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OVERVIEW AND CHARACTERISTICS OF THE EV FAST CHARGING CONNECTOR SYSTEMS

PRZEGLĄD I CHARAKTERYSTYKA STANDARDÓW ZŁĄCZY SZYBKIEGO ŁADOWANIA POJAZDÓW EV

Abstract: The paper presents the existing connector systems designed for fast charging EV battery. The work has paid particular attention for differences between charging systems like nominal voltage, speed of charging, plug type and place of occurrences.

Streszczenie: Artykuł przedstawia przegląd istniejących systemów złączy do ładowania akumulatorów pojazdów elektrycznych. Zwrócono w nim szczególną uwagę na różnice pomiędzy poszczególnymi standardami takimi jak typ złącza, napięcie ładowania, dokonano również analizy ich popularności oraz możliwości rozwoju.

Keywords: *Fast charging connectors, Tesla Supercharger, CHAdeMO, SAE CCS, SAE J1772, AC charging, DC fast charging, EV*

Słowa kluczowe: *złącza szybkie ładowanie, Tesla Supercharger, CHAdeMO, SAE CCS, SAE J1772 , ładowanie AC, szybkie ładowanie DC, pojazdy elektryczne*

1. Introduction

In the last few years, the automotive world has witnessed a real revolution. Decade ago nobody even thought that diesel engines which are dominated a market in first years of XXI century will be gradually withdrawn from the automotive solutions.

Universal striving to reduce climate changes forces car producers to use hybrid powertrains or to completely abandon their conventional internal combustion engines for electrical or hydrogen solutions.

Increasing share of electric cars in the world will forced the development and continuous modernization of charging infrastructure. The biggest EV`s problem is the shorter range than conventional car and long charging time up to 8 hours when battery is charging from 1-phase 230V socket (EU example). Everyone wants to move quickly and cheaply.

To meet customer requirements engineers and scientists of all world creating different solutions for fast charging but idea is the same – safely charge car battery as quickly as it is possible. Exemplary studies are carried out at the Lublin University of Technology, the scope of which is quite intensive and cover cooperation with Grid Power Electronic Converters [1] as well as Control Strategies and topologies of DC/DC converters [2].

On this moment we have a few fast charging systems, in this paper was presented a first-dominating 3 systems Japanese CHAdeMO, American SAE J1772 Combo (IEC type 1) and European IEC 62196-2 type 2 Combo Charging System (IEC CCS type 2) all types of charging systems are divided to 4 mode:

-Mode 1- directly passive connection between grid and EV, only AC charging in EU 250V for 1- phase or 480V for 3-phase systems, maximum current is 16A, without control pins. Electrical protection problem is solved by providing earth line to the EV by EVSE (electric vehicle supply equipment/ electric vehicle charging station)[12]. Mode 1 is prohibited in some countries, including USA the biggest problem is earthing requirements because it is not present in all home installation. Mode 2 is a solution to this problem.

-Mode 2-its semi-active connection of the EV to AC grid, also 250V for 1-phase system and 400V for 3-phase, maximum current is 32A, semi-active because EVSE should be a part of AC grid or must be situated with not longer than 0.3 m cable. Between charger and EV is active connection with control pilot. Charging station provides PE(protective earth) line presence detection, over-current, over-temperature, ground fault protection.[12]

-Mode 3- This is full active connection between EV and EVSE either 250V for 1 or 480V for 3 –phase including PE and CP (control pilot), with captive cable with extra conductors to achieve current to 250A or compatible back to mode 2 with maximum current of 32A. To start charging EVSE requires proper communication over CP.[12] This mode and communication type allows for an integration into smart grids.[13]

-Mode 4- This is also full active connection EV-EVSE 600V DC charging with maximum current of 400A. Direct current is rectified from Alternating current power from grid by charging station.[12] That type of EVSE is more complicated than Mode 3 or lower, which is consequently more expensive, but Mode 4 can provide to car up to 240 kW DC power.[13]

2. SAE J1772 Combo Charging System

2.1 History

Progenitor of SAE J1772-2009 Combo charging system are SAE J1772 REV NOV 2001 that was capable to delivery up to 6,6 kW of electrical power via AVCon rectangular connector – *Fig. 1*, this type was named SAE J1772 AC (Alternating Current) level 1 charging [1]. California Air Resources Board (CARB) regulation of 2001 mandated the usage of SAE J1772-2001 beginning with the 2006 model year. Later it was necessary to achieve a higher current and power than the AVCon connector could provide. This has led to the introduction of a new type round connector, that allows transfer up to 80 amperes via single phase at 240 V AC it was named SAE J1772 AC level 2 charging.

This plug type is approved by Society of Automotive Engineers (SAE) Motor Vehicle Council in SAE J1772 REV 2009 document and adopted as a standard plug by Smart, Chrysler, General Motors, Ford, Toyota, Honda, Nissan and Tesla car manufacturer. Also in 2009 SAE is developing a Combo Coupler variant of J1772-2009 connector with additional 2 pins to allow DC (Direct Current) fast charging up to 90 kW. SAE J1772 CCS plug is adopted and introduced by Audi, BMW, Daimler, Ford, General Motors, Porsche, Volvo and Volkswagen in mid-2012 [2].

2.2. Plugs and differences between US/Japan and EU chargers

Right now existing two types of SAE charging system plug only AC (slow charging) , AC&DC (fast charging) and this two types have different plug in US (AC-Fig. 1 & CCS-Fig.2) and in EU (*Fig. 3 & Fig. 4*), it is caused by different electrical systems in EU and US. J1772-2009 connector are designed for single phase installation like in US or Japan it's have a 5 pins L1, L2/N, PE (protective earth), PP (proximity pilot), CP (control pilot), for Europe are designed similar plug but for three phase AC installation, L1, L2, L3, N, PE, PP, CP and it was named SAE IEC 62196-type 2 .

Fig.1 SAE J1772-2009 AC US plug, (1-L1; 2-PP; 3-PE; 4-CP; 5-N) [3]

Fig.2 SAE J1772 Hybrid type AC/DC – two lower pins are "DC+" from left and "DC-" [3]

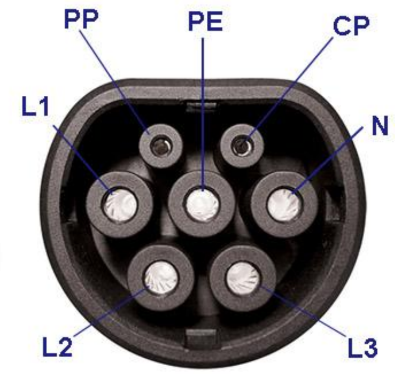

Fig.3 SAE IEC 62196-type 2 AC EU 3-phase plug [3]

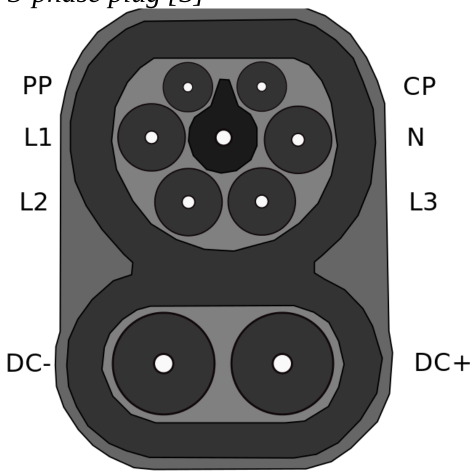

Fig.4 SAE IEC 62196- hybrid type 2 (SAE CCS type 2)- SAE CCS Superfast DC Charger plug.[3]

2.3 SAE J1772- Technical data

In the *Tab. 1* are contained parameters of characterizing individual communication states between charger and EV. It's important because normally when charger is not connected with car the power lines pins don't have any potential, only CP and PP pins have potential 12V (CP-PE). PWM (Pulse-Width Modulation) wave signal helps charger to set maximum power charging level, the relationships between PWM duty cycle and maximum current for SAE CCS AC charging is described in *Table 2*.

In the *Tab. 3* & *Tab.4* was shown differences between SAE AC and DC chargers for EV battery. SAE CCS Communication is provided by a PLC (Programmable Logic Controller), which allows the consumer to manage the charging process at a high level in example- control charging process by smartphone. [4] The most important advantage is significantly reduced of charging time from 20 to 90 %SOC (State Of Charge) up to 20min. It was really important because drifting between these values allows safely charge battery pack with really high current with a skipped car onboard charger.

Tab. 1 SAE CCS COMMUNICATION STATES [3]

Base status	Charging status	Resistance, CP-PE	Car parallel resistor	Voltage, CP-PE
Status A	Standby	Open, or ∞ Ω	-	+12 V
Status B	Vehicle detected	2740 Ω	-	+9±1 V
Status C	Ready for charging	882 Ω	1300 Ω	+6±1 V
Status D	With ventilation	246 Ω	270 Ω	+3±1 V
Status E	No power (shut off)	-	-	0 V
Status F	Error	-	-	-12 V

Tab. 2 THE RELATIONSHIPS BETWEEN PWM AND MAX. CURRENT [3].

PWM	SAE continuous current	SAE current peak
100% = 1kHz	maximum current value	maximum current value
50%	30A	36A peak
40%	24A	30A peak
30%	18A	22A peak
25%	15A	20A peak
16%	9.6A	
10%	6A	

Tab. 3 SAE J1772-CCS CHARGING TECHNICAL DATA

SAE J 1772-2009 CCS DC Charging Hybrid (PHEV)-14kWh, Electric Vehicule (EV)-24kWh)				
Level 1				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
200-450	< 80	< 36	PHEV 0-80	22 min
			EV 20-80	1.2 h
Level 2				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
200-450	Up to 200	< 90	PHEV 0-80	10 min
			EV 20-80	20 min
Level 3				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
200-600	400	< 240	not been determined	
			Only EV 10-80	<10 min

Tab. 4 SAE J1772-2009 CHARGING TECHNICAL DATA

SAE J 1772-2009 AC Charging Hybrid (PHEV)-14kWh, Electric Vehicule (EV)-24kWh)				
Level 1				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
120	< 12	< 1.9	PHEV 0-100	7 h
			EV 20-100	17 h
Level 2				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
240	< 14	< 3.3	PHEV 0-100	3 h
			EV 20-100	7 h
240	< 30	< 7	PHEV 0-100	1.5 h
			EV 20-100	3.5 h
240	< 80	< 20	PHEV 0-100	22 min
			EV 20-100	1.2 h
Level 3				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
not been determined		>20	not been determined	

3. CHAdeMO

3.1 History

CHAdeMO is trademark of fast charging method an abbreviation of "CHArge de MOve", equivalent to "move using charge" or "move by charge". The name is also a pun drawn from "O cha demo ikaga desuka" in Japanese translating to English as "How about some tea?", referring to the time it would take to charge a car.[5]

CHAdeMO timeline: [6]

- 2005- R&D on CHAdeMO begins
- 2009- First CHAdeMO infrastructure commissioned
- 2010- Establishment of CHAdeMO Association
- 2011- First charger in Europe deployed
- 2013- 100,000 CHAdeMO compatible EVs globally
- 2014- CHAdeMO published as IEC and EN
- 2014- 1,000th CHAdeMO charge point in Europe was launched
- 2015- 10,000 CHAdeMO charge points globally
- 2016- CHAdeMO was published as IEEE
- 2016- 150kW (max 400A) specification released
- 2017- Next generation of CHAdeMO should be launched.

3.1 CHAdeMO Plug

CHAdeMO connector is the most complicated between all charging standards. A "CHArge de Move" standard is only for DC charging, so its requires two plugs in car, one for AC charging (SAE J1770) and one for DC charging (CHAdeMO)-Fig. 5.

Fig.5 Nissan Leaf charging plugs, from left CHAdeMO and from right SAE J1772 type 1 (US) [6]

Fig. 5 shows a clear difference in size of CHAdeMO and SAE plugs. Description of the pinology in left connector is in Fig. 6.

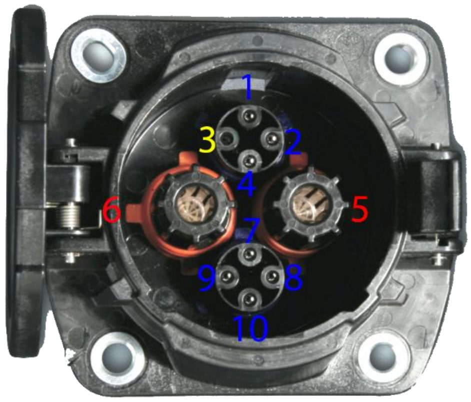

Fig.6 Zoom and description of CHAdeMO plug [6]

1) GND
2) Start/Stop charger
3) NC (not connected)
4) Start/Stop charging process
5) DC-
6) DC+
7) Control pilot (for connection control)
8) CAN bus High signal
9) CAN bus Low signal
10) Start/Stop charger.

3.2 CHAdeMO- Technical data

Communication between charger and charging car is provided by CAN bus. Using this communication type was due to the fact that every car must have can controller on board and it's simple way to make compatible between devices in car. CHAdeMO power levels are described in *Tab. 4*.

Tab. 5 *CHADEMO TECHNICAL DATA*

CHAdeMO technical data Hybrid (PHEV)-14kWh, Electric Vehicule (EV)-24kWh)				
Level 1 (DC only, hybrid-14kWh, EV-24kWh)				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
500	< 125	< 62.5	PHEV 0-80	~15min
			EV 20-80	~50 min
Level 2 (DC only) – not launched yet				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
500	< 200A	< 100	PHEV 0-80	<10min
			EV 20-80	<30 min

4. Tesla Supercharger

4.1 History

Fig.1 Tesla Supercharger Akkerhage , Ghent, Belgium.

Tesla company was incorporated as Tesla Motors in July 2003 by Martin Eberhard and Marc Tarpening. In 2008 Elon Musk- the largest private investor became CEO. Tesla is a the biggest American EVs manufacture but it's not all, they produce energy storages, solar panels, roof in solar technology and finally since 2012 in order to allow quick charging of Tesla cars – Tesla Superchargers – fast DC chargers. At the beginning of existing Tesla Superchargers are completely free for Tesla car owners. First Supercharger was built in 2012 in California, USA. It was a start point of big Supercharger station network across the biggest US highway. Today Tesla have 848 Supercharger stations on North America, Asia, EU & UAE with 5,487 Supercharger points (few on every station *Fig. 7*) [7].

4.2 Tesla Supercharger plug.

Tesla Supercharger is equipped with two plugs, one for AC charging (SAE J1772- *Fig. 3*) and second for fast DC charge- *Fig. 8* . This type of plug have only 5 pins, 2 big, and 3 smaller, which makes them the smallest solution for fast DC charging on the market. Charging stations have also adapter to CHAdeMO or SAE CCS 2 plug.

Fig.2 Tesla Supercharger fast DC plug. [8]

4.2 Tesla Supercharger-technical data

Tesla Superchargers can deliver up to 120 kW of power per car via DC current. Interesting option is free charge when the consumer owns of Tesla car which was ordered before 15th January 2017. After this date each car will receive 400 kWh of free Supercharging credits per year it was like 1,600 km of free riding per year. Tesla never published technical information about Supercharger, all available information was described in *Tab. 6* [8]

Tab. 6 *TESLA SUPERCHARGER-TECHNICAL DATA*

Tesla Supercharger technical data				
Level 1 (DC only) Tesla S (90kWh battery (577km range))				
Voltage [V]	***Current [A]***	***Power [kW]***	***SOC [%]***	***Time***
480	< 250	< 120	5-50 (60kWh)	~30 min
			0-100	~1h 15 min

5. Conclusions

All standards has good and bad solutions, SAE CCS have one plug for AC and DC, many stations in EU and USA, really high potential for upgrades. The biggest problem is with communication because charging level must be selected by charger, it is problematic especially in case of each car configuration because any EV need different power and voltage value.

CHAdeMO have huge charging station network on the world:

- 4,052 stations in Europe
- 7,133 stations in Japan
- 2,145 stations in USA
- 587 stations in other places on Earth
- It's 13,918 stations in all world.

Up to 32% of world EVs are equipped with a CHAdeMO inlet. Another 19%, Tesla EVs, are CHAdeMO-compatible thanks to Tesla's CHAdeMO adapter [9].

The most uncomfortable is the need for two plugs in the car separated to charge AC and DC, too low power compared to other standards, occupy more space than other solutions and unnecessarily increase the weight of the EV, the DC plug is too complicated and bulky.

Tesla`s solution have few unique features like free charging, also big network of charging stations, really innovation software with which consumer can planning a trip including superchargers places along to route. The biggest problem is another socket, now using only in Tesla`s cars, every other users must have special adaptor, another disadvantage is that like in CHAdeMO, two plugs- one for AC charging and second for DC charging.

This review aims to determine the most appropriate standard for charger work for EV for the European market. Because of the advantages and popularity of the standard in the world SAE CCS was chosen as the basis for creating a mathematical model and then 25kW prototype on which further research will be conducted.

My research is on matching and using a PSFB (Phase Shifted Full Bridge) topology synchronous converter with bi-directional energy transfer capability between smart grid and a vehicle.

6. References

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