DC charging infrastructure

- Towards achieving carbon neutrality -

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ABSTRACT: To achieve carbon neutrality, the vehicle mobility is going to be electrified by the 2030's. In the course of mobility electrification, the energy transforming device, charger and power conditioner can help power grid stabilization by smart charging or feeding energy back from the electric vehicle (V2G). This technology can also enable electric vehicles to supply energy to the shelters in the affected areas in the event of a power outage due to natural disasters. We report on the historical achievements, current tasks, and the future direction of V2G from the viewpoint of in-market experience and technical innovation for more than 10 years.

KEY WORDS: electric vehicle, DC charging, standardization, V2G

1. INTRODUCTION

Until recently, the electrification efforts primarily focused on passenger cars and the main technological issue has been how to increase the output power of chargers with the increase of vehicle battery capacity.

In order to achieve our vision of 'Powering global zero-emission mobility for the happiness of future generations' we have set our mission as 'Providing safe, affordable and interoperable DC charging. We have expanded the scope of CHAdeMO protocol applications from small motorcycles to large buses, trucks, ships and aircrafts expanding the original CHAdeMO to the entire transport sector. In addition, it has been 10 years since CHAdeMO developed a DC fast charging standard and CHAdeMO remains the only charging standard implementing a bidirectional power supply interface in the market, which is becoming increasingly important as renewable energies become more widespread worldwide and is now largely recognized as a prerequisite for the spreading of electric vehicles.

2. DEVELOPMENT OF PROTOCOL

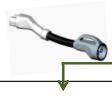
Since the first edition of the CHAdeMO protocol in 2010, the Association has continued to revise and evolve the specifications, including detailed quality requirements and the additional functions to meet the market needs. There are three basic design philosophies that have been followed throughout the history of CHAdeMO over the past 10+ years.

The top priority of design philosophy is safety. Since DC fast chargers are about the only high-voltage, high-current equipment that can be handled directly by general users, safety measures such as prevention of electric shock are extremely important. From the initial development stage, CHAdeMO has set safety requirements in the standard specifications at each of the three levels: hardware unit, at the system level, and during operations. A performance confirmation document is specified for the connector, as the most important safety measure. As a system-level fail-safe, multiple signal lines are provided in addition to the CAN (Controller Area Network) signal line used for charging control communication. Even if there is a single hardware failure, the current can be cut off as soon as an abnormality is detected. In terms of operations, several safety measures are envisaged: charging start procedure, safe plug disconnection in the event of a failure, and the implementation of an emergency stop button.

The second priority is the electrical quality and reliability. Since fast chargers are used in public places, CHAdeMO stipulates, in accordance with international standards, that the chargers shall not affect the power distribution lines or surrounding electrical equipment with electromagnetic noise such as EMC or harmonics, and that they shall operate normally even when they are exposed to external noise.

The third priority is to ensure operational compatibility. As public infrastructure, chargers shall be available to all EV makes and models. Furthermore, both EVs and fast chargers should

Table 1 DC fast charging standard

	CHAdeMO	CCS1 (US COMBO)	CCS2 (EUR COMBO)	GB/T	Tesla	ChaoJi	Ultra-ChaoJi	MCS
Connector								
Vehicle Inlet								
IEC	✓	✓	✓	✓		NP proposal for IEC62196-3	NP proposal for IEC63379	NP proposal for IEC63379
	IEEE	SAE						✓
EN	✓		✓					✓
JIS	✓	✓	✓	✓		✓	✓	
GB				✓		✓	✓	
Communication	CAN	PLC	PLC	CAN	CAN	CAN/Ethernet	CAN/Ethernet	Differential PLC
Max output	400kW (1000V*400A)	350kW (900V*400A)	350kW (900V*400A)	185kW (750V*250A) 1200kW (1500V*800A)	250kW (400V*630A)	900kW (1500V*600A)	1.8MW (1500V*600A)	4.5MW (1250V*3000A)

remain interoperable even if different versions of hardware and software come out over a usage period of 10 years or more.

This is the reason why CHAdeMO has not only standardized the design requirements, but also established and maintained a certification system from the very beginning so that all products are in conformity with the CHAdeMO standard.(1) When the certification system was first launched, the self-developed certification system was operated at TEPCO's R&D Center as the certification criteria were not formalized. Charger manufacturers in Japan and around the world brought their products to improve the system, and the criteria were developed through repeated trials and errors.

When the specifications were revised in 2013, we issued the certification specifications to systematize the test items and developed a second-generation certification system using a commercial CASE tool. In 2014, we switched to a new system implemented by third-party certification bodies, and the certification tests were made available in Europe as well. As a result, no severe CHAdeMO incident has been reported anywhere in the world for more than a decade.

3. INTERNATIONAL STANDARDIZATION

Based on the development of the CHAdeMO protocol, Japan made a new item proposal to the IEC in 2010 and became the project leader of IEC 61851-23/-24 as well as the deputy leader of IEC62196-3. These projects have resulted in the publication of an international standard (IS) in the spring of 2014 after a deliberation period of more than three years. Charging systems proposed by Germany, the United States, and China during the deliberation process were also adopted along with the Japanese proposal, all of which were developed based on the basic idea as well as the safety design concept of CHAdeMO as described above. The features of each system are shown in Table-1.

While the systems proposed by Japan and China use a dedicated connector for DC charging, the systems proposed by Germany and the United States use a combined ('combo') connector in which DC and AC are incorporated (CCS). Their intention was to differentiate from CHAdeMO as a later proposer, by appealing to reduce vehicle body design constraints by consolidating the vehicle's charging ports in one place. However, since the AC charging standards are different in Europe and the United States, connector shape compatibility was not achieved between CCS2 (Europe) and CCS1 (USA).

4. SPECIFICATIONS REVISION

By balancing the cost and technical performance, CHAdeMO initially set the maximum power output to 50kW. Indeed, if it exceeded 50kW, the hardware cost would significantly increase, and if it is less than 50kW, the charging time would increase and the quality of service would decrease.

After the revelation of the Volkswagen emissions scandal, German automakers, which used to mainly sell diesel vehicles, announced one after another their policy of switching to EVs. That coincided with the announcement of Tesla's Model 3 that enabled autonomy of 220 miles, exceeding that of its competitors at a lower price. Those events have resulted in the increase of driving range of 400 km to 500 km or more for all models launched after 2018. The reasons behind this are thought to be the elimination of user range anxiety, which was one of the stumbling blocks to greater EV adoption, and the price decline of lithium-ion batteries. To adapt to such changes, the members of the IEC deliberating on the revision of the standard agreed to increase the maximum current value to 400A and the CHAdeMO specification also revised its outpower power from the previous maximum current of 125A to 400A. From the manufacturer's point of view, the basic circuit and control software of the charger would not change significantly, but the technical issue is how to address the heat generated by the high current, and especially to avoid the temperature rise of the conductor.

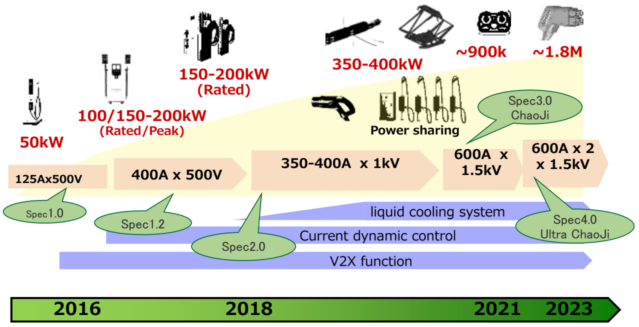


Fig. 1 CHAdeMO Roadmap

With the trend toward electrification of heavy-duty vehicles such as buses and trucks, market needs for even higher output are expected. In addition, in regions such as Asia and Africa where the automobile market is expected to expand significantly in the future, it is not desirable that multiple charging standards continue to coexist in the world in order to popularize EVs and efficiently develop charging infrastructure. CHAdeMO has agreed to jointly develop the next-generation charging standard with the China Electricity Council (CEC), and plans to widely deploy the new standard to third countries was confirmed at the Japan-China Economic Cooperation Conference in October 2018. The new standard was named ChaoJi which is positioned as CHAdeMO version 3.0, and the first edition of the specifications was published in April 2021. ChaoJi allows vehicles with the new standard to use existing charging infrastructure via adapters, making it backwards compatible not only with the current CHAdeMO and Chinese GB/T chargers but also with CCS chargers.

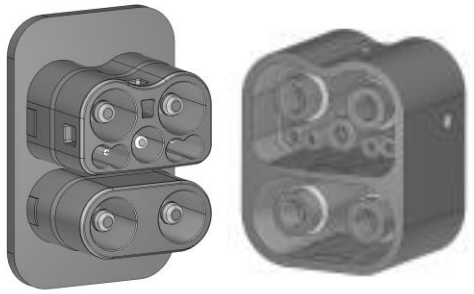


Fig. 2 Ultra-ChaoJi Coupler

Japan and China also agreed to widely deploy this new standard in third countries. The agreements between the two countries are meant to create a win-win relationship as CHAdeMO can bring its technological strengths and, in return, the production costs can be reduced thanks to the size of the Chinese market.

In the future, assuming that the electrification of transportation will extend to construction machinery, ships, and aircraft, there is also a movement to propose charging standards for high-output power exceeding 2 MW. Figure 2 shows an image of Ultra-ChaoJi, in which a power line is added in parallel to ChaoJi.

The greatest technical challenge is to suppress the temperature rise of cables caused by large currents. In parallel with the increased output of the charging standard, related technology developments are underway. For example, an Automated Connection Device (ACD) that robotically connects cables that have increased in weight and become difficult for users to handle, as well as liquid-cooled cable systems that enables carrying higher currents by circulating a coolant inside the charging cable.

On the other hand, when vehicles or ships are used under specific operating conditions (travel route, distance, time), it may be possible to apply solutions that do not necessarily require DC conductive charging systems. As an example, pantograph charging is suitable for buses that drive continuously on fixed routes, and some demonstration projects using extended CHAdeMO protocol are implemented in various countries. In the future, it is expected that different technologies will coexist for various use cases.

5. BI-DIRECTIONAL POWER TRANSFER FUNCTION

5.1. Development of the specification

CHAdeMO-compliant EVs have been on the market since 2009. In the aftermath of the Great East Japan Earthquake (March 2011), EVs were utilized as a means of transport for medical personnel and reconstruction assistance in the affected areas. Indeed, electric power infrastructure was quickly recovered while petrol was not available till much later.

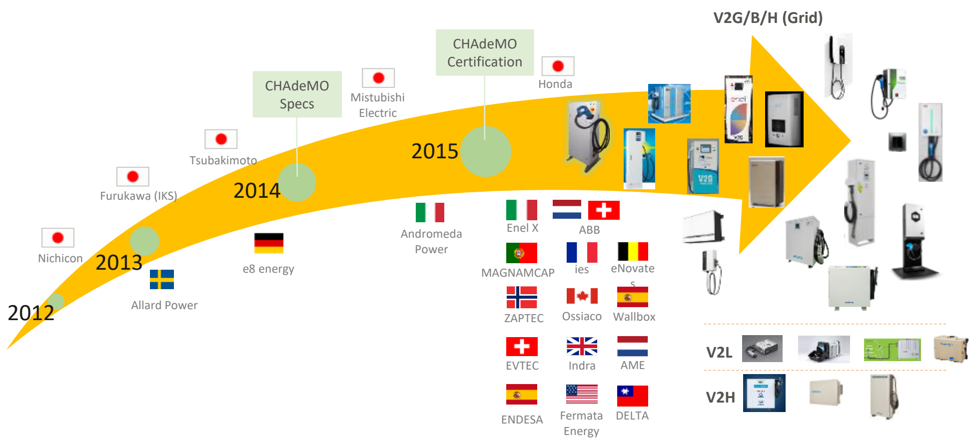


Fig. 3 V2H/V2L product development

The high-capacity batteries of EVs were recognized as an emergency source of power supply, which accelerated the development of V2H (vehicle-to-home)/V2L (vehicle-to-load) technology. The V2H systems were already commercialized in 2012, and the Ministry of Economy, Trade and Industry of Japan (METI) set up a working group (WG) to standardize, which issued the V2H Guideline 1.0 in March 2013. CHAdeMO and EVPOSSA (Electric Vehicle Power Supply System Association) established a joint WG to discuss the grid interconnection requirements, and issued the V2H Guideline 2.0 in April 2014. Following the publication of these guidelines, CHAdeMO Association developed and released a certification test specification in March 2015, in addition to the existing certification system for conventional fast chargers. As such, a certification system for V2H/V2L products was started and more than 40 models from 19 companies have been launched in markets around the world to date.[2] Almost all of the many V2G demonstration projects that have been implemented around the world are supported by systems that implement the CHAdeMO protocol.

5.2. New expectations for EV

In the coming era of transport electrification and the spread of renewable energy, the large-capacity storage batteries of EVs are expected to play an important role to absorb surplus electricity and regulate output fluctuations. Furthermore, EVs can be used as an emergency power source by taking advantage of their 'mobile' characteristics, which are not found in stationary storage batteries. In recent years, power outages caused by a series of natural disasters have indeed become a serious social problem for which a V2L system directly connected to home appliances is an effective solution.

The average battery capacity of current EV models is sufficient to respond to general household demand for several days, but the battery SOC may drop due to long distances to the disaster affected areas or if the power outage is prolonged. Even in such a case, in Japan, where 7,700 fast chargers are installed nationwide, it is easy to recharge EV batteries by traveling to a nearby charging station, where the energy supply has been resumed. It is a way to take advantage of the unique strengths of EVs. In fact, local governments in Japan have already realized many examples of efficient support for disaster victims by preparing V2L equipment and signing contracts with businesses to have their vehicles cooperate in the event of a disaster.

5.3. Vehicle-grid integration

In the future, the interconnection between the electric power system and EVs should be strengthened to enable the realization of a carbon-neutral society. That is why CHAdeMO collaborates with various stakeholders and participates in projects. In Japan, CHAdeMO works with the ECHONET Consortium to envisage harmonization with ECHONET Lite, which is a communication standard with HEMS servers, and technical guidelines are planned to be published. In Europe, CHAdeMO cooperates with the Open Charge Alliance (OCA) and published a white paper in November 2020[3] to ensure the compatibility with OCPP, a de facto back-end communication standard, and continues to collaborate in the area of V2X application. If CHAdeMO actively collaborates with these external organizations, this is because the scope of CHAdeMO protocol applications has greatly expanded beyond the conventional charge control. For the same reason, the ISO15118 series (communication interface from EV, charger to distribution network) work is ongoing for quite some time, and the IEC63110 series (use case analysis for charging infrastructure management

Table 2 List of standards by purpose

Specification	Power, battery size	Application examples
▪ CHAdeMO3.0(ChaoJi) 	▪ 150kW～	
▪ CHAdeMO 	▪ ～150kW	
▪ e-PTW CHAdeMO (NEW) 	▪ 1-10kW ▪ 20-120V ▪ Battery 2-10kWh	
▪ EPAC CHAdeMO (NEW) 	▪ <800W ▪ 36V nominal / 42Vmax ▪ Battery <1000Wh	

systems) started their use-case analysis and protocol assessment in 2017. However, these development works are not progressing quickly due to the fact that charging infrastructures are undergoing rapid expansion both in terms of functionality and scale. Besides, new elemental technologies are constantly being developed in the field of communication, and innovative business models are emerging to exploit them. Europe and the rest of the world are moving towards the diffusion of EV policies all at once. While the safety and security are important issues and it is necessary to develop standards ahead of time, premature mandating of interface standards risks hindering the introduction of innovative technologies and the development of new businesses. CHAdeMO Association has been vocal in alerting the legislators of the concern that future technological innovation could be hampered by political bias(3) .

6. EXPANSION OF APPLICABLE VEHICLE TYPES

Having started with passenger cars, the standardization of DC charging standards is today being extended to both larger and smaller size vehicles. Attempting to meet all needs with conventional standards designed for passenger cars would lead to complex system requirements, reduced efficiency and increased costs. To avoid such adverse effects, CHAdeMO is developing optimal standards for each application area.

In terms of high-power charging, as previously mentioned, CHAdeMO started to develop a new standard ChaoJi. In the future, as the electrification of transportation extends to large vehicles, ships, and aircrafts, charging systems with even higher output such as Ultra-ChaoJi may be required.

Furthermore, CHAdeMO started developing low-voltage, compact, and lightweight standards for small vehicles and motorcycles. Table 2 shows the outline of the standards for each application area. Electric motorcycles (e-PTWs, or electrically powered two-wheelers) have already begun to spread in various parts of the world, and electrically power assisted bicycles (EPACs) are rapidly becoming widespread in Europe and Japan. Today, battery swap systems are the mainstream for small batteries used in these vehicles, but market needs for public shared charging stations are also emerging. For example, operators of bike sharing services want to charge their bikes in a short time in order improve the operation efficiency, or some bike tourer wish to charge the battery while traveling a long distance.

Meanwhile, problems with battery swap systems are gradually becoming apparent on the system provider side as well. Firstly, battery swapping systems require more than twice as many spare batteries as the number of vehicles used. In many projects, initial investment costs were supported by public subsidies, ignoring business sustainability. Secondly, while vehicle manufacturers wish to advance in their competitiveness by improving the performance of batteries through technological development, battery swap systems, which use batteries as a commodity, could hinder such technological innovations. Thirdly, there is risk that the battery deteriorates if the user replaces the battery on a daily basis and if the electrodes are exposed to the outside air or get wet during swapping.

Of course, battery swap system is effective under certain conditions, such as for fleet users, but for the reasons described above, we think public charging infrastructure should be developed in order to fully and sustainably promote the electrification of motorcycles and small mobility vehicles.

7. CONCLUSION

With the Paris agreement objectives, the world is moving towards climate neutrality, and the shift to EVs is accelerating. There are also increasing expectations to utilize EVs for ancillary grid services coordinating with the power system, as well as to enhance resilience in disaster-stricken areas as mobile batteries. As the only international standard that has enabled the commercialization of bidirectional power supply, CHAdeMO is committed to continue its contribution to the spread of EV charging infrastructure in the future.

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