32nd Electric Vehicle Symposium (EVS32)
Lyon, France, May 19 - 22, 2019

DC V2X systems: advantages and evolution

Tomoko BLECH

CHAdeMO Association Europe, Paris, France, info@chademo.eu

Summary

The arrival of mass-produced electric vehicles (EVs) equipped with the DC Vehicle-to-everything (V2X) technology has allowed the validation of many grid services using EV batteries as mobile energy sources on the technical side. V2X systems are evolving with key market trends, including higher-end products for the optimisation of behind-the-meter energy management and models that are more compact and affordable for wider dissemination and aggregation (VPP). There remain however hurdles to be cleared, among which are the hardware costs and variety, certification, market access, standardisation, consumer awareness and business models. Further collective efforts on all fronts, including development of AC V2X, are expected to fully benefit from the learning from the innovators experience.

Keywords: V2G (vehicle to grid), V2H (vehicle to home), EVSE (Electric Vehicle Supply Equipment), infrastructure, standardization

1 Introduction

V2X in the context of electric vehicles is used for "discharging from the EV battery to feed electricity back via a power conditioner (PCS, or a bi-directional charger)," and is also referred to as "bi-directional charging." Depending on "to what" the vehicle discharges, there are various types of V2X systems as described in detail under Section 3. Different acronyms are used by various organisations: CHAdeMO Association has historically used V2X, while V2G is used in countries such as the U.K. and Denmark, and VGI (vehicle-grid integration) is often used in the United States [1]. In this paper, in order not to confuse with mono-directional smart charging (V1G, which can very well be part of vehicle-grid integration) and emphasise the flow coming from the vehicle to various outlets (load/home/building/grid, etc.), we use V2X.

This paper will look back on the history of CHAdeMO V2X standardisation (Section 2), review the evolution of various types of V2X products in the market (Section 3) as well as the V2X demonstrator projects and commercial operations (Section 4), before identifying some V2X product development trends we see in the market, with concrete product examples, and extracting the R&D challenges (Section 5). It shall then compare the AC and DC V2X solutions (Section 6) and explain the state-of-play of international standardisation, before closing with remaining hardware and non-hardware challenges for V2X. Inputs for Sections 2-4 are mainly based on secondary research, while for Sections 5-6, primary data sources (written surveys and email/telephone exchanges with relevant stakeholders) were used to supplement.

2 V2X: the beginning

It is well known that the idea of using EV batteries as mobile energy sources first concretised in the aftermath of the Great East Japan Earthquake in 2011. Among key power infrastructures, gas and water required much time to recover from the extensive damages, but electricity was restored relatively quickly [2], and, while internal combustion engine vehicles waited for the recovery of petrol distribution network via road transport, some one hundred EVs went around for rescue operations.

Automotive engineers saw that the Tsunami victims needed electricity to charge mobile phones and use electric heating devices. This fructified into products soon after: Mitsubishi i-MiEV's vehicle-to-load (V2L) solution and Nissan's Leaf-to-Home (V2H) system, both launched in 2012.

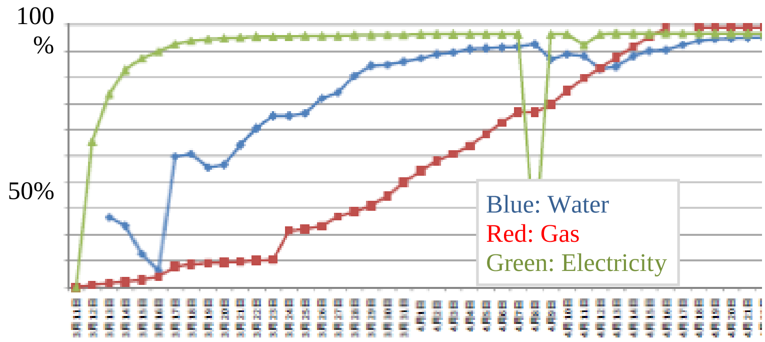

Figure 1: Recovery of infrastructures after the East Japan Earthquake in 2011[2]

CHAdeMO Association standardised DC bi-directional charging and published it in early 2014. A third-party certification system was put in place the year after, and, to date, CHAdeMO remains the only IEC charging standard that has defined the V2X protocol, with series production EVs and certified PCSs readily available in the market.

3 Market evolution of V2X products

Since the first CHAdeMO V2X systems, two new products on average have been launched each year, offering a much broader variety of products in different parts of the world as shown on Figure 2 [3]. The initial products were relatively simple with lower AC output levels for electric devices, but with the heightened awareness of post-disaster resilience and energy optimisation, in parallel with the arrival of more plug-ins equipped with the V2X functionality, a greater number of market players recognised the potential of this domain and the products in the market became more diverse and advanced, offering increasingly reliable V2G connectivity. Today we can find over 20 models. Although it is still no comparison with 260 certified CHAdeMO fast charger models [4], as more and more demo projects and commercial offers emerge, it is no surprise that the product development is gaining traction. There are different types of V2X products, depending on what it's discharged to:

Figure 2: Examples of V2X products available in the market (Products without any flag symbol come from Japan)

- V2V (Vehicle):11-50kW; to rescue stranded EVs
- V2L (Load):1.5-9kW; for output to general electric appliances (cooking, music, lighting, charging, etc.)
- V2H (Home; off-grid): 6-22kW; for optimising behind-the-meter home/office energy management
- V2G (Home/Building; grid-connection): 6-30kW; for ancillary services to support the Grid via VPP

4 V2X project trends

CHAdeMO being the only standardised protocol adapted to V2X with mass-produced EVs and certified PCS available in the market, CHAdeMO member organisations and their products are involved in a great many V2X projects, enabling various types of EV-integration to systems designed according to the user/project needs. A research paper, co-authored by Everoze and EVConsult and jointly commissioned by UK Power Networks and Innovate UK, has identified 50 V2G projects in the world by Autumn 2018, observed that "in 93% of the projects, DC solutions were featured" as shown in Figure 3, and stated that the CHAdeMO-related players "clearly dominate" in these projects, attributing this to "the legacy of the Fukushima disaster, and the successful integration of V2G within the CHAdeMO protocol." [5]

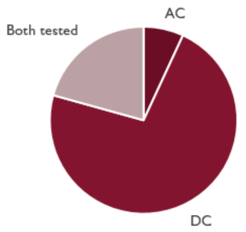

Figure 3: AC/DC solutions featured in V2G projects [5]

Initially these demo projects were quite simple, testing the technical viability of bi-directional charging with a limited number of EVs and PCSs. As the market players gain experience through more varied demo projects and more sophisticated and larger-scale demonstrators began to take place, two principal types of projects emerged: 1) various scales of behind-the-meter energy management optimisation, and 2) grid applications providing DSO services under the VPP (virtual power plant) setting via aggregators, such as participation in the balancing market by synthetic inertia and frequency containment.

4.1 Behind-the-meter energy management optimisation

V2X products were initially conceived as the back-up resource for black-outs/disasters and perhaps as a simple arbitrage tool between tariff levels behind the meter. V2H systems, in the simplest of this form, have already been deployed at over 7,000 Japanese homes, and their higher-end models were adopted by many municipal buildings, hospitals and business buildings for resilience purposes (ex. the Osaka Business Park Building [6]).

In the recent years, such energy optimisation using V2X for both homes and office buildings has evolved into an even more robust and scalable system, integrating other energy production/storage devices such as solar PV and stationary batteries. In this case, the charge/discharge control is optimised at the house or building level, typically not feeding the power back to the Grid, hence the parameters such as reaction time are secondary.

4.2 Grid applications

As the renewable energy source (RES) integration to the Grid accelerates, the notion of using the EV batteries as distributed energy source that provide services to the Grid, has become better known as something that goes hand in hand with the advancement of electro-mobility. The battery capacity for V2G-capable EVs being far greater than that for mono-directional smart charging capacity that V1G vehicles can offer [6], the technical viability, including electricity quality, response time, and quantity of the grid services in monetary terms are being tested under various scenarios.

The most well-known project for such grid applications is likely the series of demonstrators from the Parker Project (2016-2018) at the Technical University of Denmark (DTU), and in particular the world's first fully commercial demonstrator of series-produced V2X-enebaled plug-ins providing system services, the Frederiksberg Pilot. With a number of publications reporting the results of these projects, it is no use to repeat the details, but in this project using 10 Nissan eNV200 vans for two full years, €1,860 average per car/year of market participation revenue (TSO frequency containment) was generated in 2018 from the market [7]. This project led to the actual commercial offers and continue to this day.

While not directly participating in the market given the power deregulation status, such Grid applications using an islanded grid or simulation are tested elsewhere, including the United States, France and Japan.

4.3 Shift of focus

Through these numerous projects around the globe, key stakeholders generally agree that the technical validation for V2G is quite advanced. As the Everoze report puts it after having scanned 50 V2G projects in the world, "V2G has been technically demonstrated for over a decade. The sector's challenge has been identifying a viable commercial model." [8] In search of viable commercial model, large-scale subsidies for demonstrator projects is clearly an enormous push, like in the case of any other innovative technology. InnovateUK is a good example of focusing on the evaluation of the economic, customer and social values that V2X can bring and on practical, concrete project design. Through their Industrial Strategy, the U.K. government, "committed to becoming a world leader in shaping the future of mobility and in the design and development of the clean technologies of the future [9]," awarded a total of £ 30 million to 20 V2G projects with the aim of exploring and trialling both the technology itself and commercial opportunities [10].

Of these 20 projects, eight are real-world V2G trials, with more than 2,700 EVs in V2G operation, including two projects each using 1,000 vehicles, which is quite large as compared to the relatively small-scale V2G demos (1 to100 EV/PCS) thus far. As the grid applications involve "aggregating" many vehicles and collectively providing ancillary services to the Grid, the scale of demo projects is quite important. One of the selected projects, Scirius, led by OVO Energy, an energy provider based in the U.K., will deploy 1,000 V2G chargers (shown on Figure 7) and with EV drivers work to provide grid balancing services using a service platform under real-life scenarios [10].

The other project, e4Future, led by Nissan, runs grid services on a large scale (1,000), deployed by different business consumer groups and controlled by an aggregator platform, stacking multiple services that support a more efficient electricity system and decreasing ownership costs to vehicle users. Evaluating the response of distinct consumer groups to commercial V2G offers, various business cases and reward mechanisms are tested and refined, generating insights on receptiveness and acceptance of V2G operations [10].

5 V2X product trends

Such trends of demo projects and commercial offers naturally influence the directions of V2X product R&D. Today we observe a few trends that seem to go in several directions:

1) More variety of high-end V2X products: development of more complex, larger-scale, higher-complexity products is observed. Examples can be multi-source systems (described in 5.1 and 5.2) integrating storage battery and solar PV, or V2L products with higher power (e.g. 9kW) and higher output quality.

2) More affordable and compact systems (described in 5.3): pursuit of more compact PCS with limited functionality aiming at mass diffusion are emerging, eyeing at the post-FIT home energy optimisation in Japan and at the V2G charge/discharge services in Europe.

In this section onwards, the replies from the qualitative survey we ran (February-March 2019, 8 responses received) [11] are quoted and integrated to supplement our observations and to form our opinions.

5.1 Multi-source systems: integrating PV, storage battery and other components

Both for home and office usage, we see more complex/smart systems, integrating multiple elements such as PV panels on the rooftop, stationary batteries, and V2H stand(s), controlled by the PCS, optimising the charge/discharge of various systems connected to it.

A multi-source system for home, for example, can store the PV-generated energy in the stationary battery if the EV is away. When the car returns, the electricity stored in the stationary battery can be used to charge the EV battery or home electric appliances, depending on the tariffs. Nichicon has released its "tribrid" storage battery system last year in the Japanese market [12].

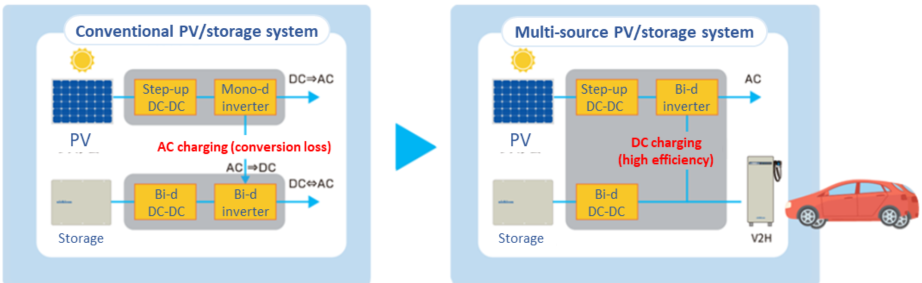

Figure 4: Advantage of multi-source DC charging systems with battery [12] (Mono-d: mono-directional, Bi-d: bi-directional)

Another V2G charger, using a single converter that can charge an EV via a DC link, while also being connected to the AC electricity grid, was developed by Delft University of Technology (TU Delft), Last Mile Solutions and PRE Power Developers [13]. With the possibility of installation at home or collective/office buildings with multiple vehicles each equipped with a PV panel on the parking rooftop, this charger can provide DC fast charging (10 and 20 kW, compared to 3.3-6kW of AC) using a bi-directional converter (IPR) and feed both mono-phase V2L as well as 3-phase V2G services, aiming to bring down the charging costs for the EV owner [14]. Energy generated by PV is stored directly to the EV battery (DC-DC), avoiding conversion losses (or taxation) to be incurred. By installing together with PVs, the payback time for PV is drastically reduced, encouraging local and behind-the-meter production and consumption.

According to PRE Power Developers, there have been several challenges in this R&D: costs (bi-directional converter being typically more expensive than mono-directional one, DC connector assembly being more expensive than that of AC), marketing (as this is new and non-existent market), and business model (as energy pricing today does not reflect the congestion of the grid, it does not reward peak load reduction) are some of them. While they keep an optimistic view about the future price trend with the expected volume production, the importance of more demonstration projects, especially large-scale ones, was emphasised to assess the true impacts on the grid [15].

5.2 Multi-vehicle V2X system with fast-charging capability

Connecting multiple V2X PCS, a V2X system that not only controls a multi-vehicle fleet for peak-shaving through V2X but can also fast-charge (say 50kW) when the user needs it, is close to market launch. This product being developed by Daihen and Tepco aims to provide convenient V2X charge/discharge under the business-as-usual scenario, and when the user is in a hurry to use an EV, parallelised DC/DC converters shall communicate amongst each other and ensure fast charging. Inspired by the concept of fast charging stations with multiple dispensers, the system allows higher (or longer) power output and power aggregation when there is need to use an EV with a short notice and works as back-up for emergency situations such as natural disasters and black-outs [16].

According to the R&D team, while the multiplication of V2X connection was already widely accepted, especially for the large-scale fast charging stations, the idea of integrating high-power output in a V2G system is not yet validated in the final product specifications, as the cost of this functionality is still not justifiable for the foreseeable market needs [17].

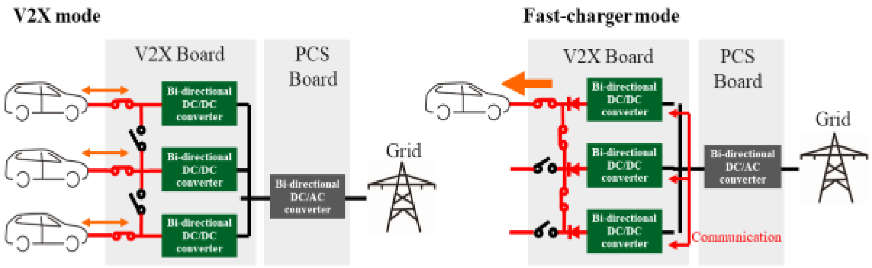

Figure 5: V2X with a fast charging option [17]

5.3 More compact and more affordable V2X for home/office use

On the other side of the spectrum, we also see more compact and more affordable DC V2G products coming to the market. In order to respond to the eternal question of DC PCS being "too expensive", there are various parties trying to beat the price bottleneck or the "2,000 EUR threshold" mentioned by several stakeholders [18], to make PCSs more affordable and comparable with AC chargers.

Figure 6: V2X (eNovates, the New Motion,

Released in 2018, eNovates, the New Motion and PRE have co-developed a new V2G charger as shown in Figure 6. Their charger, named V2X, is "the first V2G wallbox that's wall-mountable [19]" that has "small dimensions, superior efficiency and rapid response times" and is "effortless to install therefore very appropriate for home-charging [20]." This product is 65cmx48cmx32cm in size and weighs about 48kg. Its response time is less than 200ms for one quadrant and less than 500ms for two quadrants. According to the development team, the weight – and price - could not have been reduced further due to "galvanic isolation requirement" by the protocol. [19]

One of the InnovateUK demo projects deploying 1,000 EV/PCS is implemented by OVO energy, who, together with their partner Indra Renewable Technologies Ltd., is also developing a new V2G PCS wall

Figure 7: Vehicle -to-Grid Charger (OVO Energy)

box, aiming to make it available at a lower price as well as lower weight (27kg) compared to the predecessors in the market, enabling a 1-person installation. Making it compact meant cooling was a challenge: this team has used both passive and active cooling solutions to overcome this problem. Given the nascent stage of the domain, the component supplier base also remains small, limiting the choice of products as well as keeping the component price high. OVO is aiming to bring down the price to an “affordable level” but has not announced the price of this charger as of mid-March 2019.

Figure 8: new product prototype (Courtesy of Narcis Vidal, Enel X)

An innovative DC ultra-compact V2X for home use is also waiting for a major launch: in October 2018, a fully Silicon-Carbide MOSFET based DC charger (7.4kW) with V2X functionality was released (Photo on Figure 8) by wallbox, with initial sales planned for mid-2019 [21].

6 AC/DC

CHAdeMO, being a DC charging protocol, has opted for a DC off-board solution by design, but there have been various projects using both AC- and DC-based bi-directional charging. While AC smart charging (mono-directional or V1G) can be a very good initial step to shift the peak load as the EVs ramp up in volume, when it comes to bi-directional charging, CHAdeMO sees greater potential in DC (off-board) V2X, both in terms of technical and commercial viability. AC (on-board) charging may present a seemingly easier connection with a better business outlook given the sheer volume, but as the volume and technical innovations are expected to bring down the costs, DC (off-board) charging can very well become a safer, more robust and flexible option in the long run.

6.1 Technical differences

The grid calls for an AC connection, but the battery is charged in DC; therefore, we need to convert from/to AC/DC in all cases. The main differences between AC and DC V2X are similar to those of AC- and DC-based EV chargers: AC V2X uses the on-board charger (OBC) of the EV to convert AC/DC inside the car, and with DC V2X systems, AC/DC conversion takes place in the external charger (PCS or DCPC) outside of the vehicle (off-board), in which charger/inverter are located. We asked our respondents to name advantages and disadvantages of both systems, as shown on Table 1 (similar responses are bundled).

Table 1: Advantages and disadvantages of AC on-board and DC off-board V2X

	AC on-board V2X	DC off-board V2X
Advantages	▪ Simple and easy connection wherever AC mains is available, with a smaller unit providing potentially better user experience ▪ Lower EVSE cost* ▪ Potentially cheaper total per-unit cost given the vehicle volume* ▪ V2G in all locations, wherever a car is parked	▪ Faster charging with shorter charge time, higher efficiency ▪ Greater number of EVs per PCS ▪ Lower EV price* ▪ Greater electrical safety; Grid connection requirements easier to meet ▪ Direct solar (PV) charging with less loss ▪ Greater scalability, hence greater service options and financial reward to users* ▪ Faster development, as EVSE/PCS manufacturers more agile than OEMs
Disadvantages	▪ Slow charging (mostly single phase) with limited power, low efficiency ▪ Limited number of vehicles served (e.g. 1 or 2 per night) ▪ Higher EV price* and greater EV weight ▪ Difficult to fulfil all grid connection requirements as a system (slow reaction time, e.g. up to 20 seconds, sine waves) ▪ Potentially slower development, especially if OEMs need to adapt specs to each country’s grid code	▪ Limited number of infrastructures ▪ Higher PCS price* although with less space / security constraints ▪ Higher installation costs* ▪ Greater charger size and weight ▪ Multiple standards with more compatibility and testing issues

	▪ Roaming V2G a challenge to local electricity network operators, as difficult to map expected energy flow to system ▪ OBC+conventional EVSE may result in unexpected discharge and harming grid

Overall, while the AC OBC V2X can be an interesting solution in the long run in terms of lower costs and ubiquity the day a great number of V2X-capable plug-ins and EVSEs are in place, as there are no series production AC OBC V2X-capable plug-ins in the market today, the comparison remains theoretical.

It is also difficult to imagine car OEM's adapting vehicle specs according to the Grid Code of each country where the EV is sold, especially if the production volume remains at the current low level. OBC may be well suitable for V2L (AC output), but for V2G providing very fast and reliable ancillary services to the grid, the survey respondents were unsure about the vehicles' capability to provide high-quality power output ensuring electrical safety, as one respondent put it: "(the automakers) are not specialists in frequency regulation or phase adjustments, and I wonder if it makes sense for automakers to strive for high quality electricity output and fit it in the tight space in the car." [22]

6.2 Cost differences

As marked with asterisks (*) in Table 1, depending on where the V2X electronics such as power converter, indicators, and cable assemblies are located, there are implications on the cost items on both the vehicle and the charger sides.

For OBC, all components need to fit in the compact space and be certified as part of the vehicle, qualified for outdoor weather variations, vibrations and other tough conditions [23]. This will increase both the costs and the weight of the vehicle, and these modules or functionality are not even utilised while the EV runs. Relative to the point about adapting EVs to each market's grid code, it is unclear at this time who should control the interactions with the energy system [24], which shall subsequently define the additional costs OBCs should bear. We should also not forget that there would be additional costs to the AC charger side, although limited (mostly software and protections), to adapt to bi-directional flow of electricity [25].

For off-board PCS, the EV side will be lighter and less expensive, but the price of PCS is high today because of the high cost of key parts such as DC connector-cable assemblies (60A) and bi-directional converters [26]. The price will likely stay high until the volume of the PCS market grows much larger to bring down the per-unit costs, or when there is some technical breakthrough (see Section 5,3, for the R&D efforts to bring down the unit price).

There is for sure additional costs for V2X, both for OBC and off-board PCS, depending on the level of charge/discharge capability. For example, on the OBC side, if we compare the end customer price between a 2016 Nissan Leaf (V2X-capable) with a 3kW-OBC and that with a 6kW-OBC, as of September 2015 we see a difference of 1,150 GBP [27] so the cost per kW was 383GBP/kW. For the off-board PCS side, if we took the example of Nichicon's most recent V2H system of 3kW output (VCG-666CN3, 398,000 JPY) and that of 6kW output model (VCG-663CN7, 798,000 JPY), the price difference is 400,000 JPY, or 2,708 GBP, from which we obtain 903GBP/kW [28]. For both cases, with higher-power bi-directional functionality the price shall rise.

Again, as we do not see any series production OBC-equipped plug-in vehicles it is impossible to compare these incremental per kW costs with those of theoretical incremental costs of an EV with various power level OBCs and V2G-enabled AC chargers, but an industry expert mentioned the potential "lower cost of adding an inverter to a car than building a V2G charger,"[29] to which another agreed "with a much greater volume, the commercial price for OBC may decrease more quickly, while DC PCS will remain relatively high as it requires additional costs such as installation costs." [30]

There are is also the questions of volume for DC V2X. In the case of Japan, where the V2H PCS was introduced already some 6-7 years ago, historically around 5% of all EV buyers invest in the V2H system. This ratio of EV : PCS of 100 : 5 limits the number of V2H units sold and the scale effect is not evident after 8,000 units sold [31]. Japan also has its specific situation, where V2H is marketed more for resilience / back-up purposes resulting in EV drivers purchasing V2H PCS as if it were an earthquake insurance. When the market penetration of PCS improves and the volume and innovation bring down the price of PCS, some experts predict the PCS price to become "cheaper in the end than AC OBC [32]", and/or potentially leading to "a non-AC charging future, where OBC could be removed from the vehicles altogether [33]," presenting a complete opposite view from the AC OBC advocates.

6.3 Future prospects

For now, the PCS price remain relatively high and the number of both V2X-enabled EVs and PCSs remain limited to benefit from the economy of scale. On the other hand, it is generally understood that "there remains significant interest in AC, with more AC compatible vehicles expected over the coming years [34]" as pointed out in the Everoze report. However, as there is no mass-produced and readily V2X-capable EV in the market, the number of bi-directional-flow capable AC charger is also very limited, and we are not able to make a fair comparison with reliable data. As the EV adoption accelerates and when the EV OEMs decide how (or whether) to deal with V2X, we should be able to run a better cost analysis/simulation of AC OBC vs DC PCS, with various other parameters, which shall deserve a whole new article. In any case, CHAdeMO, being an advocate of pushing forward electro-mobility in a collaborative manner, hopes that V2X technology shall flourish through both AC OBC and DC PCS channels, achieving the common goal of better energy management (and financial returns) for all.

7 International standardisation

The international community of experts are discussing the standardisation of V2X-related standards. As mentioned in Section 2, CHAdeMO has already standardised DC bi-directional charging and published it in 2014, but as of the time of writing this article, CHAdeMO is the only international DC charging standard to have done so. Stakeholders hope that the discussions amongst the experts will bear fruits as soon as possible, finalising the relevant standards in the most harmonised way possible to move forward.

7.1 State of play

The IEC standards for DC charging stations (IEC 61851-23 and -24) are under revision to include bi-directional operations based on the CHAdeMO standard. As of March 2019, the IEC's TC69, the leading committee for this revision work, aims to publish this in May 2020 [35]. Indeed, the technical standardisation to connect the EV/EVSE to the energy system remains an issue, according to our survey respondents. "OCPP (Open Charge Point Protocol) 2.0 is a good step," says Menno Kardolus, PRE Power Developers, "but there is no finalised and published standard that defines the communication between EV/EVSE/Power system." Paul Codani, Nuvve, agrees that we need to "develop communication standards with low latencies for grid services" to achieve "an overall communication chain that will enable a 2-second response time for fast responding services. [36]"

In Europe there is a movement to coordinate authentication, payment and grid interface around ISO/IEC15118 Ed.2, whose various parts are expected to be published over the time frame of 2019-2020 [37]. CharIN e.V., a group developing and promoting the CCS protocol, has announced in November 2018 that the group shall use ISO/IEC15118 and aim to achieve V2G around 2025 [38], more than 10 years after the publication of CHAdeMO.

Contrary to the holistic approach of ISO/IEC15118 addressing an array of charging-related services, CHAdeMO's strategy is to remain light, flexible and compatible with any new and innovative technologies by prescribing only the minimum requirements for EV-EVSE communication. Working with all means of communication including 3G, 4G, and Wi-Fi, CHAdeMO can fit in any eco-system regional stakeholders decide to define. Should some regional market(s) decide to align on ISO/IEC15118, for example, CHAdeMO members will make themselves compatible with this.

7.2 Going forward

As shown on Figure 8, there are various other standards around V2X, beyond ISO/IEC15118 and IEC61851 and 61850, all of which define the EVSE-EV communication. For example, above the EVSE or charging station controller, IEC63110 (Protocol for Management of EV charging and discharging infrastructures; OCPP2.0 is part of this) and IEC63119 (Information exchange for EV charging roaming service) are in the making (aimed at publication in May 2020 for 63110 and August 2019 – March 2022 for 63119) [39], and IEC62909-2 (Bi-directional grid connected power converter) was just published this year, which applies to both the multi-source V2X system and multi-vehicle V2X system with fast charging capability, described under Sections 5.1 and 5.2 of this paper. This standard adds to the list of distributed energy sources - PVs, windmills and storage batteries, among others - the V2X-related use cases, so that the legislators and energy market players can factor in electro-mobility in their market design of post- energy market deregulation. Add to that IEC 62746-10-1 (a minimal data model and services for demand response (DR), pricing, and distributed energy resource (DER) communications; OpenADR) and IEEE 2030.5 that define the characteristics of the communication network to facilitate common information exchange between electricity service providers, aggregators, and end users (both already published) …and the list goes on.

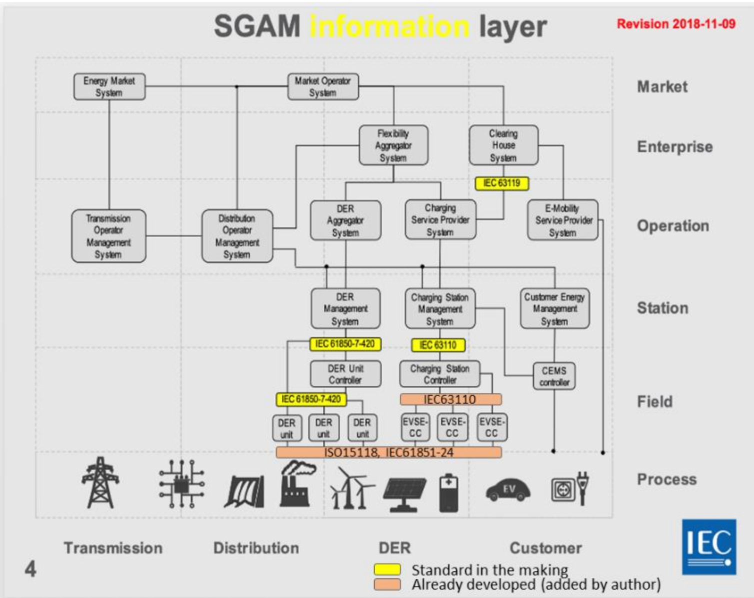

Figure 8: Smart grid architecture model (SGAM) Information layer visualisation (IEC)

These streams of standardisation work are in good hands of the global experts, though we feel it important that we emphasise that they stay technologically neutral and inclusive in these discussions in order not to penalise early adopters (EV drivers and CPOs alike) and harmonise in the best possible way. It is the only way to ensure healthy competition that shall accelerate the adoption of the best technology for all stakeholders, notably for the consumers. CHAdeMO organisation members are making active contributions in all the aforementioned EV charge/discharge-related international standardisation fora, needless to say.

8 Conclusion

As we reviewed the advent of more and more V2X systems in the market, we identified two key trends, going in different directions: higher-end systems and more affordable simplified models. This in itself is a testimonial that V2X systems are diversifying as this gets increasingly more attention and acceptance from the industry players as well as consumers.

Both DC V2X and AC OBC V2X systems have advantages and disadvantages, but the DC systems today have many more "proven" advantages over AC – as it is already proven as technology with not only demo projects but commercial project experiences – and experts say that DC offers better quality of output to the grid, including greater efficiency, scalability, and safety, as well as faster response time. Nonetheless, further demonstrations and productisation of AC solutions may prove these wrong, which would be welcome as that shall give both the car OEMs and the EV users greater options regarding V2X services.

In terms of the V2X hardware, some challenges that remain to be solved are identified through our survey. The biggest challenge today is that the DC V2X hardware costs (and weight) must come down (with the immediate target of breaking the "2000EUR threshold" for simpler versions), and for this, several conditions need to be met: first of all, more volume is needed for the economy of scale to kick in, which will eventually bring down the prices of key parts such as connector assemblies, leading to a positive spiral of more product varieties and healthy competition. If experts could agree to relax technical requirements on galvanic isolation, it would also help reduce both weight and costs, spurring further the development of the market. The certification process and technical requirements could be simplified at the broader (e.g. EU) level (and not by country) to reduce lead time and costs. Finally, cutting-edge technologies such as silicon carbide (SiC) could also become more affordable and help leapfrog this issue.

Non-hardware challenges are also identified, including market design, standardisation and business models. Relative to the certification point above, market access remains a hurdle, as markets are now being designed for this new concept of participation of highly distributed aggregation of kW-scale resources situated behind retail meters. For example, there is no clear definition of storage units, as "grid rules often address consumers or producers and lacks rules specifically for storage units [40], and grid connection requirements for small generators or storage differ by country "or even by DSOs," and at times connection procedures can be "lengthy and costly [40]. " Not only the set-up, but the operation side presents a problem of double taxation, due to the lack of clear regulatory definition for storage devices. According to the respondents, they are "taxed when the energy is purchased to charge the battery, and again when the energy is sold and exported [41]."

As discussed in Section 7, further harmonisation and finalisation in V2X-related technical standards are needed (15118, 61851, 63110, 63119, etc.) for smooth integration of V2X to the eco-system, creating the level field for collaboration and healthy competition.

Finally, collective efforts to raise consumer awareness and to test further business models have just begun. As this is a new or at times non-existent market, the innovators need to inform, convince and woo other stakeholders and especially consumers (EV drivers) to join in the effort. More voices (and more products, related to the first point about costs) to help in this communication are needed.

References

[1] CAISO, *California Vehicle-Grid Integration (VGI) Roadmap: Enabling vehicle-based grid services* (2014); http://www.caiso.com/documents/vehicle-gridintegrationroadmap.pdf, accessed on 2019-03-13

[2] N. Nojima., Gifu University, *Restorations and System Interactions of Lifelines in the Great East Japan Earthquake Disaster, 2011,* the International Symposium on Engineering Lessons Learned from the 2011 Great East Japan Earthquake, March 2012, Tokyo, Japan，pp.1526-1531

[3] CHAdeMO Association, *V2X products*, https://www.chademo.com/products/v2x-product/, accessed on 2019-02-20

[4] CHAdeMO Association, *full list of certified chargers*; https://www.chademo.com/wp2016/wp-content /uploads /pdf/Certified_charger.pdf, accessed 02-20-2019

[5] Everoze and EVConsult, *V2G GLOBAL ROADTRIP: AROUND THE WORLD IN 50 PROJECTS*, http://everoze.com/app/uploads/2018/10/UKPN001-S-01-H-V2G-global-review-compressed.pdf, accessed on 2019-22-22. Page 9

[6] T. Blech et al, *CHAdeMO V2X protocol: design concept, benefits and world-wide applications*, EVS30, Stuttgart, 2017

[7] Bjoern Eske Christensen, Nuvve Corp, *"Grid Applications: Demonstrating how electric vehicles can support our power system"*, Vehicle-Grid Integration Summit, Risø, 2018-11-21; http://parker-project.com/wp-content/uploads/2018/12/VGI-Summit-Day-1-Parker-Practical-experience-1.pdf, accessed 2019-02-20

[8] Everoze and EVConsult, *V2G GLOBAL ROADTRIP: AROUND THE WORLD IN 50 PROJECTS,* http://everoze.com/app/uploads/2018/10/UKPN001-S-01-H-V2G-global-review-compressed.pdf, accessed on 2019-02-28. Page 9

[9] InnovateUK, https://www.gov.uk/government/news/30-million-investment-in-revolutionary-v2g-technologies, consulted 2019-03-13

[10] InnovateUK, *competition results for the V2G projects with real-world demonstrations*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/681321/Innovation_in_Vehicle-To-Grid__V2G__Systems_-_Real-World_Demonstrators_-_Competition_Results.pdf, accessed on 2019-03-13

[11] CHAdeMO Association, *V2X product and market development survey*, conducted via email, February-March 2019, with 8 responses from Tepco Research Institute, PRE power developers, Nichicon, OVO energy, Nuvve, eNovates, Nissan, and wallbox

[12] Nichicon, *Tribrid home system*; http://www.nichicon.co.jp/products/tribrid/, consulted on 2019-02-29

[13] TU Delft, *"Direct high-speed charging of electric cars by solar panels"*; https://www.tudelft.nl/en/2018/tu-delft/direct-high-speed-charging-of-electric-cars-by-solar-panels/, consulted on 2019-02-28

[14] PRE, *V2G charger module*; http://www.pr-electronics.nl/en/products_service/4/products-charger-modules/, consulted on 2019-03-13

[15] Menno Kardolus, PRE Power Developers, written survey and email exchange

[16] Daihen, *"Development of EV/PHEV fast charge station equipped with storage battery: V2X market entry with TEPCO Energy Partner,"* 2018, https://www.daihen.co.jp/newinfo_2018/pdf/180711.pdf, accessed on 2019-03-10

[17] Koji Utsunomiya, Electrification Promotion Group, Resource Aggregation Office, TEPCO Research Institute, written survey and email exchange

[18] Menno Kardolus, PRE Power Developers, written survey and email exchange, explains that "a commercial solar inverter for outdoor use, made in Germany and using the exact same electronics costs EUR 1,300, so EUR 2,000 is not even that ambitious," 2019-03-01; Marco Landi, InnovateUK, conversation, 2018-03-15

[19] Rob de Vogelaere, eNovates, written survey and email exchange

[20] The New Motion, *"The Future of EV Charging with V2X Technology";* https://newmotion.com/the-future-of-ev-charging-with-v2x-technology, accessed on 2019-02-20

[21] Wallbox, Blog, https://wallbox.com/en/blog/wallbox-takes-the-stage-at-munich-and-paris-fairs/; and Carsifu, *Spanish EV charging maker Wallbox to debut first home DC charger*; https://www.carsifu.my/news/spanish-ev-charging-maker-wallbox-to-debut-first-home-dc-charger; accessed on 2018-10-24, confirmed through email exchange

[22] Respondent who wishes to stay anonymous, written survey and email exchange

[23] Menno Kardolus, PRE Power Developers, written survey and email exchange

[24] Tom Pakenham, the OVO Group, written survey and email exchange

[25] Paul Codani, Nuvve, written survey and email exchange, on their chargers, https://nuvve.com/v2g-chargers/

[26] Menno Kardolus, PRE Power Developers, written survey and email exchange

[27] Nissan News, *"New longer range LEAF: 2016 LEAF 30 kWh delivers 155 mile range,"* 2015, https://uk.nissannews.com/en-GB/releases/release-137082-new-longer-range-leaf-2016-leaf-30-kwh-delivers-155-mile-range, accessed on 2019-02-27

[28] Nichicon, "*EV Power Station General Brochure March 2019"*; 2019

[29] Tom Pakenham, the OVO Group, written survey and email exchange

[30] Koji Utsunomiya, Electrification Promotion Group, Resource Aggregation Office, TEPCO Research Institute, written survey and email exchange

[31] Hiroshi Saeki, Nissan, "*Worldwide usage of CHAdeMO V2X and certification,"* IEA Task28 conference, Jeju, South Korea, 2017

[32] Menno Kardolus, PRE Power Developers, written survey and email exchange

[33] Tom Pakenham, the OVO Group, written survey and email exchange

[34] Everoze and EVConsult*, V2G GLOBAL ROADTRIP: AROUND THE WORLD IN 50 PROJECTS, http://everoze.com/app/uploads/2018/10/UKPN001-S-01-H-V2G-global-review-compressed.pdf,* accessed on 2019-02-28

[35] IEC, *TC 69 (Electric road vehicles and electric industrial trucks) work programme dashboard*; https://www.iec.ch/dyn/www/f?p=103:23:9920138081360::::FSP_ORG_ID,FSP_LANG_ID:1255,25, accessed on 2019-03-13

[36] Menno Kardolus, PRE Power Developers and Paul Codani, Nuvve, written survey and email exchange

[37] IEC TC69, *dashboard*, https://www.iec.ch/dyn/www/f?p=103:23:10618319527657::::FSP_ORG_ID,FSP_LANG_ID:1255,25, accessed on 2019-03-13

[38] CharIN e.V., “The five levels of Grid Integration” - CharIN e.V. Grid Integration roadmap published, https://www.charinev.org/news/news-detail-2018/news/the-five-levels-of-grid-integration-charin-ev-grid-integration-roadmap-published/, Grid integration levels Roadmap (PDF); https://www.charinev.org/fileadmin/Downloads/Papers_and_Regulations/CharIN_Levels_Grid_Integration.pdf, accessed on 2019-02-28

[39] IEC, *TC 69 (Electric road vehicles and electric industrial trucks) work programme dashboard*; https://www.iec.ch/dyn/www/f?p=103:23:9920138081360::::FSP_ORG_ID,FSP_LANG_ID:1255,25, accessed 2019-03-13

[40] Paul Codani, Nuvve, written survey and email exchange

[41] Paul Codani, Nuvve and Menno Kardolus, PRE Power Developers, written survey and email exchange

Authors

Tomoko Blech is the Secretary General of CHAdeMO Europe since 2013. A former marketing strategy consultant and business reporter with work experience in Asia-Pacific, U.S.A. and Europe, she oversees the overall activities of CHAdeMO Association in Europe and beyond, including public relations, institutional communication, member services and event coordination. Tomoko holds a B.A in International Relations from the University of Tokyo, and Master in Business Administration (MBA) from the University of California, Berkeley.