging station was ended and visualization of the real measurement data of SoC-power relation can be seen in Figure 6.

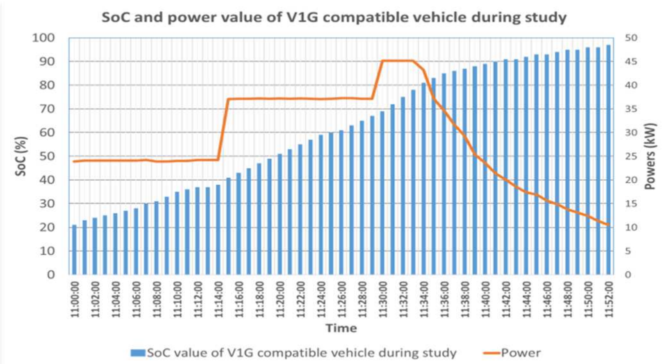

Fig. 6. DC charger charging power curve and SoC relation during optimization.

After the ending of V1G charging session, the V2G vehicle was charged with the maximum power possible according to the threshold level, and the user reached the DSOC input level of 70% at 13:00. During this process, the battery was charged or discharged according to the setpoint determined for the battery threshold level. As the threshold level determined by the DSO was relatively low between 13:00 and 14:30, as can be seen from the Table II, both the V2G vehicle and the stationary battery storage system were discharged. Here, priority was given to discharging the stationary battery at full power by algorithm, taking into account the possibility of the user ending the session early.

According to the Table I, a "demand response" signal was sent by the DSO between 14:15 and 14:30. The DSO requested 10 kW of flexibility to the grid. During this time, discharging was carried out from the V2G vehicle instead of the battery storage system, since the stationary battery had reached its minimum SoC level of 20%. After 14:30, the charging process continued with battery support in order to reach the desired SOC level of the vehicle, and the process was completed around 16:00 to achieve the user's desired

70% vehicle charging level. Visualization of the real measurement data of SoC-power relation for V2G compatible vehicle and battery storage system can be seen in Figure 7 and Figure 8.

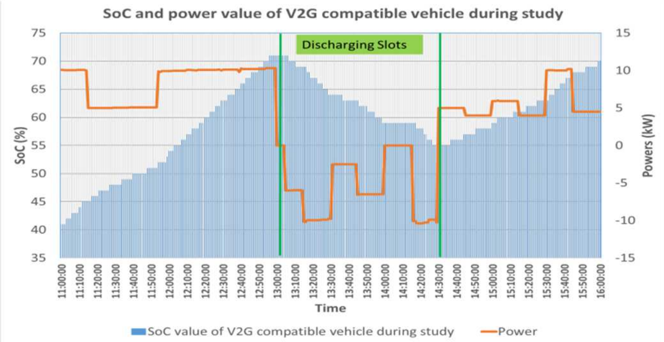

Fig. 7. V2G charger charging/discharging power curve and SoC relation during optimization.

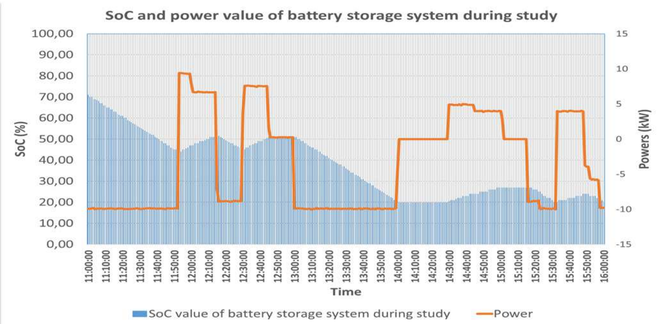

Fig. 8. Battery storage system charging/discharging power curve and SoC relation during optimization.

The graph in Figure 9 shows the changes in transformer loading throughout the process. As can be seen, the load thresholds determined by DSO (see Table I) during operation were not exceeded. In one of the slots, it is seen that the final loading level is above the DSO threshold because the max discharge power of the assets (10 kw for V2G and 10 kW for battery) is not so much that it reduces the transformer load value to the DSO threshold level. Here, it can be seen that a maximum discharge setpoint is sent to the assets by the algorithm.

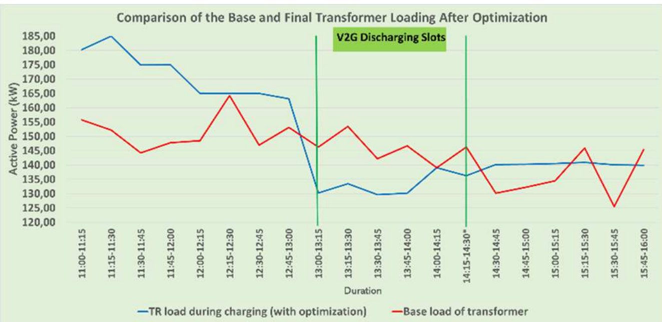

Fig. 9. Comparison of the transformer's before and after loads

V. CONCLUSIONS

The proposed test case was demonstrated with the presented assets and platforms in a real environment (including DSO, Charging Point Operator (CPO) and EV users) to provide flexibility to the local distribution grid. It was shown that through the implemented smart charging tool, optimal setpoints can be calculated during sessions involving V1G (uni-directional smart charging), V2G, and battery storage systems, and these setpoints can be transferred successfully to the assets in real-time and the assets have acted according to the desired setpoints, to avoid transformer overloading. As a result of the study, it has been shown that if a similar structure is established between DSO, Charging Point Operator (CPO) and end users, DSOs can manage load especially during peak hours. This study has shown that V2G compatible vehicles could provide an opportunity for DSOs to utilize vehicle batteries as a flexible asset, especially during peak hours, by taking advantage of the bi-directional charging feature. In can be concluded from this work that the operability of the systems has been proven functioning satisfactorily and relevant systems demonstrated could be scaled up for larger geographical areas.

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