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CHAdeMO V2X protocol: design concept, benefits and world-wide applications

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Summary

Increase in the share of renewable energy sources (RES) into the energy portfolios drives emissions reduction but comes inevitably with the intermittency issue. Electric vehicles (EVs) equipped with Vehicle-to-everything (V2X) technology, with ability to store and release electricity, represent today around three times higher capacity per vehicle in its potential to help mitigate variable RES generation as compared to EVs without V2X. As the only international protocol to standardise the V2X functionality for production EVs, CHAdeMO contributes through demand response in a variety of V2X demonstration projects as well as in commercial applications.

Keywords: EV (electric vehicle), renewable, smart charging, standardization, V2G

1 V2X technology background

The transport sector, responsible for almost a quarter of the total emissions in Europe and almost exclusively dependent on oil, is going through major changes, in which EVs can play a key role in emissions reduction. EVs, while efficient and clean, remain relatively expensive for many consumers, because the high upfront costs of investing in a new EV today cannot be justified.

The utility sector is also under pressure. The Renewable Energy Directive (2009/28/EC) requires of Member States that, by 2020, 20% of their energy (27% by 2030) and 10% of their transport fuel come from renewable energy sources (RES), urging European utilities to accelerate RES energy integration. However, variable RES, such as wind and solar, raise the issue of intermittency in the energy systems.

Vehicle-to-everything (V2X) technology is ready to accommodate the intermittency of renewables as well as to encourage EV adoption by providing market-based financial incentives for the users, addressing both RES integration issues and the transport emissions reduction goals. Thanks to their batteries that can store and release energy, EVs can be used to balance the renewable energy supply fluctuations and to help manage grid frequency control. More concretely, V2X-enabled EV batteries can be used as devices to charge in periods of RES overproduction and to discharge a considerable amount of electricity when there is a risk of power shortfall, in a flexible and quick manner. It is a win-win technology, as the EV owners can provide important services to the grid operator when not even driving them, and bring economic benefits to all.

CHAdeMO Association, having noted the great potential of EVs in helping to stabilise the grid, was the first international charging protocol to standardise this technology. In this article, we shall assess the scale of RES integration risk, explore the V2X benefits, explain the CHAdeMO V2X design concept and give an overview of V2X demo projects world-wide.

2 RES risk assessment and V2X impact

RES energy is clean and improves energy security and environmental sustainability by reducing our dependency on fossil fuels as well as reducing CO2 emissions. However, variable RES, such as wind and solar, comes with the issue of intermittency, which requires flexibility in the energy systems both on the supply and the demand sides.

On the supply side, in the case of RES-based electricity, such flexibility ensures compliance with the power systems' paradigm that the generation and the load must be balanced on a second by second basis. Flexibility of electric systems can thus be defined as the ability on the generation side to follow quickly and efficiently the fluctuations of the net load, which is the total load after accounting for variable RES power output (i.e. the difference between total demand for electricity and RES power output). The net load must always be positive to avoid negative electricity prices and therefore financial losses. Otherwise, variable RES need to be curtailed, stored or exported. The surplus from wind power and PV (solar) can be balanced by exporting excess capacity to adjacent markets – at least in the EU – to a certain extent. Dispatchable back-up supplies, quick to ramp up and down according to net load fluctuations, are also part of the solution.

On the demand side, smart charging and V2X technologies are expected to contribute to smoothing the power load through both excess supply absorption as well as load shedding. In this section, we shall first quantify the scale of the imbalance risk associated with wind power and PV on the supply side, evaluate the demand side solutions by comparing the effects of smart charging with V2X, and thus demonstrate that the flexibility capacity per EV is significantly higher for V2X-enabled EVs.

2.1 Scale of imbalance risk: wind power and PV

Fig. 1 is the electric power curve in Europe from 2015. Though it shows that the aggregated power consumption is relatively constant across the day, in view of the geographical, social and climatic diversity of Europe it is naturally presumed that there are occasions at a local level when the imbalance risk increases. Indeed, the different activity profiles of European countries as well as seasonal weather variations result in a wide variety of peak demand for electricity occurring at different times of the day and of the year, as shown in Table 1. Fig. 1 also shows that the demand is much higher in winter than in summer in Europe. Considering the longer daytime hours coupled with lower consumption, the importance of flexibility in balancing the grid is evidently higher during the summer time in Europe. As more variable RES are expected to penetrate the grid in the coming years, such surplus and imbalance risk is anticipated to further increase accordingly.

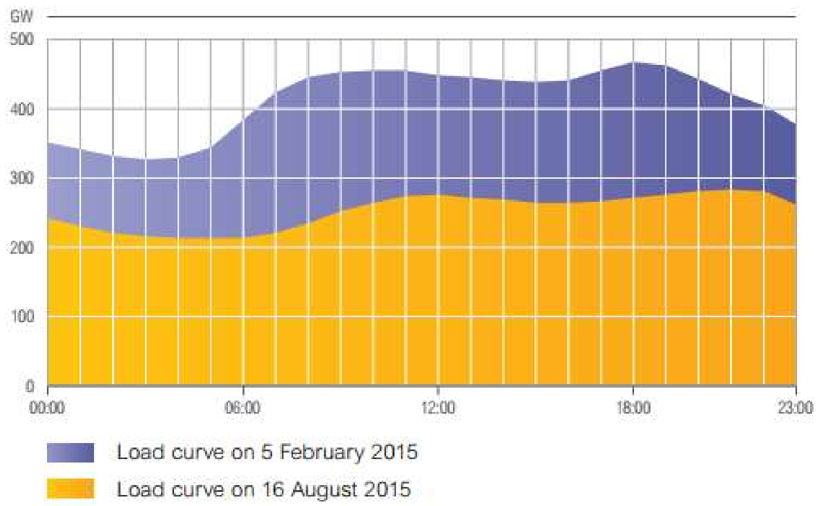

Figure 1: ENTSO-E load diagram on the days of the highest and lowest load values [1]

Table 1: ENTSO-E Highest and lowest hourly load values of each country (2015) [1]

	Highest load Date	Time[2]	value (in MW)	Lowest load Date	Time[2]	value (in MW)
AT	24.11	17:00	11386	23.08	03:00	4722
BA	31.12	17:00	2105	02.05	03:00	858
BE[3]	22.01	18:00	13129	02.08	06:00	6556
BG	08.01	18:00	7100	07.06	05:00	2781
CH	12.02	08:00	10155	02.08	06:00	4875
CY	04.08	14:00	954	01.06	05:00	270
CZ	09.02	12:00	9982	02.08	05:00	4428
DE	24.11	17:00	79893	25.05	03:00	36146
DK	10.06	10:00	5844	26.04	03:00	1915
EE	07.01	15:00	1394	27.07	04:00	498
ES	04.02	20:00	40324	25.12	05:00	18041
FI	22.01	07:00	13584	19.09	02:00	5194
FR	06.02	18:00	91611	16.08	06:00	29299
GB[4]	19.01	18:00	59576	12.07	06:00	20871
GR	30.07	12:00	9813	25.10	14:00	3599
HR	22.07	12:00	2950	22.06	05:00	1160
HU	08.07	12:00	6106	25.05	05:00	2857
IE	14.01	17:00	4662	19.07	07:00	1804
IS	25.02	13:00	2327	08.08	06:00	1622
IT	22.07	15:00	59648	26.12	04:00	18785
LT	07.01	16:00	1748	12.07	04:00	784
LU	07.07	11:00	1087	02.08	03:00	339
LV	08.01	15:00	1225	25.06	03:00	438
ME	22.07	13:00	583	11.05	04:00	225
MK	08.01	23:00	1439	02.06	03:00	530
NI[5]	14.01	18:00	1737	14.07	06:00	538
NL	06.01	17:00	17761	02.08	06:00	8892
NO	04.02	08:00	22530	23.08	05:00	9527
PL	07.01	17:00	23069	26.12	00:00	10143
PT	07.01	20:00	8618	05.04	07:00	3419
RO	08.01	18:00	8488	12.04	14:00	3799
RS	31.12	17:00	6879	10.05	05:00	2486
SE	05.02	17:00	23395	19.07	05:00	9242
SI	05.02	11:00	2086	01.05	03:00	960
SK	25.11	17:00	4145	02.08	05:00	2231
ENTSO-E[6]	**05.02**	**18:00**	**528093**	**16.08**	**06:00**	**240673**

Using the figures for the average power generation per year and the net generation capacity of wind power and PV from the electric power generation forecast in 2020 [2], the average power generation per hour and the average rate of expected capacity utilisation that may potentially cause the surplus output in 2020 are calculated as below. This demonstrates that despite the larger capacity of total nominal wind power facilities compared to PV, the latter presents a higher surplus risk.

Wind

- Average power generation 462,720 GWh/year = 52.7 GW
- Net generation capacity 207GW
- Average rate of expected capacity utilisation 25%

PV

- Average power generation 154,722 GWh/year = 70.5 GW
- Net generation capacity 136GW
- Average rate of expected capacity utilisation 52%*

**NOTE:* Assuming the average duration of sunlight to be 6 hours/day, we use 6/24 of the net generation capacity and arrive at the average rate of expected capacity utilisation of 52%

In addition, wind power by its nature requires frequency regulation with very short response times, as it is more difficult to predict the timing and scale of wind, while PV tends to have a longer fluctuation cycle (day-night) and marries better with supply-demand adjustment, representing a stronger affinity for PVs with smart charging/V2X.

2.2 Smart charging and V2X

Smart charging is frequently referred to as the primary measure of demand side response. Smart charging here means the mono-directional intelligent charging of EVs to achieve flexible loads, where charging can be shifted based on the grid and on the vehicle owner's needs. It is a win-win solution for both the grid side as well as the driver's.

There has been a great deal of discussions about the various methods and results of smart charging, including programmes for customer participation with dynamic price signals and other incentives. However, if the EV is not V2X-enabled, the quantity of contribution any EV can provide for excess supply absorption is limited to the energy the EV consumes. More concretely it means that:

- The battery capacity of today's EVs is 24-30 kWh. Using the average annual driving distance in Europe of 14,000 km [3] and the drive energy consumption rate of 0.12 kWh/km [4], the average daily consumption is calculated as (14,000km/365 days) x 0.12 = 4.6 kWh. This is how much capacity an EV without V2X can provide for surplus absorption via smart charging.
- With the bi-directional charging capability using the V2X technology, it is possible to discharge the battery in advance according to the electricity demand and weather forecasts for the next day, meaning that the equivalent of the full battery capacity (24-30 kWh) can be theoretically used for the grid. Staying conservative and setting aside 50% of the capacity for the energy need for driving as well as for minimising battery degradation, we can safely say that 12-15 kWh is available.

That is, a V2X-capable EV can make 2.6 to 3.3 times more contribution to the grid than a non-V2X capable EV today, depending on the EV battery capacity.

With the ever-increasing trend of battery capacity, the bigger the EV batteries get, the higher the energy capacity EVs can offer to the grid operators through V2X in the future. Consequently, the positive impact of V2X against the imbalance risk would increase, while EVs without the V2X functionality would be constrained to a small quantity since the distance driven is not expected to change drastically with the battery size increase.

Indeed, even if the EV stayed parked all day and did not move at all, bi-directional charging with V2X functionality can continue to provide a buffer to the grid, unlike the mono-directional smart charging, which can only provide the capacity consumed by driving. Fig. 2 shows a scatterplot of 11,192 EVs in California by daytime home parking rate (Y-axis) and average distance driven by month (X-axis). Assuming almost all EVs remain parked at home at night, we can see that EVs that are not used for commuting (two upper-quadrants, 33% and 16% of total samples) remain parked at home almost all day (and at night), representing the great potential of V2X activities.

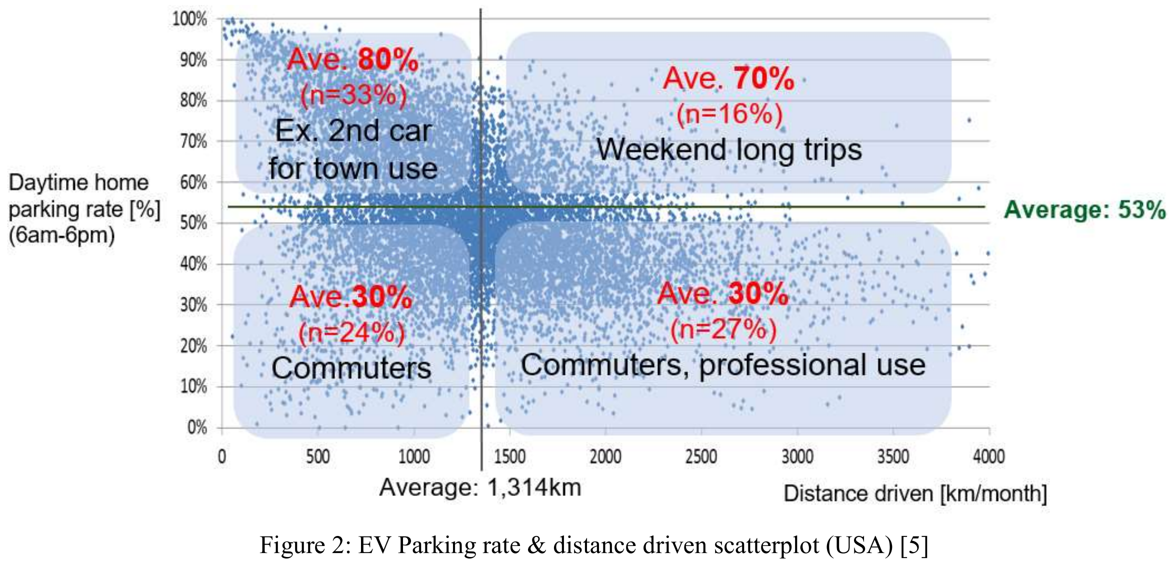

Figure 2: EV Parking rate & distance driven scatterplot (USA) [5]

Lastly, it is often noted that the high cost of V2X devices remains a major barrier to the wide dissemination of V2X. Some may argue that V2X is not necessary as long as we have home stationary battery systems, but the price points of existing household stationary batteries as of today are 4 or 5 times higher than those of V2X power conditioners of the same capacity [6]. Although the price of such stationary batteries is expected to decline in due course, considering the expected acceleration of EV adoption and the eventual decrease of EV battery prices due to economies of scale and to the technological developments, there is little doubt that the price competitiveness of V2X over stationary battery systems shall continue.

3 CHAdeMO on V2X

CHAdeMO took notice of V2X technology's potential to complement RES integration early on and was the first to standardise the technology. To date, it remains the only international charging protocol that has already defined the V2X functionality, with a certification system in place to ensure interoperability across EVs and V2X devices for global use. Bringing automotive and electrical equipment players to work together, the V2H (Vehicle-to-home) team in the Technical Work Group of CHAdeMO Association (V2H-WG) focused its work on the standardisation of communication expansion and safety in bi-directional operations, and on identifying and documenting grid-connection requirements. Our communication interface is now deployed by many demo projects across the world.

3.1 CHAdeMO V2X protocol, certification and products

The first CHAdeMO-V2X specifications were made available to its members as of 2013 as an extension to the CHAdeMO charging protocol and the full version of the protocol was published in 2014. CHAdeMO's V2H-WG has since then defined the test procedures, which began in March 2015 at designated third-party certification bodies, to ensure the transparency and fairness of the tests.

A wide variety of V2X-capable EVs and devices are already available on the market. On the vehicle side, as some manufacturers made V2X functionality a standard feature, there are around 55,000 CHAdeMO V2X-compatible production EVs, provided by 3 manufacturers, on the roads in Europe [7].

In terms of V2X power conditioning systems (PCS) that enable charging/discharging to/from EVs, a number of CHAdeMO members have developed various V2X products, including Vehicle to Vehicle (V2V), to Load (V2L), to Home (V2H), to Building (V2B) and to the Grid (V2G), as per the below visualisation with product examples (Fig. 3). The output power varies from 1.5kW to 10kW (the protocol caps the max power at 10kW), but the mainstream power level is around 6kW for home and 10kW for building/grid connection usage.

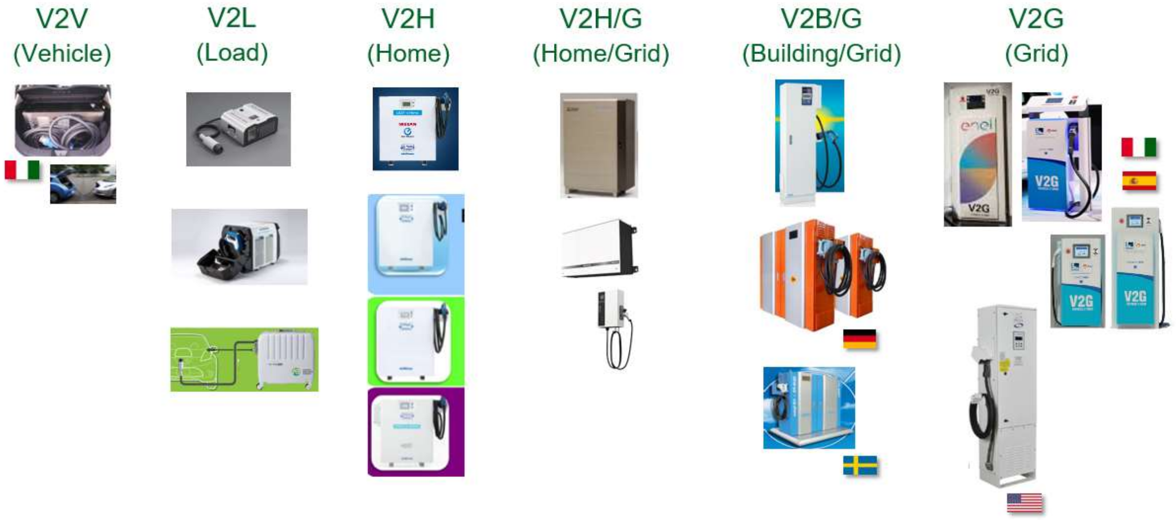

Figure 3: CHAdeMO V2X products on the market

3.2 V2X international standardisation

The IEC standards for DC charging stations (IEC 61851-23 and -24) are now under revision for the second edition, with bi-directional operations, including the one defined in the CHAdeMO-V2X specification. The IEC's TC69 is designated to be the leading committee for this on-going revision work, referencing various other standards such as IEC 62909 (grid-connected bi-directional converter), 61850 (communication systems for distributed energy resources) and 15118 (V2G communication interface), among others, with the goal being to finalise the next version in 2019.

TC69 WGs are also tasked to look at roaming and backend product distributed energy resource (DER) management- the former group considering E-mobility systems including clearing houses and other systems enabling roaming, and the latter the communication beyond the EVSE (electric vehicle supply equipment), connection to the grid via central or local charging system management systems (CSMS).

The CHAdeMO protocol covers only the communications between an EV and an EVSE. All other related standards above the EVSE, up multiple layers and across to the energy systems side, to where the connection to the Flexibility market is established, are needed and the international work around these standards to encourage harmonised development of the systems is just starting.

CHAdeMO's approach to this immense standardisation work is to define the minimum and remain flexible and compatible with any other adjacent systems and the rest of the ecosystem. CHAdeMO V2X is designed in such a way that any communication design or the user interface beyond the EVSE (e.g. smartphone applications) will not be constrained by CHAdeMO. The reverse is also true: CHAdeMO shall be seamlessly integrated into any systematic CSMS, whereby an EVSE shall play a gateway role, regardless of the protocols used between the EVSE and the energy management systems.

4 V2X demonstration projects

With the objectives being to push further technical development in V2X functionality and to demonstrate the effectiveness of EV battery-based devices for grid stabilisation, several V2X-related projects have been launched since early 2000, mainly in the US and Europe. Since 2013, with the V2X extension of the CHAdeMO protocol, more projects with production EVs have been added to the portfolio around the world.

Together with the increase of companies adopting V2X technology to their product portfolio and R&D strategy, demonstration projects are growing in both scale and number. We have counted at least 40 trials globally, including 20 in Europe, 10 in the US/Canada and 10 in Asia-Pacific (Fig. 4), which cover various types of V2X applications such as V2V, V2L, V2H, V2B, V2G, V2I (infrastructure), and V2N (neighbourhood).

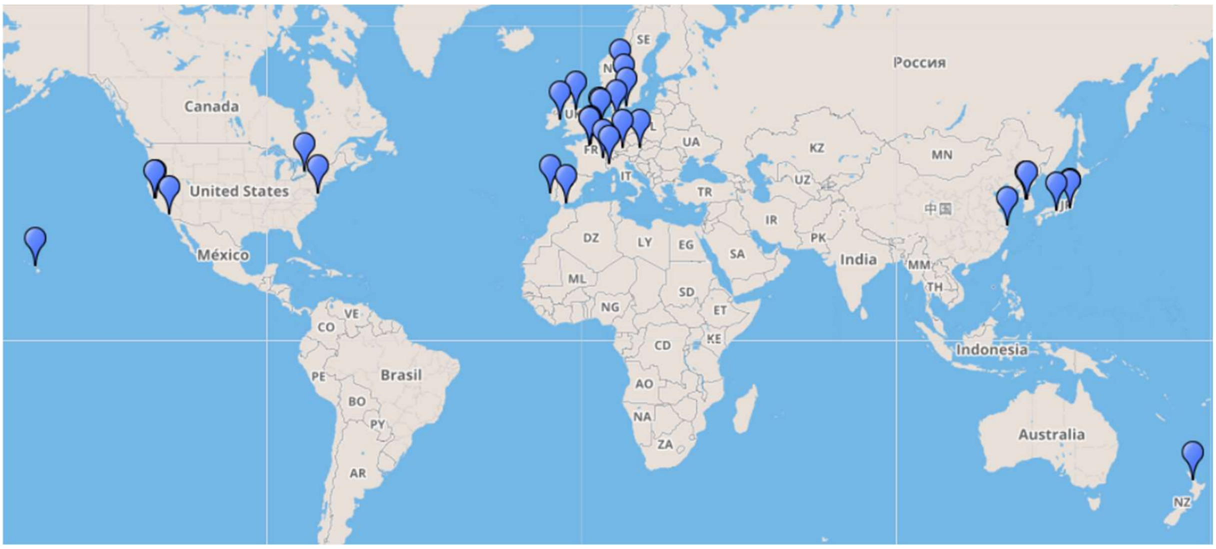

Figure 4: Locations of V2X demonstration projects

A large variety of players are involved in those projects, from industrial and business actors to research institutions and universities, subnational entities such as cities and regional departments and, naturally, utilities and national grid operators. The multi-level governance and broad participation throughout the V2X trials demonstrate the inclusive and collaborative approach adopted from the inception phase of research & development projects.

Although many of the V2X trials are still ongoing or were just recently launched, the partners and V2X application installers are trying to identify obstacles and opportunities that V2X services face across different local circumstances, load profiles and vehicle characteristics, such as technical and regulatory parameters, impacts of V2X technology on the power system operations, and the implications on electricity market pricing. As the demonstration projects increase, commercial activities have also started, no longer on the demonstration phase and generating revenues for EV end users. Below we shall present some project examples as a glimpse into the variety and scale of projects from different regions.

4.1 Nikola and Parker projects (V2G)

In Denmark, initial EV technology investigations were conducted in the framework of Edison project (2008) and carried over to Nikola (2013-2016), which focused on the synergies between the EV and the power system. Upon the completion of Nikola, the Parker project (2016-2018) was launched for upscaled service validation.

The purpose of Nikola was to clarify the EV's potential in supporting a power system based on RES and reducing the costs of energy for consumers and EV owners. The team defined a power and energy service as "the act of influencing the timing, rate and direction of the power and energy exchanged between the EV battery and the grid to yield benefits for user, system and society," made a catalogue of such EV-related services, followed by the world's first demonstration of ancillary services using production EVs. The team has also compared the communication standards and concluded that IEC15118 and CHAdeMO are both "best positioned" to support frequency regulation at the EV-EVSE level [8] [9].

Parker followed, using 40 EVs, with the aim to validate that production EVs as part of an operational vehicle fleet can support the power grid by becoming a vertically integrated resource, providing seamless support to the grid both locally and system-wide [10]. According to the project's aggregation software provider, the 10-EV fleet has been generating 1,000-1,400€ per year per EV thus far [11].

The ACES (Across Continents Electric Vehicle Services) project is also expected to start for further validation with up to 100 privately owned EVs on the Bornholm island, where 75% of the energy production is from renewable sources [12].

4.2 JUMPSmartMaui (V2H/G)

The JUMPSmartMaui Project aims at the development and demonstration of a smart grid on the island of Maui in the US. The main target of Phase I (2013-2016) involved installing PCS, PVs, stationary and fast chargers, along with EVs, and starting data collection around V2H in order to step forward for the efficient and maximum utilisation of RES. Phase II (2015-2017) aimed at expanding upon and optimising systems installed and demonstrated in Phase I, including a V2H/G demonstration with EVs charging and discharging to power homes and businesses, and was completed this year [13].

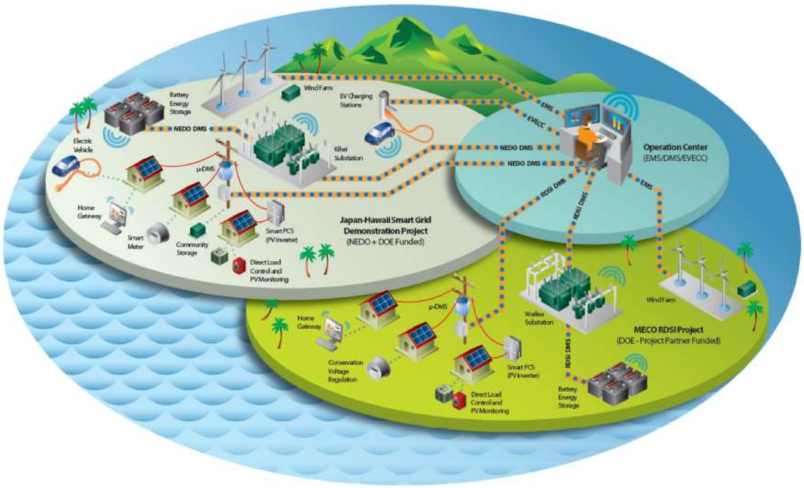

Figure 5: JUMPSmartMaui project [13]

Since the project launch, 530 residents and businesses participated in this demonstration project. In Phase I, the project recruited more than 200 EV users and 30 homeowner volunteers for data collection around their charging behaviours to evaluate how the devices could contribute as more renewables were being integrated. Phase II advanced the energy management system involving the V2X functionality. A total of 80 volunteers were provided with the bi-directional PCS units at their homes, which charged the EV and discharged the power to the home or directly to Maui Electric in response to the needs of the electric grid [14].

4.3 Osaka Business Park (V2B/G)

In the post-Great East Japan Earthquake Japan, building resilience combined with smart energy management has become an important topic. Office buildings, hospitals, local government offices and private apartments alike, have started to equip their buildings with V2X systems.

The Osaka Business Park project (2013-2015) is one of such projects for a business complex of 26 stories mostly with business offices, shops, conference halls, etc. As shown in Fig. 6, under the business as usual (BAU) scenario, marked as 1, their 5-EV fleet was used for load shaving via PCS, with demand-response incentives to optimise the building's energy management. In case or emergency, marked as 2, these EVs would provide for back-up electricity to guarantee continuity of business by providing lighting in meeting rooms, lifts and water pump operations.

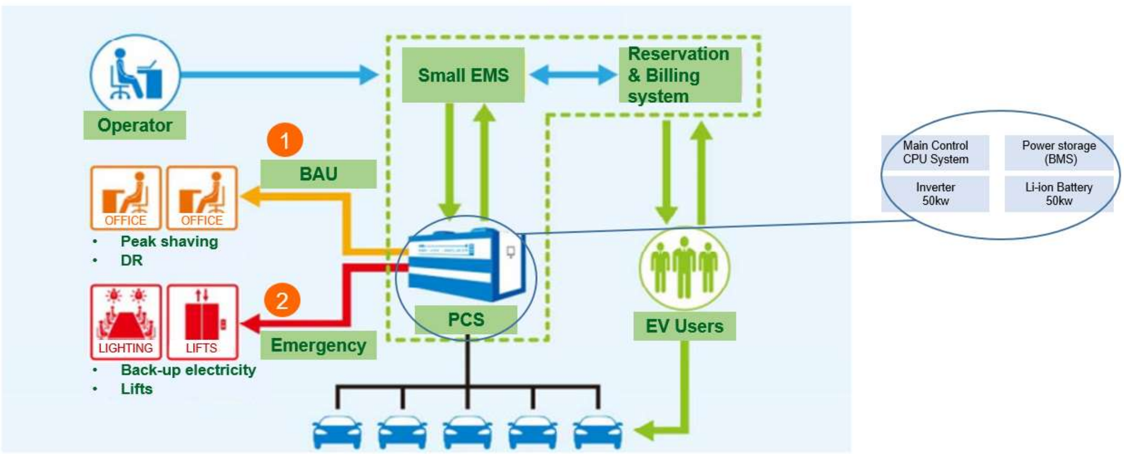

Figure 6: Osaka Business Park project [15]

4.4 DMAT (V2L)

CHAdeMO V2X technology is also applicable to fuel cell EVs. CHAdeMO-compliant portable energy providers are now a familiar sight when large-scale medical help is called upon. For example, training sessions of Japan DMAT (Disaster Medical Assistance Team) are periodically assisted by a CHAdeMO-certified 9kW V2L power device for the past few years. These devices provide zero-emission electricity output for emergency medical fronts such as disaster-hit areas or large-scale sport events like marathon races, from both lithium-ion battery EVs and fuel cell EVs that are CHAdeMO compatible [16].

5 Conclusion

Comparing simple smart charging and V2X charging, the latter's intrinsic potential to smooth the grid fluctuations is much higher already. Looking ahead, the gap shall only widen because, while the battery capacity will be on an upward trend (V2X), the average distance driven is not expected to grow that much with the evolution of the EV battery size (smart charging).

Having seen great potential to contribute to addressing the intermittency issue of RES integration through its V2X functionality, CHAdeMO has standardised its protocol to include V2X, and is the only international standard to have done so. Following this, a wide variety of V2X-capable EVs and PCS units have already been made available on the market, mobilising many players from different sectors to collaborate in demo projects and business operations along the way. CHAdeMO shall continue to evolve its technology with the market feedback and collaborate with key players to improve its functionality as the leading enabler of V2X.

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