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CHAdeMO's V2G technology: an accelerator of shift towards carbon neutrality

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Summary

As demonstrated at COP26, the world is accelerating its move to decarbonisation and expectations are running high for the vehicle-to-grid (V2G) technology. By allowing EVs to become mobile power sources, V2G offers diverse benefits to accelerate the CO2 emissions reduction and the shift towards carbon neutrality.

Since the publication of CHAdeMO protocol in 2014, there are over 30 bidirectional charger models and about a dozen plug-in vehicles have been introduced to the market. This led to over 100 demonstration projects[1], through which we begin to see some evidence that V2G could have substantial economic, social, and environmental benefits to EV users, power systems and the society as a whole. Yet, there are remaining barriers to the mass adoption of V2G and further in-depth research would be needed.

Keywords: V2G (vehicle-to-grid), VGI (vehicle-grid-integration), carbon neutral, renewable energy, decarbonisation, CO2 reduction, energy efficiency

1 Introduction

The electrification of transport, if powered with renewable energy sources (RES), can offer an efficient way to reduce CO2 emission and enable the shift towards carbon neutrality. However, if everyone goes electric and plugs in at the same time in the evening peak hour, the grid may not be able to cope with the increased peak demand, which may require further grid reinforcement investments. Besides, more RES integration brings the issue of intermittency caused by variable power generation.

Then, how can we decarbonise the transport sector with an increasing share of renewable energy sources in the energy mix? Bidirectional EV charging, typically called vehicle-to-grid (V2G) or vehicle-grid-integration (VGI), can support to make it happen. Allowing the vehicle's battery to store and release energy and to provide more services than as a means of transportation, EVs can become 'batteries on wheels' that can supply power wherever needed, be integrated in the home or office building's energy management system, or eventually connect with the grid.

CHAdeMO Association has standardised its 'CHAdeMO V2X (vehicle-to-everything) protocol' in 2014 and remains the only international standard that provides the technical specifications, testing protocols and third-party certification in place. Since the publication of the 'CHAdeMO V2X protocol', there are over 30 bidirectional charger models (see Figure 1) and a dozen or so plug-in vehicles introduced to the market.

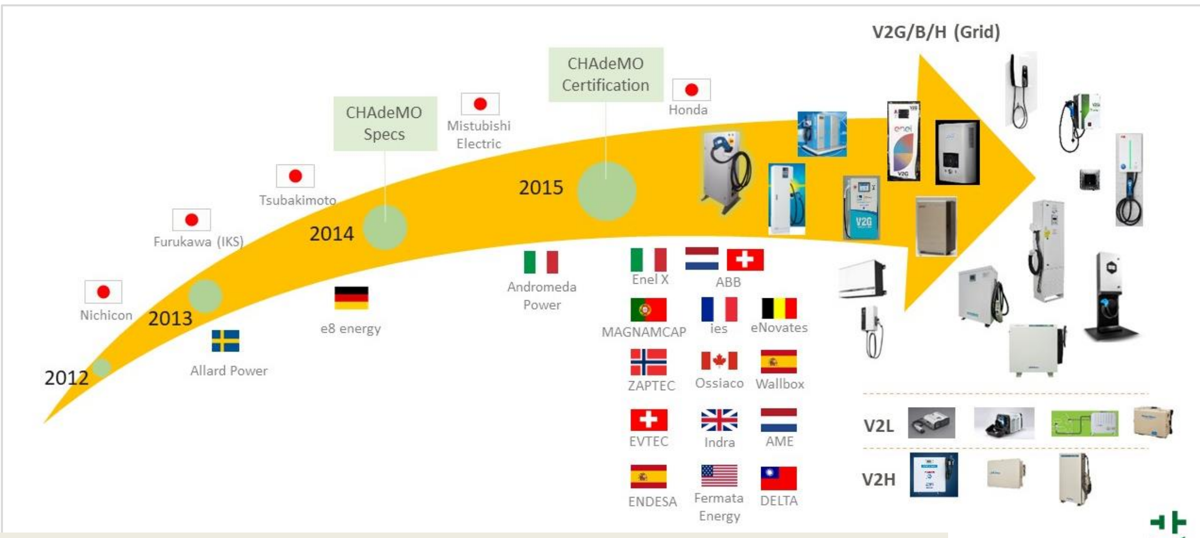

Figure 1. CHAdeMO V2G protocol and product development

As the number of products increased, so did the number of projects: there are over 100 V2G demonstration projects in 24 countries. Through these projects, the validation of V2G technical viability is quite advanced and research projects on the economic, social, and environmental benefits of V2G are being demonstrated.

Looking at the achievements as well as barriers and lessons learnt identified through the demonstration projects from Europe and elsewhere, this paper describes the project findings and explore how the mass-adoption of V2G can be advanced.

1.1 V2G/VGI applications

V2G/VGI is the concept of discharging EV batteries so that the EVs can be used for a secondary purpose other than that of a means of transport. It applies to a wide range of use cases, as shown in Figure 2.

Figure2. V2G/VGI application examples

- V2L (Vehicle to load) to provide power at camping/construction sites and other mobile energy source needs such as in case of an emergency.
- V2H (Vehicle to home) to optimise home energy management, especially effective when combined with PV and/or heat pumps and/or storage battery.
- V2B (Vehicle to building) to improve the energy management of office /collective residential buildings.
- V2G (Vehicle to grid) to provide advanced services to the grid, typically via an aggregator.

In this paper, V2G is used as a generic term for these different applications.

2 V2G demonstration projects

According to V2G-Hub, an online platform mapping out V2G projects around the world, there are over 100 V2G demonstration projects in 24 countries to date. Today, the focus of on-going and upcoming projects is shifting from technical demonstration to identifying and pursuing viable business models to prepare for the V2G mass-market development. We shall present some project examples as a glance into the variety and scale of projects from different regions.

2.1 Resilience and disaster relief: Blue Switch Initiative (Japan)[2] [3]

Japan is a disaster-prone country and enhanced resilience is essential, especially when it comes to maintaining and restoring critical lifelines such as the electricity grid. Nissan's Blue Switch initiative (2018-present) is an interesting case as a model of cooperation between local authorities and industry stakeholders for utilising EVs as a back-up emergency energy source that is easily replicable in other disaster-prone regions of the world.

The case of Typhoon No. 15 in Chiba Prefecture is noteworthy because it is one of the largest deployments of EVs as emergency power sources and demonstrated the social value that V2G could deliver as part of the local government's disaster management plan. In September 2019, Typhoon No. 15, the most powerful typhoon on record in the Kanto Region in Japan, inflicted extensive damage to various areas, causing over 930,000 households to lose power. In Chiba Prefecture, which was in the typhoon's path, blackouts continued for an extended period of time in multiple dotted zones because both damage to the power system and traffic interruptions caused delay in the recovery work. Nissan alone provided over 50 EVs and 50 V2L devices to the local authorities as well as to medical and welfare institutions, where people were having difficulty in evacuating.

Electricity provided for lighting/ fan operation/ smart phone charging (photo by Nissan)

The electricity generated by EVs was used to help support the post-disaster recovery work and people's daily lives.

Today, more than 10,000 Japanese households have installed bidirectional systems linked to the energy management systems (HEMS/BEMS) of their houses and flats as backup in the event of power failure.

As to the Blue Switch initiative, at present, more than 100 municipalities and business entities have signed cooperation agreements. Building on the achivement made during the 2021 Typhoon Rai[4] in the Phillipines, the Blue Switch model is now going to be also expanded to other ASEAN countries to help communities and peoples, from disaster relief efforts to providing energy management solutions[5].

The Nissan LEAF charging up mobile phones during the 2021 Typhoon Rai in the Philippines.

2.2 Renewables integration to the island grid and usage optimisation (USA)[6] [7]

In isolated territories like island regions, energy supply can be costly and taking full advantage of the RES can be a challenge. Jump Smart Maui Project on the island of Maui, USA, started with the objective of reducing expensive petrol supply and benefitting from the solar power abundant on the Hawaiian isles.

On top of 13 fast chargers and 200 normal chargers to serve the 300 EVs for the participants, the project installed 80 bidirectional chargers at 80 homes and small offices to demonstrate managed EV charging as well as advanced grid services (frequency regulation) from 2011 to 2017. They scheduled EV charging and discharging according to the power supply forecast and succeeded in reducing peak loads and pushing most of EV charging to later during the night. The project also confirmed the effect of frequency regulation through smart management of bidirectional chargers, which was commercialised after the project ended.

2.2 For a greener grid: energy market participation project (residential) (UK)

Funded by the UK's Department for Business Energy and Industrial Strategy (BEIS) and the Office for Zero Emission Vehicles (OZEV) in partnership with InnovateUK, Project Sciurus[8][9], aggregating 320 real homes across the UK, has been the world's largest residential real-life V2G trial to participate in the UK's Piclo demand-response market, providing services to both the market and distribution network (UK Power Networks).

Participating customers installed a bidirectional EV charger at home and were paid for all energy exported from the property (the results are explained in Section 3). All chargers were monitored, and the best charging schedules were decided based on the customer needs, energy wholesale and balancing market. The use of EV as a transport tool was guaranteed as the EV user could set 'ready by' times and as well as a preferred charging range for the battery. They could also boost charging in the event they needed to use the car on a short notice. They have built a platform to aggregate and optimise V2G units, created a customer app as well as the first UK-manufactured V2G charger, achieving significant hardware cost reduction.

2.3 For a greener grid: energy market participation project (commercial fleets) (DK, UK)

While it is more difficult to predict and manage the charging behaviour of private EV owners, commercial fleets present a promising set-up for advanced V2G services. Fleet vehicles represent 40% of total kilometres driven and half of total emissions from road transport in Europe[10][11]. As they typically run on a pre-defined route and can be centrally managed, they are a good fit for electric vehicles and for providing advanced grid services.

The ground-breaking research on this front was the Parker Project[12] in Denmark. From 2016 to 2018, ten commercial vehicles at Frederiksberg Forsyning plugged in at the end of each workday until the next morning, during which time the vehicles engaged in advanced frequency regulation services. Under temporarily relaxed market terms, each one of the ten commercial vans successfully provided a total of 13,000 hours of the demanding FCR (frequency containment reserve) services.

This project has demonstrated that it is possible to optimise market participation without adverse effects to the driving of the commercial vehicles and continues today as a fully commercialised operation.

DTU Electrical Engineering. 2017. *The Parker Project – Grid integrated electric vehicles*. https://www.irena.org/-/media/Files/IRENA/Agency/Events/2017/Oct/EU-Utility-week/The-Parker-Project.pdf

EV fleets in combination with V2G are trialled in several countries including France, Australia, and the UK[13]. In the UK, the e4Future V2G[14] project (2018-22) deployed 58 V2G chargers for commercial/public sector fleets to determine the technical and commercial potential of V2G to support the electricity system. Distribution, transmission, and whole-electricity system models were used to assess system-wide impacts, benefits, and potential revenues from V2G. The project affirms that V2G can contribute to much needed system flexibility and reduce the CO2 emissions and the cost of the electricity system by enabling the improved RES integration and providing more efficient balancing services.

3 Key figures, barriers and lessons learnt

In this section, we will present key figures, barriers and learnings identified through above-mentioned projects and beyond. These findings include both concrete outcomes of the project as well as the results of simulation performed by the implementers. In some cases, the scale of the project was reduced from the project planning phase due to several reasons (e.g. the difficulty in recruiting participants who meet the selection criteria and ready to experience V2G[15]). However, these findings start to validate our hypothesis that V2G can become an enabler of carbon neutrality and the mass adoption of V2G.

3.1 Key figures

We begin to see that the V2G technology presents concrete economic, social, and environmental benefits. While V2G for disaster relief embraces more social values that are not measurable, multiple demonstration projects have quantified other types of V2G benefits in the form of financial benefits (incentives for the users, cost savings for the power grid) and CO2 emissions reduction:

One partner of the Blue Switch initiative, the City of Aizuwakamatsu in Fukushima Prefecture has achieved the CO2 reduction of **1,123kg of CO2 per year** and the fuel cost savings of **¥141,339 (around €1,000) per year** with the seven EVs purchased as part of its public fleet and disaster management plan[16]. Energy management of business entities, another pilar of the Blue Switch initiative, is also producing promising results with various on-going V2B projects. For example, a telecommunications company, NTT West (Nippon Telegraph and Telephone), sought to achieve **the cost saving of approximately ¥890,000 (around €5,000) per year and the reduction of carbon emissions of 9.6t of CO2 per year** for the overall power system with the use of three V2B chargers, three EVs and PV panels[17].

Sciurus Project has seen **over 750MWh of energy offset through V2G[18]**. According to their analysis, if just **26%** of all EVs used V2G today, then the net EV charging demand at the peak could become negative, completely offsetting the potential additional load of the electrification of vehicles.

According to the e4Future Project analysis[19], one million V2G-enabled fleet EVs could achieve **annual cost savings of up to £883m (around €1 billion) and the reduction of carbon emissions of up to 243g of CO2/km per vehicle for the overall power system.** It is regrettable that only 58 V2G chargers and an unknown number of EVs (most likely less than the initial target of 1,000) were deployed at the real-life trial due to the difficulty that the implementers met in recruiting fleet owners eligible for their participation criteria (e.g. a small pool of (V2G-capable) EVs, customer driving profile, charger compatibility with mixed EV fleets, load profile of site, costs/payback period).

Tangible financial benefits for individual EV users are also confirmed in some of these projects. In the case of the Sciurus residential project, the EV users were paid **30p (€0.34)** per kWh of energy exported or **26p (€0.30)** per kWh if they have existing microgeneration. On average, customers have been paid **£80 (€91)** per month in V2G credits, which has resulted in approximately **£30 (€34)** a month net energy bill savings, or **£360 (€411)** per year[20].

The financial return from the commercial fleet projects can be even bigger. In Denmark's Parker Project using ten electric vans, an average revenue of **€1,860** per car per year was made during the 2 years of the project[21]. Analysis from e4Future Project estimates that one million V2G-enabled fleet EVs could achieve annual financial benefits of up to **£1,250 (around €1,412)** per EV, on top of the power system cost savings and carbon emissions mentioned above[22].

3.2 Barriers and lessons learnt

Key figures demonstrate that V2G have the potential to deliver substantial CO2 emissions reduction, energy management, and financial benefits to the EV owners. However, only a few projects have evolved into full-blown commercial operations (e.g. vehicle-to-home and vehicle-to-building applications in Japan, private fleet V2G participation in Denmark, residential V2G in the UK), while others, mostly because of the energy market regulations or business case reasons, remain demonstrator projects, after whose learning new projects are designed to identify sustainable business models and to collectively advance our knowledge and innovation. This section highlights the barriers and lessons learnt during these demonstration projects, as well as the findings and thoughts shared by the speakers of CHAdeMO's V2G webinar series[23].

Technical:

- Hardware costs cost will be a key factor for the wider adoption of V2G. According to the survey[24] conducted by Project Sciurus, ¾ of V2G customers expect the cost of DC V2G charger to be less than £2,000 (around €2,500), while the cost of the installed hardware for the trial was £4,700 (around €5,700) excluding VAT, which indicates that hardware costs need to be reduced further for the wider uptake of V2G. Economies of scale can help bring down the cost.
- AC V2G charging is seen as an option to reduce the V2G cost, but it requires the vehicle-side on-board charger (OBC) to be also bidirectional, which can be both costly and sizable (i.e. extra weight and costs in the car) for the OEMs. Should the vehicle OEMs need to customise their OBC to comply with the specific grid code requirements of each country/region like for PV inverters, it would be yet another hurdle, because as compared to external DC bidirectional chargers, the on-board parts need to clear additional constraints such as vibrations, temperature, and space limitation[25][26].

Commercial & business:

- Incentives for higher plug-in rate is important. According to the feasibility study 'V2GB[27]', if the EV plug-in availability goes up to 75%, a 7kW V2G charger could capture annual revenues of around £436 - four times that achieved with the average plug-in rate, which is 30-40%. The industry needs to offer consumer value propositions that are easy to understand and act on so that the message 'the longer you plug in, the more the financial gain' sinks in. To increase plug-in rates, gamification (e.g. customer point systems) can be a good idea.
- A 'one-size fits all' standardised V2G offer for businesses is difficult to achieve for the moment due to various elements of each user's environment, such as the consumption (and plug-in) patterns, and production capability. To make the most of V2G, it is important to target the right customer segments,[28] which have high plug-in availability with adequately sized EV batteries (**40kWh battery or bigger)** and use solutions that can generate value from grid services and higher wholesale prices.
- Limited vehicle models capable of V2G reduces the choice of customers, which keeps the volume of V2G chargers low and the price points of the hardware high.

Customer-side:

- More guidance and education must be provided to customers (including fleet owners) for V2G to gain public acceptance. The e4Future project, for example, had met difficulty in recruiting participants for trial due to the lack of understanding of V2G and significant time needed to be spent on educating customers before any commitment was made by the potential participants.
- The Sciurus project shows promising signs for customer acceptance and confidence for V2G once they had their initial experience. It indicates that customers' concerns (e.g. battery degradation, costs, car not charged) could be reduced once they have experienced V2G. Comparing the survey results before and after having experience with a bidirectional charger, the majority of respondents expressed they no longer had those initial concerns after the project[29].

Regulatory:

- The grid connection process can be complex and costly, which needs to be more transparent and simplified. For example, in the case of the UK, prior to connecting to the grid, an approval from the distribution network operators (DNOs) is required as V2G chargers are to enable export of electricity to the distribution network. Depending on the details of the connection situation, there may be associated evaluations and design fees from DNOs. These fees can vary from region to region[30].

- The procedure for providing frequency control services was not an easy task in the UK, and a more simplified process is needed, according to the Sciurus project. For example, the UK's National Grid ESO (Electricity System Operator) requires that each unit in the V2G portfolio be individually validated for the V2G aggregators to provide the services. This entails additional efforts and costs as the aggregators must conduct physical field tests each time a new charger is incorporated. As a contrast, Denmark applies type testing whereby a specific type of unit is evaluated only once to provide frequency response services and can be widely deployed once approved. RTE, France's transmission system operator (TSO), has recently certified the participation of a CHAdeMO-based V2G system to provide frequency control services[31] for the first time.

4 Conclusion

We see in these emerging reports from large-scale demonstration projects that V2G can provide substantial economic, social, and environmental benefits. Whether you start at an individual energy use optimisation level or scale up to megawatt capacity, V2G contributes to jumpstarting a positive spiral for achieving carbon neutrality. By reducing electricity bills, V2G makes EVs more affordable (lower total cost of ownership) and boosts the uptake of EVs, which reduces the CO2 emissions from the transport sector. Aggregated EVs will then be able to support the integration of renewal energy sources in the power grid, help reduce the flexibility investments otherwise needed as well as CO2 emissions from the power systems, while rewarding the EV users with incentives.

Yet, if V2G is to make a significant contribution to a carbon neutral society, much more needs to be done. As presented in the previous section, there remain numerous technical, commercial, customer-side, and regulatory barriers. To address these barriers, considering the lessons learnt through the demonstration projects, key areas for improvements include: more product variety, more economic solutions (e.g. economies of scale), simplified regulatory framework (e.g. grid connection process), easy and simple customer proposition (e.g. clear revenue streams), and more customer education. Each of these areas shall deserve further in-depth research, but we were unable to identify many of them in the public domain. CHAdeMO Association hopes to continue monitoring the V2G development and serving as a platform of collaboration that create and innovate solutions for the transition towards carbon neutrality.

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