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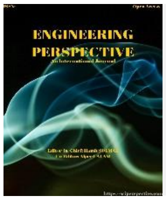

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Review Paper

Charging Techniques, Infrastructure, and Their Influences

Ahmet Kilic[1]

[1] *Mechatronics Engineering Departmeny, Faculty of Engineering and Architecture, Nisantasi University, Istanbul, 34398, Türkiye*

ABSTRACT

The automotive industry is currently engaged in the biggest transformation of recent years. Electromobility presents a new technological challenge for the automotive industry. In this context, the charging system will play an important key player in the coming years. The requirements for charging systems are very dynamic and diverse from norms, standard and laws as well as from end customers. There is currently no common charging standard for the charging socket worldwide. Worldwide, three charging standards are currently established, which are supported by the European Commission, among others. Here, the individual components and functions charging technologies are systematically described. With this work, the current status for conductive charging technologies and the future trend is summarized. The power consumption of the battery was presented with a measurement result for one charging session.

Keywords: Charging infrastructure, Charging system, Charging technologies, Conductive charging, Electric vehicle

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Author Contacts
e-mail address: ahmet.kilic@nisantasi.edu.tr

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1. Introduction

Due to increasing air emissions and scarcity of fossil fuels, alternative drives such as electromobility are playing an increasingly important role in private motorized transport. As a result, electromobility is becoming increasingly important. Electromobility is based on the development and use of electrically powered and rechargeable vehicles and the move away from traditional vehicle design that uses fossil fuels and oils. Car manufacturers are showing high interest in the future with their new vehicle concepts and new charging technologies. In automotive development, powertrain and vehicle concepts are now changing fundamentally. In compliance with strict new regulations and laws, electromobility is trying to produce more environmentally friendly and efficient vehicles. Electromobility is important drivers for the future of the automotive industry. There are two types of electric vehicles, either all-electric vehicle or hybrid vehicle. A hybrid vehicle has both an electric drive and an internal combustion engine. Hybrid car has either full hybrid or plug-in hybrid. Full hybrid the battery is charged while driving. Plug-in hybrid the battery is charged at the charging station with a charging cable.

There were approximately 25.9 million electric vehicles in 2022, over nine million more vehicles than the previous year. In 2022, 18 million most of the vehicles were battery electric only and 7.9 million of the vehicles were plug-in hybrids. The number of electric cars is increasing worldwide and is expected to be about 226 million new electric cars by 2030 according to the International Energy Agency (IEA) [1]. Among them, most of the vehicles are expected to be exclusively battery electric, with around 180 million, and about 46 million of the cars will be plug-in hybrids, Figure 1 In Germany alone, The Federal Government has set a target of 15 million electric vehicles by 2030 and has been promoting them with the environmental bonus since September 2023.

The charging infrastructure plays a significant role in the future of electromobility development. Successful electromobility development depends on the technical and political supports. For the technical support of electromobility development, the optimization and further development of the HV battery with ranges, charging infrastructure with convenience and power grid with secure energy supply play a significant role. An important point is the competitiveness of electric vehicles, as the costs without subsidies are too high compared to a normal combustion engine. are too high compared to the normal combustion engine. The additional costs are due to the Batteries and their production [2]. As a result, manufacturers are under high-cost pressure to make the vehicles attractive for the market.

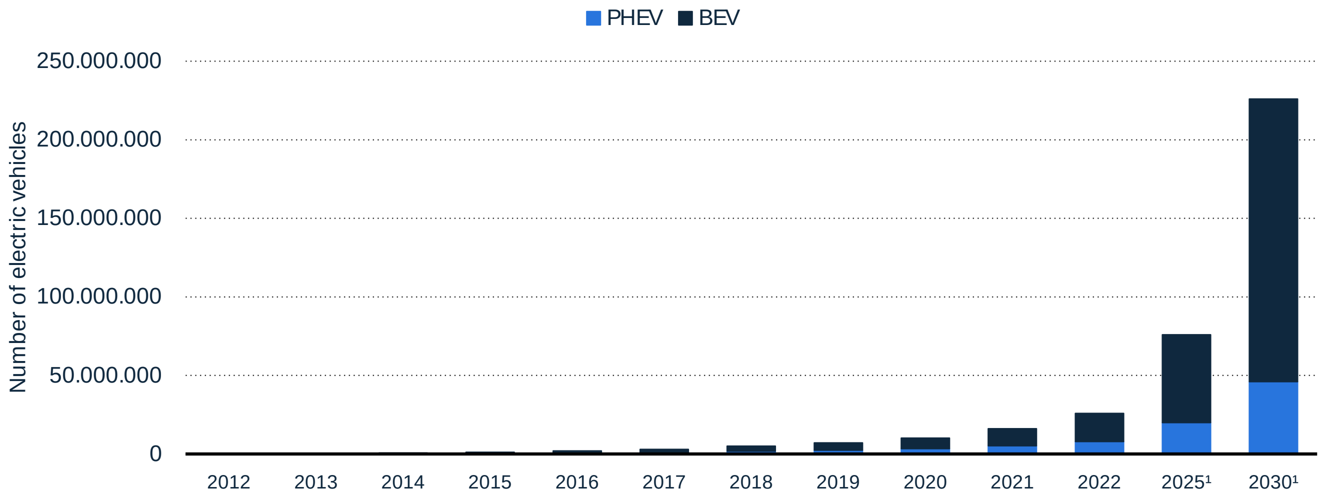

Figure 1. Number of electric vehicles worldwide from 2012 to 2022 and forecast to 2030 [1]

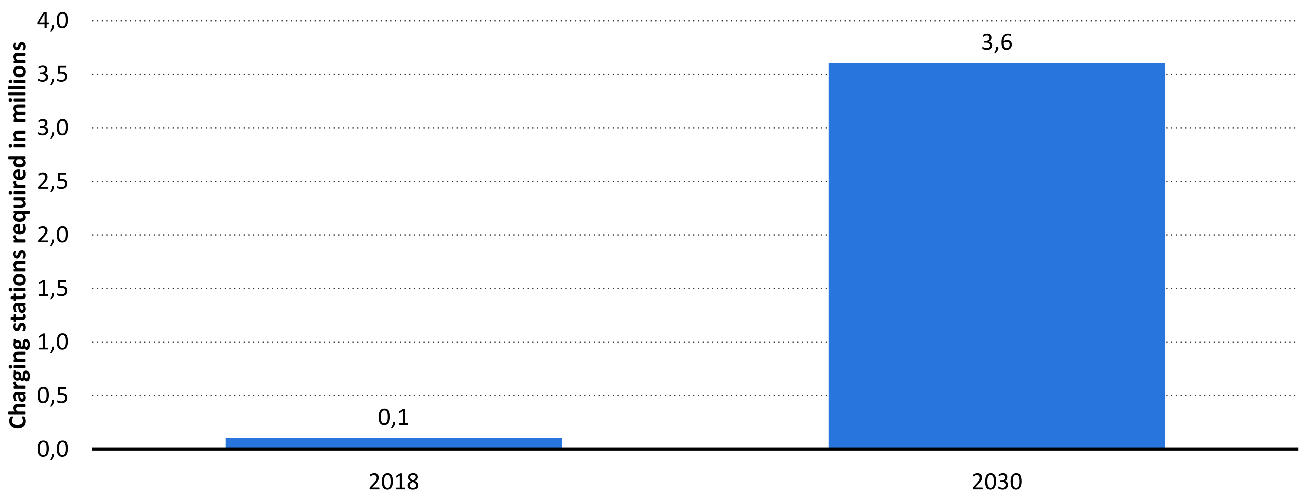

Figure 2. Prognosis for relevant charging stations in European Union countries [4]

In 2018, there were about 0,1 million charging stations in Europe, Figure 2. As the number of newly registered electric vehicles increases, the demand for relevant charging stations increases sharply [3]. Sufficient charging stations for electric vehicles need to be newly built. In Europe, about 3.6 million public charging stations will be needed by 2030 [4]. Thus, the demand of the electric vehicle can be compensated. In Germany in 2022, according to the Federal Network Agency, there were about 70,000 e-charging stations. The aim is to reach one million by 2030.

Improving customer acceptance for charging electric vehicles are essential secure and convenient charging process e.g., plug and charge, shorter charging times with sufficient power, sufficient available charging stations and high battery ranges.

The charging technologies are very dynamic [5]. There are always new requirements. With this work, current status and future for charging infrastructure parameters and their influences as well as conductive charging systems are considered and evaluated in Section 2. In section 3, the charging process and charging power from measurements are presented. In section 4 the results are summarized.

2. Charging Infrastructure Parameters and Their Influences

2.1 Electric vehicle

The main components in the electric vehicles are [5,6], Figure 3:

- High voltage battery
- Low voltage battery
- eAxle with electric motor
- Power electronics
- Charging converter
- Vehicle control unit

Energy is stored in the form of current in the high-voltage battery. The battery must be charged each time and its capacity determines the range of the vehicle. Electrical energy from the current stored in the high-voltage battery is converted by the electric motor into mechanical power by generating magnetic fields. These magnetic fields generate attractive and repulsive forces - and electric vehicles start driving.

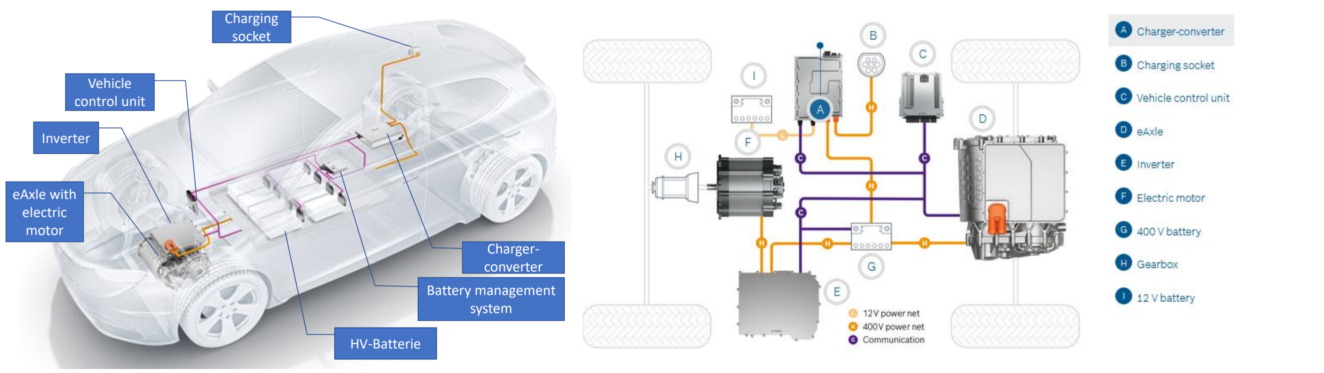

Figure 3. System overview electric vehicle [6]

2.2 Charging technologies

There are different systems for charging the HV battery [7-9], Figure 4. With this work conductive charging systems are considered. Conductive charging is done with the help of a cable and plug connection between the vehicle and the power grid [10].

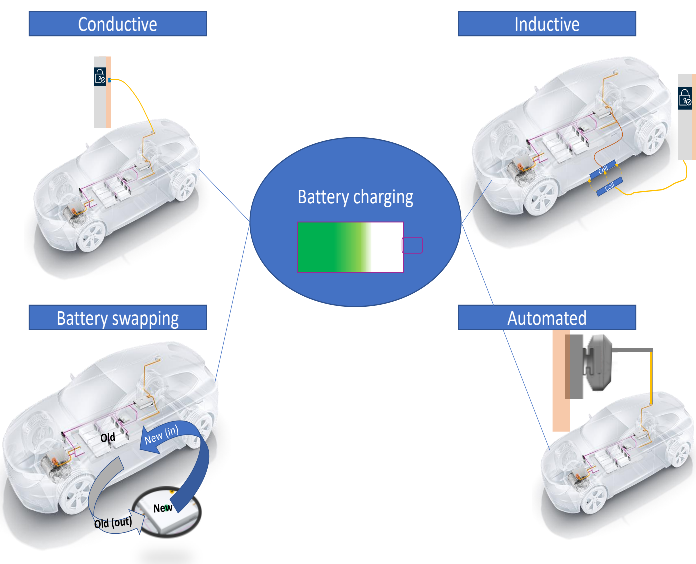

Figure 4. Charging systems for charging the high voltage battery

Charging the HV battery [11] with conductive system allows using the direct current (DC) or alternating current (AC) charging technologies. DC charging transports the direct current from DC charging stations directly to the battery. AC charging transports the alternating current from charging stations to the on-board charger (OBC). OBC converts alternating current to direct current and transports it to the battery in the vehicle, Figure 5.

2.3 Charging modes

There are different international norms and standards (ISO, IEC, DIN, DKE, SAE) for electric vehicles and charging systems. These norms and standards determine the plug types, charging modes, sockets, charging control, safety. The charging modes are defined according to international standard IEC 61851-1 [12]. There are four charging modes for electric vehicles. This charging mode describes the communication between vehicle and charging stations, safety, current and voltage limit, type of cable connection between vehicle and charging stations, type of charging technologies (AC or DC), Figure 6.

Charging mode 1-3 describes AC charging with a standardized plug-in device. Charging mode 4 describes DC charging at a permanently installed charging station. Due to the high safety requirements, the charger is not located in the vehicle but is part of the charging station. The charging line is also permanently connected to the charging station. In Mode 4, the vehicle can be charged using two different plug-in systems. The "Combined Charging System" (CCS) with a charging current of up to 200 A and a charging power of up to 170 kW and the CHAdeMO system originating from Japan with a lower charging power.

2.4 Charging plug types

The communication and energy transfer between charging station and vehicle was done with charging plug in conductive charging. The plug types for electric vehicles is summarized with international standard IEC 62196 and is maintained by the International Electrotechnical Commission (IEC). According to the standard, the plug types must be adapted between the vehicle and the charging stations. There are currently different plug types worldwide. The plug types are based on the regions, current type (AC or DC), maximum power (current and voltage), Figure 7. A high charging power leads to a faster charging of the battery.

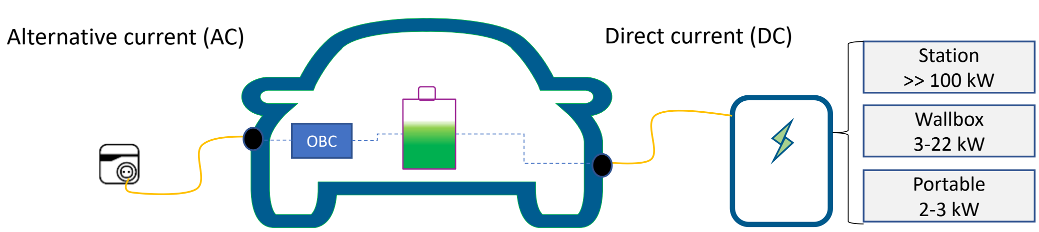

Figure 5. Conductive charging technologies for charging the HV battery

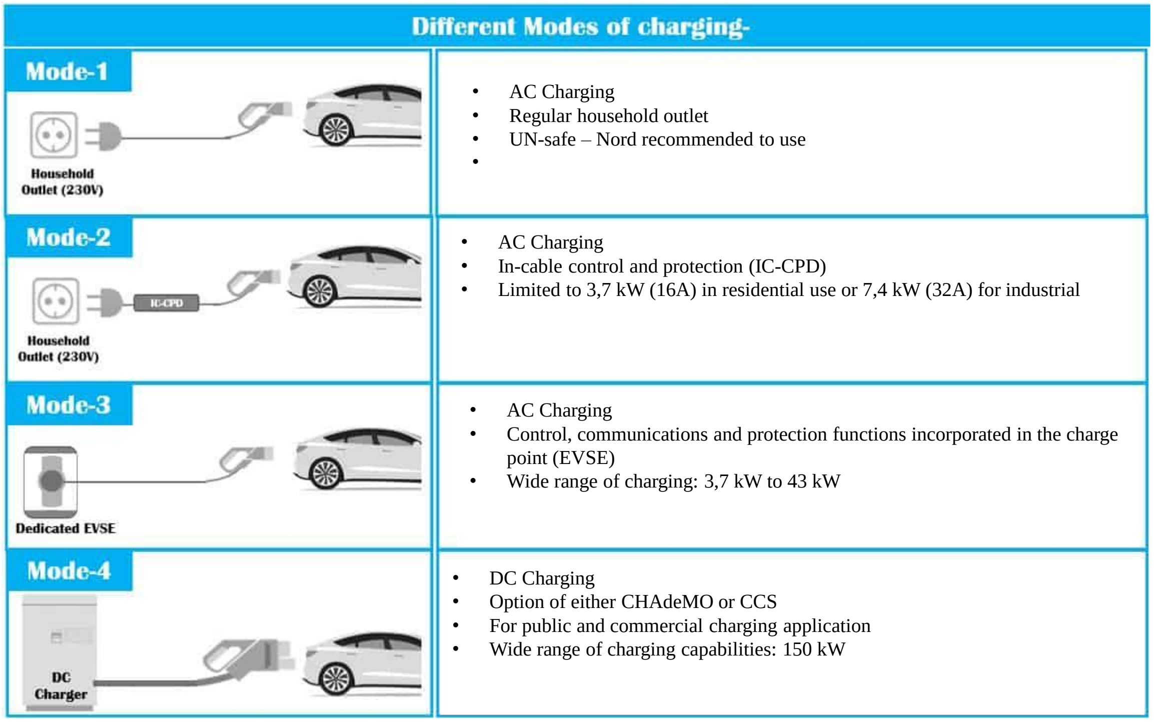

Figure 6. Modes of charging [14]

Combined Charging System (CCS):

Combined Charging System describes a combined fast charging system and is an international charging standard according to IEC 62196 [15]. The plug variants are Combo-2 (Type 2) for EU and Combo-1 (Type 1) for NA standardized. The standardized CCS connector system can be used to implement both DC and AC charging methods [16]. The plug is divided into 2 sections. The upper part corresponds to the Type2 connector, which is used in the DC area only for communication between the vehicle and the charging pole. The lower part is used for DC charging. Thus, the CSS connector in the vehicle offers the possibility to use both DC and AC cables. With the CCS connector, charging can be done via direct current with a power of max. 350 kW and voltage 400 V (up to 950 V). The charging power is strongly dependent on the battery charge level and temperature.

CHAdeMO plug:

The CHAdeMO plug describes a Japanese fast charging plug for charging with direct current (DC) up to 400 kW power (CHAdeMO 2.0).

Type 1 plug:

Type 1 plug describes a single-phase plug with its maximum charging power at 7.4 kW (230 V, 32 A) and is an international charging standard standardized according to SAE J1772 as well as used inn North America and Asia.

Type 2 plug:

Type 2 plug describes a three-phase plug with its maximum charging power at 43.5 kW (4000 V, 63 A) and is an international charging standard standardized according to IEC 62196-1 and used in Europe.

GB/T plug:

The CHAdeMO plug describes a Chinese fast charging plug according to 20234- GB/T standard for charging with alternating and direct current. There are two variants of GB/T plugs: one for AC charging and one for DC fast charging. The GB/T AC charging plug is single-phase and delivers up to 7.4 kW. It does look the same as the Type 2 plug.

Tesla plug:

Tesla connector describes AC and DC charging capabilities according to NACS standard with AC connector 240V, 48A and with CD connector 1000V, 400A. NACS stands for the North American Charging Standard and is the proprietary charging plug used by Tesla vehicles in North America. It has been adopted by several automakers, including Ford, GM, Rivian and Lucid, signaling a shift away from CCS in North America.

ChaoJi plug:

There are different charging technologies currently in the market for charging the electric vehicle. The requirements are to develop a uniform, international, faster and safer charging technologies. For this, there are different development activities worldwide. Japan and China agreed to jointly develop a next generation charging technology. This is referred to as "ChaoJi." It has the potential to become a global standard with power up to 900 kW [18]. In addition, it is also much more compact. Due to the high charging power, electric vehicles are charged within a very short time. Even very large batteries of electric trucks can thus be charged faster with the ChaoJi connection.

Megawatt Charging System (MCS):

Megawatt Charging System describes a fast-charging system for mainly trucks with a power 4.5 MW (max charging current 3000 A, 1.5 kV) and further development of CCS. MCS technology is currently in the development phase with international partners and standardization committees [20,21].

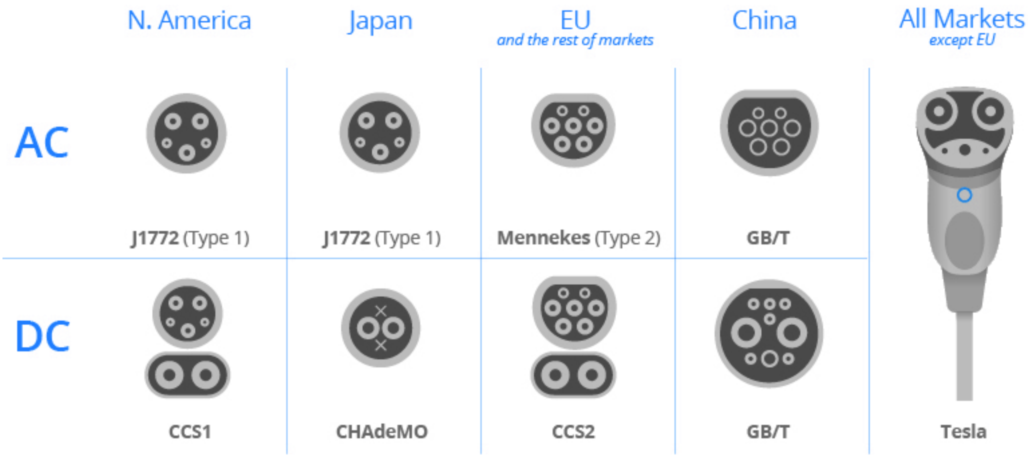

Figure 7. Types of electric vehicle chargers [17]

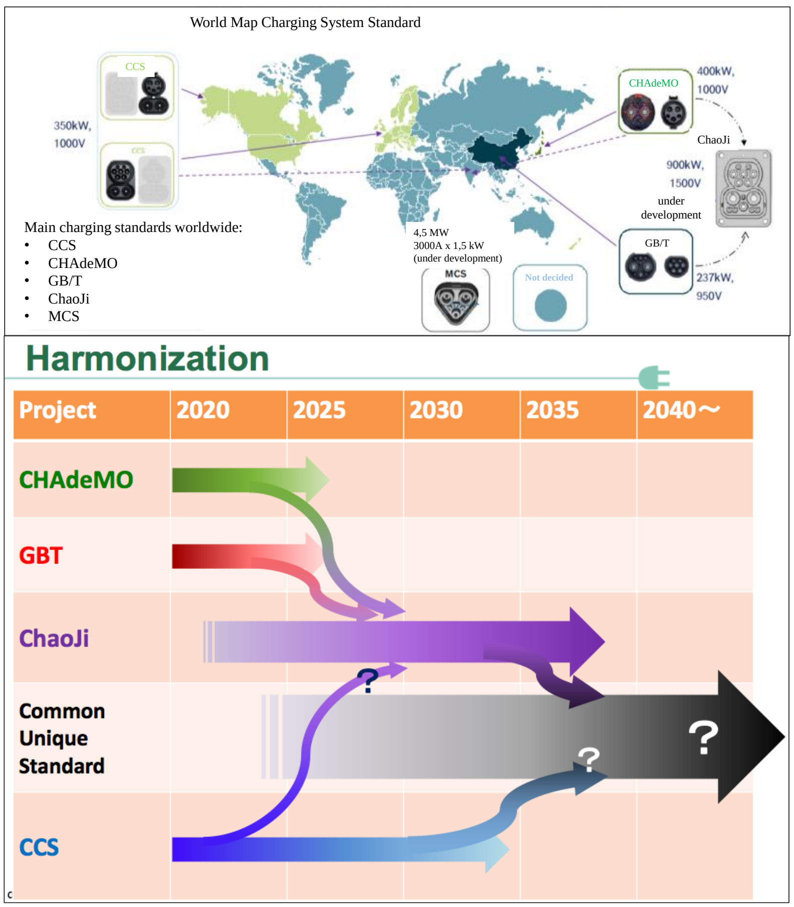

Figure 8. Trend for charging technologies [18,19]

3. Charging Process and Charging Capacity

3.1 Charging process

Cable is plugged into vehicle. The lines marked PP and CP correspond to the plug detection (PP) and the pilot line (CP). The existing CP and PE (ground) lines are used for high-level communication [22,23]. The connection to the control units of the EVSE and the vehicle is made via one PLC modem each. Charging process must be prepared: First, the charging cable is connected, insulation test is performed, voltage to the battery is regulated, then first pre contactors are closed. Before the energy transfer from charging station to electric vehicles is started, the relevant current and voltage limit and demand must be sent from vehicle (battery) to charging station. The current and voltage demand of the battery is sent from vehicle to charging station. Charging station provides this requested power demand to vehicle. Then the main contractor in the charging station is closed. Thus, the energy transfer to vehicle started until the HV battery is charged, Figure 9.

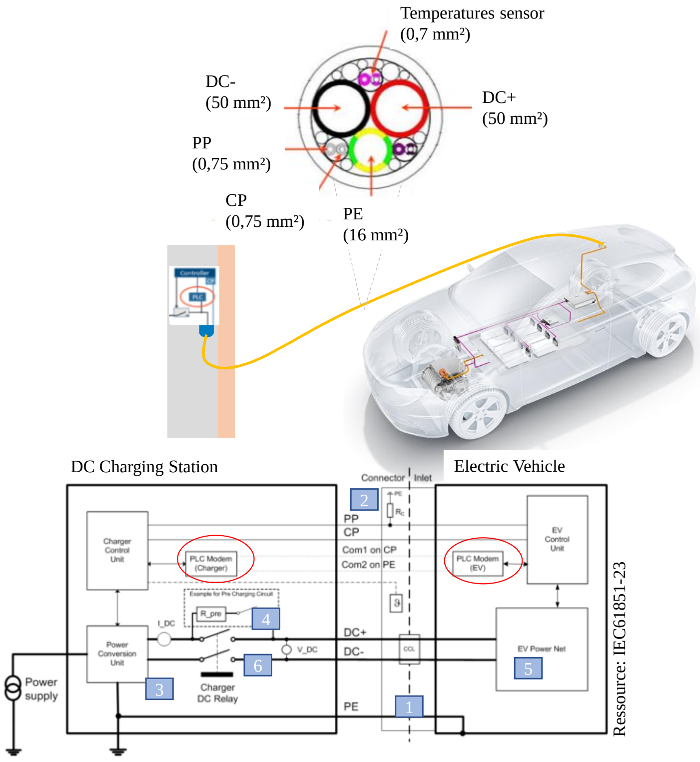

Figure 9. Charging process and architecture for DC charging

3.2 Charging capacity

One of the important requirements for charging a battery is the duration of the charging process. The duration depends on the charging power of the vehicle and the charging station. The trend is towards the shortest possible charging time for a charging process. Increasing the charging power of the vehicle and the charging station can lead to faster charging of the electric vehicle (battery), Figure 10. The charging power is determined by the amperage, voltage and number of phases. Household appliances usually use only one phase, but electric vehicles can also be charged in three phases. In this way, double or triple the power reaches the vehicle - while the amperage remains the same. With a three-phase connection, the way in which the charging station is connected to the grid also plays a role. Depending on whether it is connected in a star or delta connection, the voltage is 230 or 400 volts.

Enclosed is the charging capacity (single-phase alternating current):

•Charging capacity (3.7 kW) = phases (1) * voltage (230 V) * amperage (16 A)

Charging capacity (three-phase, three-phase alternating current), star connection:

•Charging capacity (22 kW) = phases (3) * voltage (230 V) * amperage (32 A)

After the contactors of charging station and battery are closed, the energy transfer from charging station to HV battery is started. Thus, the battery voltage increases, Figure 11. To avoid damage of HV battery, the charging process of the battery is set at constant charging current. This also prevents the battery from aging faster. The voltage of the battery is regulated at constant battery current until the SOC reaches 80%. SOC state from 80% to 100%, the battery current is reduced at constant the voltage of the battery.

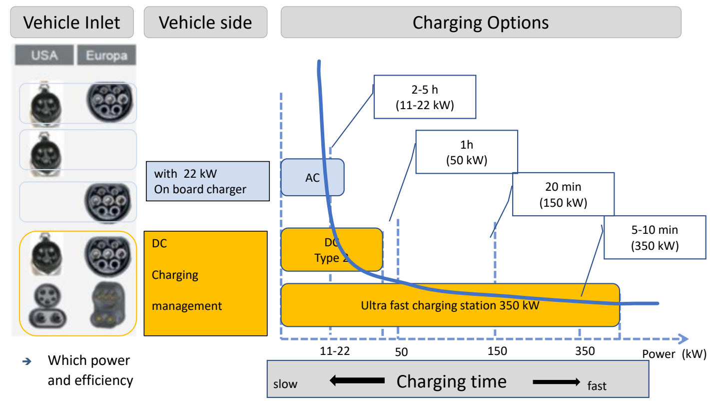

Figure 10. Relationship between charging capacity-charging duration

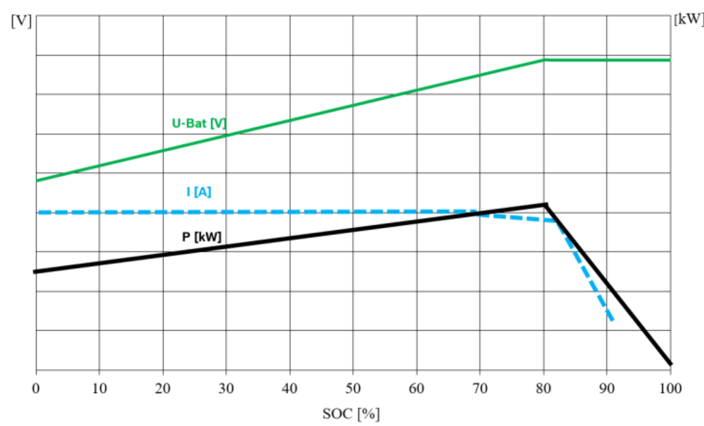

Figure 11. Battery charging power for one charging process

4. Conclusions

The charging infrastructure is the important key player for electric mobility. Here, the current status for electric vehicle and charging stations and for the future prognosis worldwide is presented. Demand of relevant charging stations have increased drastically.

With this work, the latest trend and charging technologies regarding charging plug ChaoJi and Megawatt Charging System plug, and their roadmap are presented.

The requirements for charging power and charging time are presented. The goal is to charge HV battery within the shortest time. There is trend towards ultra-fast DC charging with 350 kW charging power.

Here the regulation of charging power was interpreted with a measurement result first by voltage and then by current and the power consumption of the battery was evaluated for one charging process with measurement result.

Nomenclature

AC	Alternating Current
BEV(s)	Battery Electric Vehicle(s)
BMS	Battery Management System
CC	Constant Current
CCS	Combined Charging System
CHAdeMO	CHArge de MOve
DC	Direct Current
EV(s)	Electric Vehicle(s)
EVSE(s)	Electric Vehicle Supply Equipment(s)
GB/T	Guo Biao/Tuījiàn (Recommended)
HPC	High Power Charging
HEV	Hybrid Electric Vehicle(s)
I	Battery current
IEA	Internationalen Energieagentur
IEC	International Electrotechnical Commission
MCS	Megawatt Charging System Stecker
OBC	On-Board-Charger
P	Charging capacity (power)
PHEV	Plug-in Hybrid Electric Vehicle
SOC	State of Charge
SoH	State of Health
U-Bat	Battery Current

Conflict of Interest Statement

The author declare that there is no conflict of interest in the study.

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