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Ghotge, Rishabh; Van Wijk, Ad; Lukszo, Zofia

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Challenges for the design of a Vehicle-to-Grid Living Lab

Rishabh Ghotge, Ad van Wijk,
Faculty of Mechanical, Maritime and Materials Engineering,
TU Delft,
Delft, the Netherlands.

Zofia Lukszo
Faculty of Technology, Policy and Management,
TU Delft,
Delft, the Netherlands

***Abstract*— This paper outlines the challenges faced during the implementation of a Vehicle -2-Grid set-up from the design phase, through project planning, application for permits and clearances, procurement of equipment and installation. It is based on the experience of designing a living lab at the Green Village in TU Delft, the Netherlands. Desk research and active collection of information from various stakeholders was performed to outline the current state of the technology and the barriers for various stakeholders. It is the aim of this work to provide insight into the subsequent design of V2G systems for future research and pilot projects.**

***Index Terms*-- V2G, smart grid, smart charging, EV.**

I. INTRODUCTION

Vehicle-to-grid (V2G) technology is generally described as the delivery of electricity from vehicles to the electricity grid as a service for electric utilities. The electricity may either be stored in Battery Electric Vehicles (BEVs) or Plug-in Hybrid Electric Vehicles (PHEVs), as described in [1] or may be generated in Fuel Cell Electric Vehicles (FCEVs), as described in [2].

Since the early demonstrations of concepts, vehicle to grid technologies have progressed significantly toward technological maturity. Electric vehicles (EVs) have been demonstrated to be capable of delivering a wide variety of ancillary services to the grid including peak shaving, provision of spinning reserves, frequency regulation [3], response to bids in frequency regulation markets and aggregation of EV assets [4], increasing self-consumption of locally generated solar energy [5], voltage support in low voltage networks [6], etc. More recent work has focused on standardisation of services across different Original Equipment Manufacturer (OEM) brands [7], updating, improvement and standardisation of legislation, development of business cases and bringing the technology closer to customers through pilot projects [8].

Standardised V2G compatible Electric Vehicle Service Equipment (EVSE) is already commercially available today (mid 2019). There are also a few mass produced BEVs and PHEV models on the road which are capable of delivering electricity to the grid. However, although the technology has matured in several areas, there still exist several barriers to implementation of vehicle-to-grid infrastructure and its usage by EV drivers.

A V2G Living Lab is currently being designed at the Green Village experimental site on the TU Delft campus, where innovative technologies and businesses in the field of water, energy and mobility are tested in operational environments. A Nissan LEAF will be connected to an existing and occupied all-electric house, the Prêt-à-Loger for self-consumption of the solar photovoltaic (PV) energy produced by the 4.88kWp array on the roof of the house and the 5.4kWp array on the carport roof while also delivering energy to the home at peak hours. An overview of the planned system is shown in Fig. 1.

The Living Lab aims to provide insight not only into the technical operation of the vehicle, equipment and energy management system but also into the integration and acceptability of the system by the EV users and the home owner. This paper aims to provide an overview of the challenges that exist today for various stakeholders involved in the implementation of such a system, encountered from the stage of design through project planning, application for

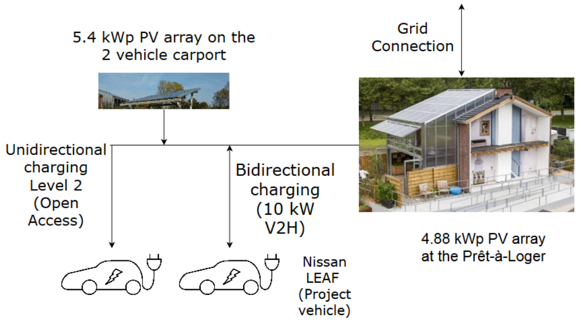

Figure 1: Overview of planned system at the Green Village, TU Delft campus

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permits and clearances, procurement of equipment and finally installation. It is the aim of this work to provide the reader with both an idea of the current state of this rapidly evolving technology and an overview of the challenges which currently obstructing its implementation.

While such challenges are often unique to each specific project, the challenges addressed here are mainly universal to the design and implementation of a similar project anywhere in the world. It is hoped that the insights and knowledge gained from this project can help researchers, project planners, Distribution System Operators (DSOs), Transmission System Operators (TSOs), policy makers and other stakeholders to overcome these challenges in their individual projects.

The paper is organized into sections as follows: Section II describes the methods used for conducting this research. Section III outlines the challenges identified and includes discussion regarding the same and finally, Section IV presents the conclusions of the study.

II. METHODS

The research methods included desk research and literature surveys conducted in 2018 and 2019 as well as active collection of information from EV OEMs, TSOs, DSOs and V2G compatible EVSE suppliers. The challenges presented which are more universal, such as legislative and economic challenges are based on literature review whereas others, such as those faced during procurement are based on experiences gained over this project.

The literature surveyed includes both scientific and non-scientific literature, since a significant amount of literature from projects such as the Parker project in Copenhagen [9] and the SEEV4-City project in multiple cities [10] is included in project reports but remains as yet unpublished in the scientific domain. Further, communication protocols and connection standards which are of significant influence on project design are also typically only available in non-scientific literature. However, every attempt has been made by the authors to verify the authenticity of all the information presented here.

III. OVERVIEW OF CHALLENGES

The challenges outlined in this section have been further divided into technical, economic, current market state, legislative, procurement, institutional, product quality assurance and social. It thus goes beyond the PESTEL (Political Economic Social Technological Environmental and Legislative) analysis conducted in [11] for four European countries. However, political challenges which are largely country-specific have not been addressed in this work and environmental challenges which can be highly dependent on battery material sourcing, degradation rates, lifetimes and reuse/recycling, have not been covered.

A. Technical challenges

1) Accuracy of EV response to current setpoints and quality of electricity provided: EVs were tested for a variety of ancillary services, and across many tests, the speed of response of the vehicle was not found to be an issue. EV batteries were generally found to respond within 1s to about 10s, which is sufficient for frequency regulation services, the service needing quickest response. However, the accuracy of response to a setpoint was found to present a challenge. This occurred in two cases, with either less current delivered than that demanded by the setpoints [12] or excess inrush current when charge or discharge to the grid starts [13]. The inaccuracy is described to be in the range of 1A or 400W [12]. With most charging infrastructure in the range of 10kW, this corresponds to an inaccuracy of about 4%.

Inaccuracies at the individual vehicle level are not significant, but over a large fleet, this can lead to further imbalances in the grid, which were to be solved through V2G delivery. Inrush currents on the other hand can result in the connection capacity of the DSO being exceeded for a period of milliseconds and can cause voltage fluctuations. However, this can be resolved through the inclusion of soft starters in the EVSE, whose costs are not significant [14].

2) Low efficiency of power electronics in EVSE/ EV in discharge and in partial loading: Power conversion efficiency in V2G equipment or within the EV itself has been shown to perform at low efficiencies in discharging mode as well as at partial loads. In [15], the losses during discharging in the power electronics unit for a modified BMW Mini E were found to be in the range of 8 - 22% as opposed to 0.9 – 16.5% in the power electronics unit during charging. This made the discharging power electronics the component with the highest losses when compared with the losses in the alternating current (AC) EVSE, circuit breakers, low voltage transformer and battery. Both [15] and [16] found high losses (>20%) in the EV power electronics and the EVSE power electronics respectively at low currents (partial loading) for both charging and discharging. These high losses can considerably reduce the value that EVs can provide as storage.

3) Location disparity of DSO level services by EVs and potentially variable setpoints: Services that EVs can offer to DSOs include voltage support, congestion management at the low voltage level, black start function, etc. However, all these services are dependent on the location at which the EVSE is coupled to the grid. As an example, we may consider the case of EVs providing voltage support due to deviation of measured voltage from a fixed range such as that required by the EN 50160 standard in Europe [17]. EVSE which is connected to heavily loaded phases and those connected further along the low voltage line are more likely to be used for V2G services since these are the sections of the feeder most likely to have lower voltage measurements [6]. Participation in voltage support is thus distributed unfairly among plugged-in EVs.

In case all the EVs on the connected line and/or phase are to respond equally in an aggregated manner to a deviant voltage measurement at a location on the line, then the permissible voltage ranges at various points along the line are different. This requires either location specific setpoints or centralised control over all EVSE on that line. This increases the complexity of communication and control of the system and also requires continuous adjustment of the system over time.

4) Time required for data transfer through Information and Communication Technology (ICT): Depending on the service provided by the EVs, the required response times vary, generally being in the range of <10s for TSO services like frequency regulation and of the order of a few minutes for DSO services and behind-the-meter services [14]. EV batteries are easily capable of delivering current within these times, with typical setpoints being sent at intervals of 100 to 200 ms in accordance with ChadeMo and CCS protocols respectively [18]. However, the transmission of information related to inclusion and acceptance of the vehicle in a market bid, communication with the EVSE though the backend as well as handshakes can take longer, and the entire process has been found to impose delays of the order of minutes in multiple projects [4], [19]. However, this has already been resolved in some projects and is expected to be less of an issue with the rollout of a 5G network.

B. Economic challenges

1) High capital cost of V2G equipment: Due to both the low number of OEMs producing V2G equipment as well as the low demand, the costs for V2G equipment remain "prohibitively high" [8] – in the order of five times or higher the cost of off-the-shelf EV charging equipment [14]. With increasing standardization and mass production, these prices may be expected to reduce in case of further uptake.

2) High cost of metering equipment: For measurement, validation and billing purposes, assets providing services to the grid are typically required to have settlement meters. Multiple meters may also be required if the assets provide multiple services. Since these meters are typically designed for larger scale central generation assets, they tend to be proportionally much higher fractions of the overall V2G costs. It may be compared with other distributed generations assets, such as small scale PV inverters, which are legally required in many countries to deliver reactive power [12]. However, the grid service is not measured, necessitating inverters to deliver the service without the need for a market or meters.

3) Uncertainty regarding revenue generation: One of the largest economic obstacles to the adoption of V2G infrastructure among the various stakeholders is the uncertainty about the mechanism of revenue generation, the magnitude of revenue and the division of this revenue among the stakeholders involved.

As an example, estimates of the annual value provided per EV vary from €100 or less in Germany [20] through the offer of secondary frequency reserve to over €15,000 for a school bus in the USA through energy and capacity markets [21]. In addition, the distribution of this revenue across the various stakeholders such as the Charge Point Operator (CPO), the Electric Mobility Service Provider (EMSP), the electricity supplier and the EV owner is often inadequately addressed.

C. Challenges related to the current state of the market

1) Low Uptake of EVs: Although the global uptake of electric vehicles has increased greatly in recent years, the share of electric vehicles remains relatively low at 1.3% of the global fleet share [22]. The relatively small fleet share means that there is low demand for EVSE and also relatively low impacts of EVs on the grid. It also means that there is much less average consumer awareness about of EV technology, battery management, etc. as compared to the average knowledge about internal combustion vehicle technology.

2) Low share of OEMs with V2G charging ability: Of the EVs currently on the market, a relatively low number of OEMs (only Japanese ones) offer V2G compatible BEV and PHEV models. A list of commercially available V2G models in Europe is given in Table 2:

TABLE I: List of commercially available vehicles in Europe supporting V2G (Source: [8])

No	**OEM**	**Vehicle Model**	**Vehicle Type**
1	Nissan	LEAF 2013 onward	BEV hatchback
2	Nissan	e-NV200	BEV light commercial van
3	Mitsubishi	Outlander	PHEV sports utility vehicle

D. Legislative challenges

1) Limited or insufficient legislation providing incentive for storage: Although the legislation differs from country to country, a wide majority of EU countries have limited legislature in place for recognizing electrical energy storage let alone incentivizing it [23]. In many countries, they are classified as generation assets and treated as such. Subsidy schemes such as high feed-in tariffs and net metering, which were widely used for encouraging distributed (primarily solar PV) generation, do not encourage local storage, either in stationary batteries or in EVs. Many of these issues have been fully or partially addressed at the EU level based on new (mid-2019) directives [24].

2) Multiple taxation for connected storage: As a result, either of the lack of the storage specific legislature or the incorrect classification of storage devices as generation assets in many countries, V2G capable vehicles are taxed multiple times over the plugged in period [11]. As an example, in Denmark and Sweden, EVs are required to pay tax both for charging as well as for discharging, considerably reducing the economic incentive for storing energy. Another example is in the Netherlands, where if an EV is initially charged for a grid service, discharged for a grid service and later charged again for mobility service, the EV user is taxed for both charging sessions, despite the fact that one of them was for a grid service [39]. Solutions include tax exemption/ reduction for EVs over the duration for which they perform grid services, or through alternative contractual arrangements between the stakeholders involved. The new EU directives recently prohibited double taxation for energy storage operators [24] but makes no special mention of V2G.

3) Insufficient inclusion of DSOs in EVSE rollout: The roll-out of EVSE has included different stakeholders in different countries, from entirely DSO owned and operated in roll-out of public charging infrastructure in Greece, Cyprus and Luxembourg to a relatively more market driven and unbundled roll-out in the Netherlands [13], [25]. Fig. 2 shows an example of the contractual relationships governing EV charging in a non-DSO owned environment, where the Charge Point Operator (CPO) typically is contracted to install the

charge point and contacts the DSO only at the initial connection to the low voltage grid.

1a. EV driver- CPO (direct)
1b. EV driver – CPO (intermediated by a MSP)
2. CPO – Electricity Supplier
3. Electricity Supplier – DSO
4. DSO-CPO (only for connection)

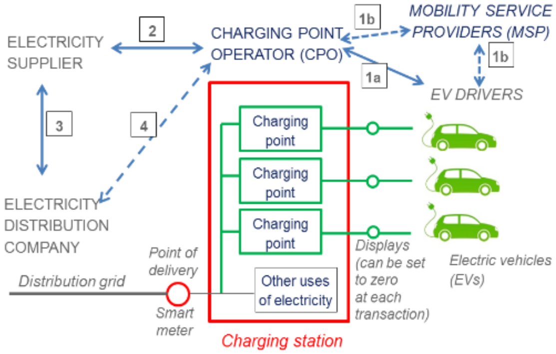

Figure 2: Contractual relationships governing EVSE and charging in a competitive market environment (Source: [25])

Here the EV user typically interacts directly with the CPO or more commonly though the intermediate Electric Mobility Service Provider (EMSP), with little or no involvement of the DSO.

However, the use of V2G for DSO services and arguably even TSO services necessitates information flow (anticipated time of departure, desired SoC, selection of vehicle in a market bid, etc.) between the EV driver and the DSO. Since many DSO services are location specific, there is a need for DSOs to play a larger role in other stages of EVSE rollout such as the location of installation of public infrastructure, the choice of EVSE at both public and private locations and possibly even temporary control of EVSE in order to manage power quality issues at the low voltage level. The prohibition of DSOs from owning assets can prevent them from owning, operating and getting access to EVSE. However, intermediate parties such as CPOs or aggregators can provide the linkage between the EV users and the DSOs at the operational stage.

E. Procurement related challenges

1) Lack of clarity about manufacturers of V2G hardware: Procurement of hardware is still a challenge for a variety of reasons. Although many companies advertise V2G compatible equipment, many of them do not have off-the-shelf inventory [8], have stopped production, are still in the development phase or lack certification for the products they have. For projects which do not include OEMs within their consortia and are manufacturer-agnostic, sourcing and procurement of hardware can present a significant barrier to both project planning as well as implementation.

2) Lack of clarity about software capabilities and non-availability of data sheets: The capabilities and objectives of the software governing the charging and discharging cycles for V2G EVSE are also often unclear. Often key words such as 'time shifting', 'power balancing', 'smart grid', etc. are mentioned without adequate explanation of the capabilities and potential configuration of the set-up.

F. Challenges related to product quality assurance

Even from the OEMs whose EVs support V2G behavior, the position taken on the impact of V2G on the EV battery or how this affects the lifetime and the warranty on the product offered by the OEM is not clear. In Japan, Nissan is reported to cover 'accepted cycles' or 'certified cycles' of 5 kWh within their warranty, but in other markets and for other OEMs, the battery usage permitted under the warranty coverage are as yet unclear [8]. Understandably, EV drivers are unwilling to risk breaking the conditions of their warranty unless it explicitly covers the range of cycles which the V2G EVSE runs on their batteries.

G. Institutional challenges

1) Split of the direct current (DC) standard between ChadeMo and Combined Charging Standard (CCS): A large majority of V2G projects have focused on DC charging due to the unidirectional DC standards' inclusion of a mechanism for communication between the EV and the EVSE. However, the division of both DC charging infrastructure and vehicle compatibility between the Japanese ChadeMo and the Euro-American CCS standards has been a barrier to both DC fast charging points as well as to V2G products. The ChadeMo standard has been used in a vast majority of pilot tests and has supported the early development of hardware, whereas the CCS has been at best ambivalent towards V2G development. This position is changing however, with the CCS standard expected to support V2H and V2G through compliance with the ISO/IEC 15118 protocol for greater grid integration of vehicles [41], [42]. In addition, Tesla has its own DC supercharger network, which is unlikely to support V2G owing to the focus on highway locations and fast charging.

2) Lack of an alternating current (AC) standard: Generally, V2G with AC EVSE has lagged behind DC EVSE due to the requirement of an on-board inverter in the EV and the lower communication capabilities of both the IEC 62196-2 connectors. Relatively few pilots like the Smart Solar Charging project in Utrecht [26] and the Korean V2G project [14] have involved AC EVSE, and Nuvve is the only commercial supplier of AC hardware to the best knowledge of the authors. However, this is expected to change with automobile manufacturers showing interest in AC products to integrate EVs better with the AC grid [27]. As with the CCS standard on DC, AC hardware is expected to comply with ISO/IEC 15118, which is not specific to DC.

3) Lack of markets and non-optimal market structure: Primarily for DSO services which may be delivered by EVs, there are generally no markets in which these services can be offered or traded in exchange for compensation. Potential services that EVs at the fleet level are capable of offering DSOs include provision of fast reserves, short time operating reserves (STOR), demand turn-up or ramping reserve, black start functionality, reactive power service and voltage control service [10].

For TSO level services such as frequency regulation and control, for which markets do exist, the large size of minimum bid, low frequency of auction duration, long duration between gate closure and delivery of service, lack of asymmetric bidding, long duration of service, etc. can all prove to be obstacles to the active participation of EV fleets in the frequency markets [28]. In addition to frequency regulation, EV fleets can provide TSOs with services like congestion management, for which suitable market structures are lacking.

4) Non-universal and competing ICT protocols for communication between stakeholders: There are many available communication protocols governing the information exchange between the various stakeholders and devices involved in EV charging. Universal and open standards help promote interoperability across EV equipment, roaming, universal access, switching of service providers, and ease of billing and help avoid technology lock-in and unnecessary investment in redundant infrastructure. The OCPP standard has emerged as a de facto standard in Europe [29], but is slower to be implemented in other places.

H. Social challenges

With the use of the technology still in its infancy, social barriers to V2G remain highly unaddressed, with less than 2.1% of V2G related academic studies between 2015 and 2017 considering consumer routines and norms and less than 1.1% considering range anxiety [30]. Further, special attention needs to be given to the education of EV users who are unaware of technology as well as the influence of various contracts offered to them on their acceptance.

IV. CONCLUSIONS

The paper provides an overview of the challenges faced for the implementation of an operational V2G system. Although there are technical barriers, these are relatively minor and are expected to be addressed with the next generation of hardware. The major barriers in the way of implementation are expected to be legislative and institutional. Social barriers are relatively unexplored as compared to the other fields and it is expected that further research in this area will provide an impetus to the technology.

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