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Vehicle-to-Everything (V2X) Technology Insights

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Summary

During last years scientific research as well as multiple international pilot projects has proved the economic and environmental advantages the Vehicle-to-Everything (V2X) technology can provide to, not only end-users, but also the electric power system, electric vehicle car industry and infrastructure stakeholders. V2X Technologies refers to the applications EVs can support for other purposes than powering the vehicles.

This paper enumerates the multiple benefits of V2X implementation at different V2X value chain level by means of analyzing multiple experts' contributions on the field covering different subjects such as: V2X business models, challenges for implementation, regulation, standards and V2X world-wide projects revision, among others including current business cases. Nevertheless, V2X applications are still in a research and development stage with some challenges and barriers preventing the commercial roll-out of this technology. This paper identifies these gaps and proposes an action plan to overcome them in order to strengthen the V2X future deployment.

1 Introduction

Vehicle electrification and smart grid technology implementation present an opportunity for EVs (electric vehicles), through charging strategies and aggregation, to support and provide valuable services to contribute to reliable management of the electricity grid. Smart charging can be seen as a first approach to market integration by allowing the EV to respond to variable energy prices on the energy market. Research, development and demonstrations projects have been exploring, especially during the last years, the potential for Vehicle-to-Everything (V2X) services and how to enhance enabling technologies. The Vehicle-to-Grid (V2G) technology can be seen as the second step where EVs increase their potential as a resource for the grid and enables more market integration concepts. V2G is just one of the possible applications EVs can be used for beyond mobility services but there are multiple ones involving different electro mobility and power systems stakeholders (see Section 1.1). EVs can therefore be seen as a distributed energy source and are able to offer values and services that exceed its primary function as a mean of transportation. [2,3]

This paper aims at highlighting the multiple V2X benefits to the whole value chain stakeholders while identifying gaps and barriers preventing the V2X technology deployment as well as providing some recommendations to overcome these barriers.

Following a brief introduction on the definition of V2X technologies, Section 2 focuses on the potential benefits of V2X depending on its applications. Section 3 identifies the detected barriers for V2X technology deployment covering subjects such as standardisation, battery degradation, regulation or users engagement, among others. Finally, Section 4 presents the conclusions derived from the analysis made in this paper around the applications of EVs for other purposes differing from mobility issues.

The content and results presented in this paper have been produced since 2014 within the framework of the "Vehicle to grid Technologies" (Task 28) of the Hybrid and Electrical Vehicle Technological Program (HEV-TCP) of the International Energy Agency (IEA). Task 28 is led by the Catalonia Institute for Energy Research (IREC) with the contribution of Spain, France, Denmark, Ireland, South Korea, USA, Canada, Germany, Switzerland and private the companies Nissan, Enel and Vedecom.

1.1 What does V2X stand for?

The term V2X used in this paper refers to the different ways EVs can provide multiple services beyond mobility such as those to enhance grid stability, reliability and security. With V2X technology, it is possible to use electricity stored in large-capacity batteries of electric vehicles and plug-in hybrid electric (PEV) vehicles when necessary.

Customers may use their PEV electric storage capabilities for other applications such as vehicle-to-grid (V2G), vehicle-to-home (V2H), vehicle-to-load (V2L), and vehicle-to-vehicle (V2V) [1]:

- V2G: Electric utility may be willing to purchase energy from customer during periods of peak demand, and/or use the EV battery capacity for providing ancillary services.
- V2H: Use of the PEV as a home generator during periods of electrical service outage and for increasing self-generated renewable energy usage.
- V2L: Use of the PEV storage to provide power to a remote site or load that otherwise has not electrical service. Examples include construction sites or camp sites.
- V2V: Use of the PEV storage to transfer electrical energy to other PEVs in case of emergency.

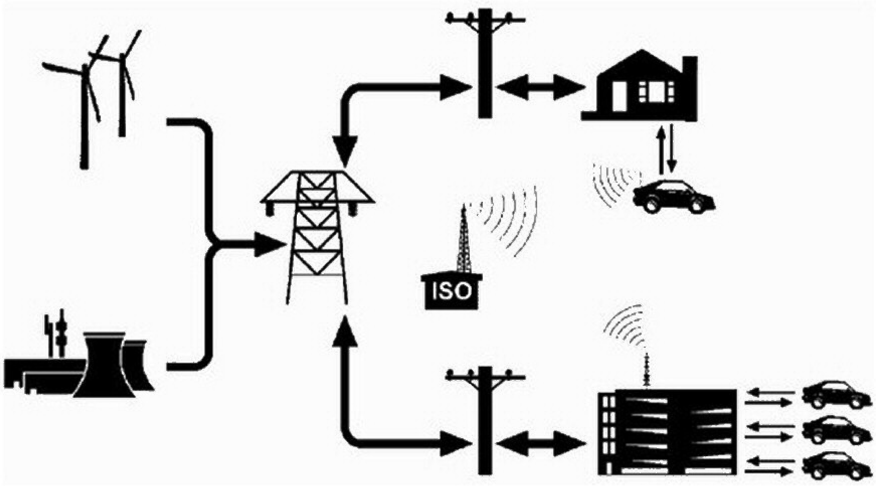

Figure1: V2X Concept. Source: "Effects of Battery Degradation on Economic Analyses of V2X Service Provision", A. Thompson

Notice that, despite the multiple applications of V2X applied to EVs to get and provide power from and to the grid, most of the research and demonstration pilot projects are presently focused on V2G and V2H applications. These latter applications have shown a more powerful business case potential than the other ones.

2 V2X potential benefits and business cases

The potential benefits of V2X technologies have proven to be multiple, but depend on their application. For V2G services, for instance, the main benefit is the availability to participate in the wholesale power market providing services to the grid. By participating in grid-balancing services, such as frequency regulation or demand response, EVs can accrue revenue and increase the return on investment of the vehicle to the owner. A real example for the use of V2G as part of frequency containment reserves with a viable business case is experienced in *Frederiksberg*. The Danish company *Frederiksberg Forsyning* in part of greater Copenhagen uses a fleet of vehicles for service and maintenance assignments, providing frequency regulation on market terms. The Danish Transmission System Operator (TSO) is tasked with ensuring a sufficient supply of frequency containment reserves as part of system operation. While some of the traditional providers of such services are being replaced by renewables, it becomes prudent to support new providers of such services. One possibility, tested in *Frederiksberg,* is to have aggregators to become part of the market using aggregated fleets of V2G-enabled EVs. The *Frederiksberg* case could be replicated, for private owners or other markets, if certain limitations regarding technical requirements and equipment costs are overcome.

With the increasing penetration of renewables, mainly wind and solar, PEVs can also serve as a potential storage means allowing a better renewables integration into the grid (V2H and V2G applications). This is a key development for the V2X market because EVs represent an increase in load that could be used to capture renewable electricity generation and help balancing generation with demand, theoretically making electricity marginally cheaper and cleaner. In this way, self-consumption is strengthened and the independence from the grid increases.

In the case of the V2L service, the main benefit is the availability of providing power in remote sites not otherwise available. These include: access to information and instruction broadcasting in connection with an emergency, electric heating and preparation of food needed by the local population, floodlights, signs used for evacuations, etc. In fact, in 2011 when the most powerful earthquake ever recorded in Japan (Pacific coast of Tohoku) of magnitude 9 snatched the lives of thousands of people, V2L applications proved to be very profitable as emergency power in case of a tragic natural catastrophe. The application could be scaled up for any individual or organization which may be adversely influenced by the occurrences of natural disasters and, in general, power cuts.

V2L technology can also be upgraded to supply energy to another EV (V2V). V2V applications could be used for on-road assistance (for instance in case an EV would run out of battery) or as a way to more efficiently manage an EV parking, optimizing the state-of-charge (SOC) of EVs by charging/discharging them according scheduled usage..

In short, V2X is enabled through technology tools and products to provide reliable and dependable vehicle charging services to EV owners, and potentially additional revenue opportunities, while reducing risks and creating cost savings opportunities for grid operators.

3. Detected barriers for V2X full deployment

By means of several international experts' workshops, a set of different barriers preventing the V2X full deployment have been identified.. Main priorities and action lines to overcome these barriers have been proposed and classified in the following 3 categories: technology development, market and regulation and, finally, user's engagement, and demonstration projects.

3.1 Technology Development

Main hurdles regarding the V2X technology development are standardization, harmonization and battery degradation. The next sections expound the main issues within this topic.

3.1.1 Standardization and Harmonization

With the introduction of the EVs standardization was needed both in the EV and EVSE (Electric Vehicle Supply Equipment) side to allow interoperability among all actors. The end goal is that EV users are able to plug their vehicles for charging purposes wherever charging infrastructure is available. Despite strong efforts and transversal initiatives on standardization and harmonization there are still few issues open mainly due to industrial or regional interests and independent developments by some of the stakeholders. V2X technology still requires an additional level of complexity by interacting with the grid (G), the home (H) or the load (L).

Therefore one of the main barriers that V2X faces is related with equipment standardization, harmonization and communication protocols. Automakers and infrastructure operators must deploy equipment conforming to a harmonized set of standards. The lack of standards between the EVSE and the upstream electric infrastructure is a significant drawback for V2X technology deployment. Consistent requirements for EVSE should be established. This creates the needs for standardized plugs, standardized infrastructure and a standardized communication platform. New grid codes together with common standards will enable the use of the full potential of EVs delivering ancillary services to the overall power system, and ancillary services to the local grid. No consistency among standards on the whole V2X value can lead to limited access for V2G services [5].

Standards are needed to harvest V2X properties such as the fast response time, high power load, possibility of V2X support and high degree of flexibility. Therefore, early development of standards can be considered a key factor to V2X deployment. Figure 2 illustrates some of the standards that apply to the different components in the V2X value chain. In the case of the interface points, there are multiple standards that are applicable depending on the location or application. It is not prudent to have the EV adhere to multiple standards in order to provide the flexibility of connecting to any point. Likewise for EVSE it would be advisable that the interface with the grid and buildings is harmonized to enable this new product to sell in larger volumes   thereby addressing customers’ concerns regarding adequate charging infrastructure.

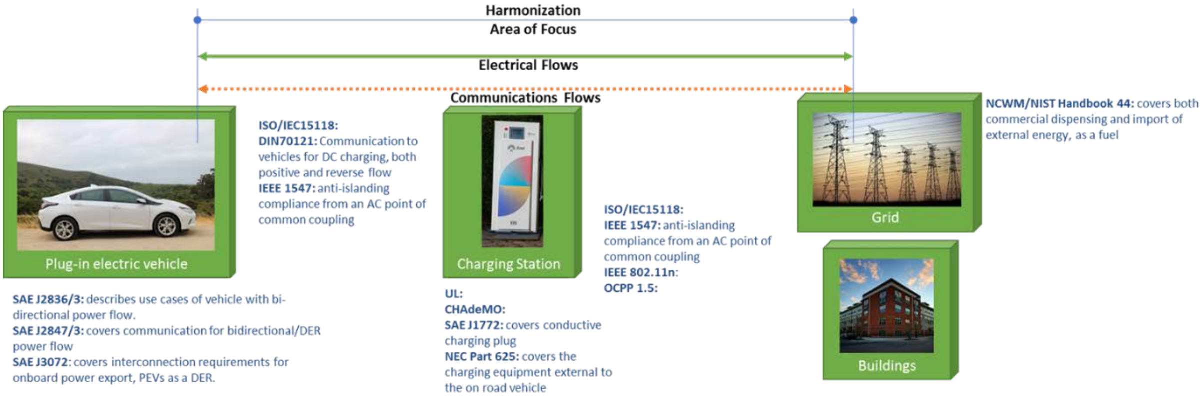

Figure 2: Example of standards that apply to Plug-in EVs, charging stations, the grid and buildings. Source: Task 28 HEV TCP IEA

3.1.2 Battery degradation

It is a fact that battery degradation is also in the spotlight among the public; the battery pack is an important contributor to the total cost of the EV and its degradation effects due to the provision of V2X services are of general interest. In fact, 60% of the respondents in a small survey during a plenary session in the EEVC-2017 (European Battery, Hybrid & Fuel Cell Electric Vehicle Congress, Geneva March 2017) chose *battery degradation* as the main concern about using the vehicle for V2G applications, in front of 13% who chose *revenue* and 27% who chose *range anxiety*. It is interesting to note that the attendees were mostly experts in the field of V2X technologies (automotive industry, energy sector, universities, research organizations, etc).

Battery aging mechanisms can be separated into calendar and cycling fade. Calendar fade is the degradation experienced when the battery is at rest over time while cycling fade is the degradation experienced by battery usage; both often impacting the battery lifetime simultaneously. All aging mechanisms will contribute to either an increase in internal impedance (affecting the battery's ability to deliver power to the system) or a decrease in total battery capacity.

Nowadays there has been no published study which has investigated battery degradation caused by V2X service provision to a sufficiently sophisticated level which takes the interplay of Calendar and Cycling Fade effects and their fundamental drivers of temperature, state of charge (SOC), depth of discharge (DOD), charge rate (C-rate), and time into account. Nevertheless some studies claim that the effect of additional uses of the battery is minimal or even negligible [8] while others claim it to be a barrier to V2X (Bishop et al., 2013).

Truly empirical battery lifetime analyses would require time scopes of 10 years or more, which is both impractical and would be rendered obsolete at completion as battery technology is improving rapidly. Due to these challenges, hi-fidelity semi-empirical electrochemical models have been developed which aim to model fundamental electrochemical phenomena mathematically while extracting rate relationships from what limited degradation data is available ([9], [10], Gyan, 2015; Gyan et al., 2013; [11],; Smith et al., 2012; [12],;[13], 2011).

Research has proved that while high temperatures trigger more calendar-life loss (chemical degradation), low temperatures and high charge rates induce more cycle-life loss (mechanical degradation) [13]. To minimize calendar fade while the battery is at rest, a low SOC and a low temperature should be maintained. Figure 3 shows the effects of temperature and SOC on a stored Li-ion battery. It can be seen that high temperatures and SOC significantly decreases the expected life of the battery. A battery stored at 100% SOC would have an expected life of 14 years at 40 degrees Cº however this drops to only 4 years with an increase to 50 degrees Cº. Furthermore, the same battery with an expected 14 year life at 100% SOC would exhibit a life of 20 years or longer if stored at 50% SOC.

In order to minimize cycling fade while the battery is in use, a low temperature, low C-rate, and a low DoD centred around an optimal SOC point should be maintained. The conclusion is that the state of charge and temperature at which a battery is at rest will have the most significant impact on overall life fade regardless of how the battery is used.

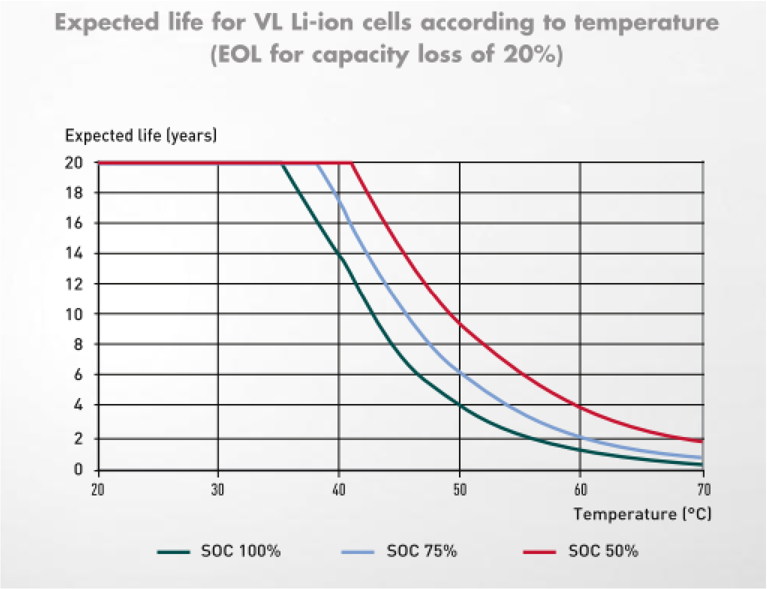

Figure 3: Calendar fade for battery storage conditions (Source: Saft, 2014).

3.2 Market and Regulation

Technology and service providers need requirements and process clarity to establish business models that can capture the program values; rules and business processes must be clear. Stakeholders expressed uncertainty regarding V2G eligibility in providing grid services, its technical and programmatic requirements, settlement of processes, and signal and messaging processes [3].

On the other hand, so far there is not a real mass market for bi-directional chargers. Subsidies could help the uptake of this technology, but proper cost-benefit analyses including positive externalities would be required in advance.

With respect to frequency-regulation service markets, it is needed to to adapt them in order to allow new distributed energy resources (DERs) (such as controllable loads, EVs/V2G or distributed generation units) to participate through new market players known as *aggregators*.
There are some detected market entry barriers for DERs. To facilitate market entry, the case studies suggest that a combination of different rules would be beneficial. It should be noted that countries are currently in a transition phase and that rules will evolve in the coming years in order to comply with the global networks codes (for example the new European Network Codes).

Table 1 provides a summary of existing barriers (to entry de market, to technological optimization and to fair remuneration) in four European countries (France, UK, Germany and Denmark) and suggests options for their resolution. It shows that there is currently no major issue in the entry market barriers (except long-term contracts for secondary reserves in Denmark) and DERs can participate in the provision of reserves in all four markets. There are minor issues, however, in France and in the UK due to the fact that there is still a scheme to mandate provision by large producers. With respect to the technological optimization, rules should evolve to allow players to provide more flexible products. However, Transmission System Operators (TSOs) might be reluctant to adapt these rules because they may fear to have insufficient reserves, which would affect the security of the system. Finally the major issues regarding the barriers to fair remuneration are the regulated tariff in France, which does not allow DERs to compete with other types of more expensive providers, and the lack of remuneration scheme for the extra-flexibility in most countries.

Table 1: Barriers to entry frequency regulation markets and options for their resolution

Barriers to entry in the market	Options for resolution
• France: limitation of volume provided by DERs, uncertainty about the evolution of the rules, mandatory provision for large producers • Denmark: long-term contract • UK: mandatory provision for large producers. Too many different schemes with inappropriate rules	• Germany/Denmark (R1): no specification of any technical discrimination, all the providers are on the same playing field • All: interoperability among DSOs and telemetry
Barriers to technological optimization	**Options for resolution**
• Germany: High minimum bid size for R2. Week-long product for R1, without variability of volume. Symmetrical product for R1. • UK: minimum bid on FFR scheme of 10 MW. Minimum time of one month, without variability from one day to the next	• France: Implementation of asymmetrical products. Time definition of 30 min., program of provision given on day-head market. Minimum bid of 1 MW • Denmark (R1): minimum bid of 0.3 MW, asymmetrical product, blocks of four hours of delivery, daily auction
Barriers to fair remuneration	**Options for resolution**
• France: regulated tariff, no bonus for extra-flexibility • Germany: pay-as-bid, no bonus for extra-flexibility	• UK: creation of a scheme to remunerate extra-flexibility • Denmark: uniform pricing remuneration

In brief, it is useful to analyse the evolution of market designs in a context where National rules are changing constantly and at different levels due to the will of the European Union to harmonize markets.

Opening frequency-regulation reserves provision to DERs is not without cost for the TSOs. These costs should be assessed, in order to balance them with the potential benefits. However, given the increasing share of intermittent renewables, TSOs, regulators, and governments should anticipate these flexibility issues and explore options for opening markets to new participants. In this case, adequate testing and validation phases and transition periods should be allocated before implementation. The UK is currently a forerunner in validating and implementing flexibility solutions and V2X technologies. .

3.3 User's engagement and demonstration projects

The awareness of the V2X capabilities is, among the general public, still scarce and its value proposition must be understood. Marketing strategies need to be enhanced in order to engage key stakeholders such as EV fleet owners or grid operators.

Large scale demonstration projects are highly needed for showing possibilities; convincing the society, identify user behaviour and acceptance and privacy matters. Especially during the last years, several worldwide V2X demonstration projects have been successfully carried out, which have considered different approaches and objectives. *Table 2* describes the main goals some of the identified V2X related projects have dealt with. Several of them have been developed in the USA. In Europe, Denmark has contributed with most of the V2X projects identified. These projects have achieved to demonstrate V2X potential for EV and renewables integration, better understand V2X capabilities and have showed how EVs can support the power system.

Among the identified V2X related projects, the Danish Nikola (applied research) and its successor Parker (pilot project) could be highlight On the one hand, the Nikola project lasted for three years (2013-2016) with a total budget of 2 million Euros. The main goal of the project was to realize the EVs potential in supporting a stable and economic power system based on renewables and thereby reducing costs for the energy consumer and the electric vehicle owner. The methodology used was to systematically investigate the power and energy services that an EV may provide to the power system. Results showed that the potential earnings with 10kW V2G units could reach up to 120 euro per month per vehicle.

On the other hand, the Parker project started in 2016 and it is expected to finish in July 2018, with a total budget of approximately 1.5 million Euros. Parker represents the next technology readiness level by allowing balancing services to be applied to a fleet of electric vehicles. The main Parker project goal is to validate that contemporary electrical vehicles can participate in advanced smart grid services. Furthermore, the project will take the first steps towards developing a V2G certificate that car manufacturers can apply to mark the vehicles' ability to support the grid. Consequently, the project strengthens Denmark's position as a global pioneer, when it comes to grid-integrated vehicles. Secondary goals are:

- To study the application of services on contemporary EVs, coordinating laboratories and field testing
- To identify, economic and regulatory barriers
- To identify viable business cases
- To promote replicability of the investigated applications across geographies, technologies and user groups
- To investigate the economic and technical impacts on the power system and markets

It is important to stress that all stakeholders are involved in this project. Research and development in the project is carried out as a multidisciplinary collaboration between commercial OEMs, technology providers, fleet owner and customers as well as academic institutions. Some of the projects outcomes suggest a recommendation to push towards 360º grid support ensuring a seamless transition between local and system-wide support across technology, grids and markets and the creation of recognition and visibility around the grid integrated vehicle [6]. Parker will interface with, and be supported by the world's first commercial pilot of series produced V2G cars providing system services, the Frederiksberg Pilot. Such collaborations will contribute to the likelihood of market adoption and ensure that the results will be applicable and re-usable to the power system in Denmark and elsewhere [7].

Table 2: Main goals of some worldwide V2X demonstration projects

Assess both the technical challenge of V2G participation and the potential financial benefit	Focus on the synergies between EV and the power system.
Analyse concepts capacities and methods for testing EV systems and their interoperability within the Smart Grid	Investigate the impact of V2X on EV battery life, the potential to mitigate this impact using a smart supercapacitor module and the economics of V2X
Harmonization of electricity demand in Smart Grids for sustainable integration of electric vehicles.	Study the distribution grid planning and operational principles for EV mass roll-out while enabling DER integration
Prove that series-produced electric vehicles, as part of an operational fleet, can support the Danish power system through power and energy services	Build and deploy six V2G-enabled type C school buses
Connection of electric vehicles to the grid by enabling controlled flow of energy and power through safe, secure, energy efficient and convenient transfer of electricity and data.	develop optimal system solutions for EV system integration, including network issues, market solutions, and optimal interaction between different energy technologies

4 Conclusions

The output of several demonstration projects as well as V2X experts insights lead to the conclusion that V2X technology deployment is being slowed down due to the presence of some barriers in different parts of the whole V2X process.

On one hand, market participation, policies and settlement rules need to be clearly defined. On the other hand, coordination between manufacturers and grid operators is fundamental to ensure a creation of a common marketplace and regulatory framework that enables a transparent, secure and cost-effective flexibility service provision.

Demonstration projects and user’s engagement is needed in order to engage the public and make them aware of the multiple benefits of the V2X technologies implementation. Current V2X projects show the benefits and demonstrate the technical viability.

Finally, a strong focus shall be placed upon the contextualization of V2X through the lense of the modern electricity ecosystem, both through the technological changes which are affecting its operation, and the policy measures which underpin its evolution. Realizing this potential, however, is highly dependent upon regulatory engagement and meaningful reform of a traditional, mature incumbent system which is changing more rapidly than ever before as technology advances.

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