COMPARATIVE ANALYSIS OF TECHNICAL CHARACTERISTICS OF CHARGING STATIONS OF ELECTRIC VEHICLES

Oleh Velychko, Dr.Sc., Prof.
State Enterprise "Ukrmetrteststandard", Ukraine; e-mail: velychko@hotmail.com
Tetyana Gordiyenko, Dr.Sc., Prof.
State University of Telecommunications, Ukraine; e-mail: t_gord@hotmail.com

Abstract. The article analyzes and compares charging stations for electric vehicles and their components. The analysis of charging modes of electric vehicles showed that four internationally standardized modes are used, three of which use alternating current with single-phase and three-phase switching and only one – direct current. When charging on direct current, the fastest charging is provided. There are four standardized cases of connecting charging stations to electric vehicles. Three cases of cable connection can be used on alternating current, only the third case – on direct current, and the fourth case – when wirelessly charging an electric car. Analysis of the principles of use of charging stations showed that they classify portable, wall, and stationary stations. National standards introduce road signs for electric vehicles, and a European standard establishes harmonized identifiers for the power supply of electric vehicles. There are some standardized protocols for the interaction of the charging station and the control server, which are designed to optimize energy resources and energy production systems. A comparison of existing types of connectors for charging electric vehicles has shown that the standardized interface between the charging station and the electric vehicle remains one of the most acute problems. Recommendations on approaches to metrological support of charging stations are formulated. The issue of international and regional standardization of electricity meters of direct current for use in charging stations remains relevant. International standards are transformed into relevant European standards without changes. However, in some cases, it is necessary to develop a special European standard, in particular for meters of active electrical energy of the direct current.

Key words. The charging station, electric car, charging mode, charging connector, interaction protocol, graphic image of the charging station.

1. Introduction

Electric mobility is a rapidly evolving field, electric cars are inevitably entering our lives and their era is coming. An electric vehicle is a vehicle equipped with a power plant containing at least one non-peripheral electric machine as an energy converter with an externally charged energy storage system [1]. Instead of an internal combustion engine, electric cars use one or more electric motors. The advantage of this use of electric motors is not only the absence of harmful emissions into the atmosphere but also a higher efficiency (up to 95%, while for diesel internal combustion engines – up to 45%). The electric car has fewer assembly units, relative simplicity of design, and low center of gravity, as the battery is part of the power structure of the body and is located directly "on the floor".

Electric cars require charging their battery with electricity. You can charge an electric car in any place where there is an electric network, and this is their great advantage. More and more car owners around the world are choosing electric cars instead of cars with internal combustion engines. The percentage of complete electric cars with electric motors in the world is constantly growing, so the issue of expanding the network of charging stations for electric vehicles (EV) charging stations for them will become increasingly important. The electric motor of an electric car uses direct current (DC), while public energy networks use alternating current (AC). Therefore, in the case of charging an electric car from the normal mains, a special current converter is additionally required, the function of which is performed by the built-in charger of the electric car.

Existing EV charging station interface technologies include cable connectors, but future technologies for such interfaces should also include wireless charging systems. Directive 2014/94/EU [2] requires periodic updating as necessary to take into account the necessary standards for technologies such as wireless charging and battery replacement. The EU is interested in developing new standards or revising existing standards to ensure compatibility and connectivity between the power supply point and the EV charging station.

2. Drawbacks

In [1], four types of EV charging stations are identified and classified, of which the first type describes the process of charging an electric vehicle directly from a single-phase power supply. In [3] discusses some types of connectors for charging electric vehicles and ways to charge them. In [4] presents a mobile charging system (MCS) for electric vehicles. MCS energy storage capacity and the ability to charge five electric vehicles simultaneously have been developed. An appropriate modular power interface has been developed and implemented between MCS, electric vehicle batteries, and electrical substations.

Directive 2014/94/EU [2] contains the technical characteristics of charging points for both conventional and high-power charging points for electric vehicles and wireless charging points. Both conventional AC charging points for electric vehicles and high power. High-power DC charging points for electric vehicles must be equipped for compatibility with the connectors described in the special European standards. The choice of equipment for normal and high-power charging points must meet the specific safety requirements in force at the national level.

The number of publications on the implementation of EV charging stations is not very significant. At the same time, the analysis and comparison of all the main components of EV charging stations and the formulation of recommendations for their development remain an urgent task.

3. Goal

The purpose of the research is to analyze and compare the components of EV charging stations and formulate recommendations for approaches to their improvement.

To achieve this goal the following tasks are solved:

–analyze charging modes and cases of connecting EV charging stations to electric cars;

– analyze the principles of use of EV charging stations and protocols of its interaction;

– compare the types of connectors for charging electric vehicles and determine their main technical characteristics;

– identify problematic directions of EV charging stations implementation and ways of its solution.

4. Charging modes and cases of connecting charging stations to electric vehicles

The charging point of an electric car is an interface that can charge one electric car or replace the battery of one electric car. A normal electric vehicle charging point is a charging point that allows electricity to be transmitted to an electric vehicle with a capacity of up to 22 kW, except for devices with a capacity of less than or equal to 3.7 kW, which are installed in private households. The recharging point of a high-power electric vehicle is a charging point that allows you to transfer electricity to electric vehicles with a capacity of more than 22 kW [2].

Two methods are used to charge electric cars: alternating current and direct current. Charging of electric cars with AC occurs through a special charger, which is built into the electric car, and refers to as "slow charging". Electric vehicles are equipped with special battery management systems (BMS), which control the chargers of electric vehicles. Charging electric cars with DC refers to "fast charging".

The International Standard IEC 61851-1 [1] applies to power supply equipment for charging electric road vehicles with a nominal supply voltage of up to 1000 V AC or up to 1500 V DC and a rated output voltage of up to 1000 V AC or 1500 V. This standard distinguishes four types of charging of electric cars depending on the level of protection and management. Modes of charging electric cars are given in Table. 1. The first three modes (modes 1-3) use AC. Each electric car has a built-in charging station, which is supplied with AC power, and from it, there is a charge to the battery with DC.

Table 1

Charging modes of electric cars (European countries)

Quantity	Mode 1	Mode 2	Mode 3	Mode 4
Alternating current	up to 16 A	up to 32 A	up to 63 A	up to 400 A
Voltage	220–240 V	220–240 V	220–230 V	up to 600 V
Power	2–4 kW	7–8 kW	7,2–43 kW	up to 250 kW
Connection mode	single-phase, three-phase			
Full charge time	10–12 hours (battery capacity 30-35 kWh)	6–8 hours (battery capacity 20-24 kWh)	0,5–4 hours	30 minutes

The minimum level is Mode 1, which provides a direct connection with a simple extension cord without additional means of communication control of the charging station between the network and the electric car. This mode is considered dangerous and prohibited in many countries, as without constant user control can lead to overheating of the equipment and fire. In Mode 1, a normal household electrical network is used. Charging in Mode 1 (standard IEC 61851-1 [1]) for single-phase connection – charging power up to 4 kW (16 A, 250 V), and for three-phase connection – up to 11 kW (16 A, 480 V).

Mode 2 also uses standard household or industrial connectors but uses a special cable with a portable charger IC-CPD (In-Cable Control and Protection Device) according to standard IEC 62752 [5]. The built-in controller monitors grounding, temperature, and charging process, as well as protects against overheating and short circuits. This mode is popular for use in private homes, individual parking spaces, and closed areas of residential complexes. Charging in Mode 2 (standard IEC 61851-1 [1]) for single-phase connection – charging power up to 8 kW (32 A, 250 V), and for three-phase connection – up to 22 kW (32 A, 480 V).

Mode 3 involves the use of a cable with special connectors on both sides and connection to special chargers – Electric Vehicle Supply Equipment (EVSE). This is the most popular charging mode, as EV charging stations with this mode are available from 3.7 kW for private use to 44 kW for fast charging in commercial facilities, municipal parking lots, etc. Charging in Mode 3 (standard IEC 61851-1 [1]) for single-phase connection – charging power up to 8 kW (32 A, 250 V), and for three-phase connection – up to 44 kW (63 A, 480 V).

In Mode 4, charging takes place by bypassing the onboard converter of the electric car – the connection goes directly to the batteries of the electric car through special outputs of the charging control system. Since the conversion of AC into DC takes place in the EV charging station, this allows overcoming the limitations on the maximum charge current of the onboard charger. This mode is the fastest but is not usually used in the private sector due to its high cost. The peculiarity of "fast charging" of the electric car in mode 4 is that the battery charge in this mode of 80% is achieved quickly, while the other 20% of the charge lasts longer. This is due to the technological processes of charge/discharge and is aimed at increasing the service life of the traction battery. Charging in Mode 4 (standard IEC 61851-1 [1]) on DC – charging power up to 80 kW (200 A, 400 V).

Modes 2, 3, and 4 must verify the correctness of the connection to the electric vehicle, the power supply modes, and the continuity of the protective earth. These control functions are achieved by using Pulse Width Modulation (PWM) or other systems, depending on the connectors used.

There are also other classifications depending on the characteristics of the network. For example, in the USA according to the SAE J1772 standard, there are three levels of charge. The first involves charging from a single-phase household power source and is the slowest, and the third – is a fast option for DC charging.

Tesla Supercharger EV charging stations [6] have such advantages in terms of power and, accordingly, the speed of charging the battery. The maximum power of the world network Supercharger V2 is 120 kW. With it, even the most voluminous Tesla Model S battery (90 kWh) is fully charged in just 40 minutes. Tesla has already launched the third generation Supercharger – V3, whose charging capacity, and efficiency are even higher – peak power of 250 kW. A new design with liquid cooling is provided for this purpose. However, the V3 requires a new special cable.

The connection of the electric vehicle using cables and connectors can be done in one of three ways, which in the standard IEC 61851-1 [1] are called cases. In Case A (Fig. 1, a) the connection to the AC mains (EV charging station) occurs without transient elements. The cable with the plug is first attached to the input of the onboard charger of the electric car. In Case B (Fig. 1, b) the connection is made by a cable that is disconnected from two sides – the charging station and the vehicle. This connection can be made to household or industrial connectors, as well as to special chargers for electric vehicles. In Case C (Fig. 1, c) the cable with the portable socket is attached to the charging station without the possibility of disconnection. EV charging stations in this case are made only with this type of connection.

Case A is used for modes 1 and 2 on AC. Case B is used for modes 2 and 3 on AC and has two varieties: Case B1 is the connection to a wall outlet (mode 2); Case B2 is the connection to a special socket (Mode 3). Case C is used for Mode 3 (AC) and mode 4 (DC).

In addition to these cases, there is another case of Wireless Charge Transfer (WPT) of an electric vehicle (Fig. 1, d). Wireless chargers, which are based on the principle of magnetic induction, are not yet very common devices. In addition, they require equipping the electric car with special equipment. The base station is mounted in a special parking lot or your garage, and the receiver is installed under the bottom of the electric car. A huge number of companies such as Plugless, WiTricity, Evatran, BMW cars, and Volvo are currently experimenting with this type of charger. Experimental tracks with special lanes for continuous charging are being built in many countries, including the United Kingdom.

The International Standard IEC 61980 applies to EV charging stations using wireless methods at a standard supply voltage of up to 1000 V AC and up to 1500 V DC and has three parts: IEC 61980-1 – general requirements [7], IEC TS 61980-2 – special requirements for communication between an electric vehicle and infrastructure [8], IEC TS 61980-3 – specific requirements for wireless energy transmission systems by a magnetic field [9].

The standard IEC 61980-1 applies to WPT equipment supplied with local storage systems (e.g., buffer batteries). It also contains the characteristics and operating conditions of the charger, the specification of its required level of electrical safety, and specific requirements for its electromagnetic compatibility (EMC), etc.

The standard IEC TS 61980-2 applies to the communication between the electric vehicle and the WPT when connected to the mains. It also applies to WPT equipment supplied from local storage systems (e.g., buffer batteries). It also contains the performance and functional performance standards of the WPT communication subsystem, the communication requirements for the WPT driving system under consideration, the communication requirements for two- and three-wheeled vehicles under consideration, and the communication requirements for bidirectional power transmission.

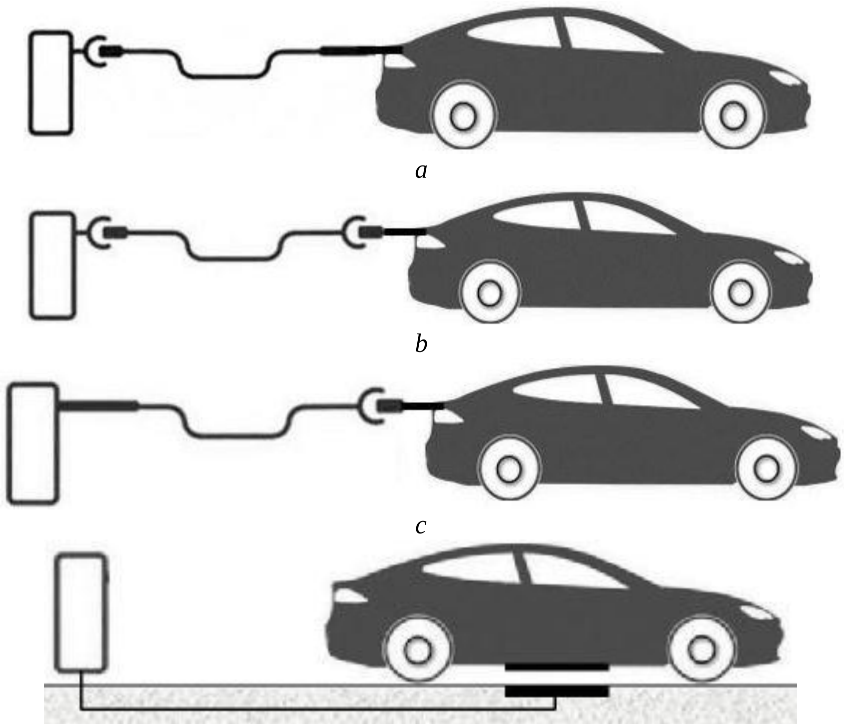

Fig. 1. Cases of charging of electric cars:
a – Case A; b – Case B; c – Case C; d – wireless charging

The standard IEC TS 61980-3 applies to equipment for wireless transmission of power by magnetic field (MF-WPT) electricity from the mains to the electric vehicle to supply electricity to the REES (battery storage system) and/or other onboard electrical systems. Power transmission occurs when the electric vehicle is stationary. This standard also applies to MF-WPT equipment supplied with storage systems (eg buffer batteries). It also contains the characteristics and operating conditions, the required level of electrical safety, basic safety and process communication requirements if required by MF-WPT, positioning requirements to ensure efficient and secure MF-WPT power transmission, and specific EMC requirements for systems MF-WPT.

5. Principles of using EV charging stations, their graphic symbols, and protocols of their interaction

EV charging stations can be classified according to the principle of their use:

– portable station for one or more places (Fig. 2, a);
– wall station (Fig. 2, b);
– stationary station (Fig. 2, c).

In many countries, there are special road signs for EV charging stations. The view of the general sign of the EV charging station is shown in Fig. 5.

In 2020, new road signs “For electric cars”, and “Electric car charging station” were introduced in Ukraine (Fig. 6). Changes have also been made to the state-building norms of Ukraine regarding the definition of mandatory parameters, and detailed requirements for the arrangement of parking spaces and/or parking spaces for vehicles equipped with electric motors (one or more).

European Standard EN 17186 [10], entered into force in 2021, establishes harmonized identifiers for the power supply of electric vehicles. The requirements of this standard complement the information needs of users regarding the compatibility between EV charging stations, cable assemblies, and vehicles on the market. The identifier is intended for visualization on EV charging stations, vehicles, cable assemblies, dealerships of electric vehicles, and user manuals. This standard specifies for each harmonized identifier the size, shape, color, and other information relevant to compatibility recognition as well as the location of the label. The identifier on the station side provides unmistakable information about compatibility either with the plug of the cable node in the case of a socket configuration or with the vehicle inlet if the configuration of the connected cable.

a *b* *c*

Fig. 2. Principles of using EV charging stations:
a – portable station; b – wall stations; c – stationary station

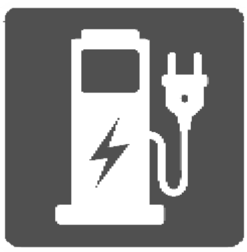

Fig. 5. EV charging station

Fig. 6. Sign of EV charging station

According to standard EN 17186, the identifier consists of a hexagon, black for the side of the electric vehicle and white with a black outline for the side of the station, with a letter indicating the type of connector (Table 4).

The issues of compatibility of information transfer between the electric vehicle, the local installation for its charging, and the information exchange network are among the most important. This connection serves to optimize energy resources and energy production systems, as electric vehicles can be charged or discharged in the most economical or energy-efficient ways.

The International Standard ISO 15118 [11] applies to the Highest Level of Communication (HLC) for wired and wireless power transmission technologies in the context of manual or automatic connection devices. This standard also applies to the transmission of energy either from power supply equipment to charge an electric vehicle battery, or from an electric vehicle battery to power supply equipment to power a house, load, or network. It provides an overview and common understanding of the aspects that affect the identification, association, control, and optimization of charging or discharging, payment, load balancing, cybersecurity, and confidentiality.

There are several protocols for the EV charging station and control server interaction.

OCPP (Open Charge Point Protocol) is an open protocol of interaction between the EV charging station and the management server: versions of OCPP 1.2-1.5 is one of the first versions of this protocol used in EV charging stations released before 2017; OCPP version 1.6 SOAP is updated version of OCPP protocol 1.5; OCPP version 1.6 Json is a protocol that uses a web socket connection to the EV charging station, which does not require a public white IP address of the EV charging station; OCPP 2.0 is the version of the protocol used in the new EV charging stations.

ModBus is an open communication protocol based on the Master-Slave architecture. This protocol is a messaging structure that is widely used to establish "master-slave" communication between smart devices. The ModBus message sent from master to slave contains the master's address, command, data, and checksum. Because this protocol is a messaging structure, it depends on the basic physical layer, which is traditionally implemented using the widespread communication ports RS232, RS422, or RS485.

Table 4

Marking of EV charging stations for the EU

Type of connector	Mark	Voltage
AC		
Type 1	B	up to 250 B
Type 2	C C	up to 480 B
Type 3A	D	up to 480 B
Type 3B	E	up to 480 B
DC		
Type AA	M	50–500 B
	N	200–920 B
Type FF	K	50–500 B
	L	200–920 B
Type 2 (Tesla)	O	50–500 B

Different electric cars have different charging requirements in terms of charging power, charging time, and DC or AC charging. Therefore, several standards have been developed for regulating the Electric Vehicle Supply Equipment (EVSE) interface, which automatically determines the car and its technical characteristics to regulate the charging process of the electric car. The Electric Vehicle Communication Controller (EVCC) protocol is a key component in maintaining communication between an electric vehicle and its fast charger. This protocol is a gateway for the mutual exchange of information between the external charger and the car engine control unit.

The OCPI (Open Charge Point Interface) protocol is used to connect third-party operators. Through this protocol, operators provide various services, such as PlugShare charging electric vehicles, transportation services, and gas stations – have the opportunity to connect to the charging infrastructure and expand the variety of services provided to customers. This protocol is based on EvRoaming technology, with which customers can charge their electric car in any network of charging stations.

The Online Certificate Status Protocol (OSCP) is an open protocol for communication between the EV charging station management system and the electricity supplier's management system, as well as to communicate with other local power control systems, such as power load balancing systems (Distribution System Operator, DSO). With the help of the protocol, you can implement online forecasting of the available power of the grid, within which the service provider or operator sets the charging profiles, such parameters as charging station power, number, and length of charging sessions, no more than available grid capacity.

6. Types of connectors for charging electric vehicles

Requirements for the types of connectors by which electric vehicles are connected to charging stations are set in three parts of the International Standard IEC 62196: IEC 62196-1 [12] – general requirements; IEC 62196-2 [13] – for AC; IEC 62196-3 [14] – for DC. The standard IEC 62196-1 applies to plugs, sockets, transport connectors, transport inputs, and cable assemblies for electric vehicles intended for use in conductive charging systems containing controls with a rated operating voltage (hereinafter referred to as accessories) not exceeding 690 V AC from 50 Hz to 60 Hz at rated current not more than 250 A. The standard IEC 62196-2 applies to accessories for charging electric vehicles with a rated operating voltage not exceeding 480 V AC from 50 Hz to 60 Hz and a rated current not exceeding 63 A for three-phase connection or 70 A for single-phase connection. The standard IEC 62196-3 standard applies to accessories that include controls with a rated operating voltage of up to 1000 V AC and a rated current of up to 250 A.

The main AC connectors are types 1 and 2, depending on the region in which they are operated.

The Type 1 connector (SAE J1772) was developed jointly by the United States and Japan for a single-phase AC EV charging station (also known as the Yazaki or J-connector) and is widely used by manufacturers in the United States, Japan, and South Korea. It has three power contacts: L1 (first phase contact), N (neutral contact), and PE (ground or zero contact), as well as two pilot contacts to control the EV charging station. Its design also provides a mechanical latch to prevent accidental shutdown. This connector is used for currents up to 80 A and voltages up to 240 V.

The Type 2 or Mennekes connector has single-phase and three-phase versions and was developed for electric car manufacturers in Germany. Since 2013, this type of connector has been recognized as the official type for all EU EV charging stations. The single-phase version of this connector differs only in the absence of contacts L2 (contact of the second phase) and L3 (contact of the third phase). Both versions have the same dimensions, which allows to embrace a three-phase cable for single-phase charging, but charging will take place only through L1, and L2 and L3 system is not used. The socket of this connector has a special hole for the possibility of blocking during charging. Depending on the design, this type has three or five power contacts and two pilot contacts. According to the standard IEC 62196-2 [13], it is possible to connect loads to voltages up to 480 V and currents up to 63 A for three-phase connection and 70 A for single-phase connection.

However, other charging modes have been developed for the Type 2 connector, for example, the European network Tesla Supercharger [6] offers to charge both AC and DC up to 500 V. Based on the Type 2 connector, similar solutions have been developed – connector SAE J3068 for USA and connector GB/T 20234 [15-17] for China (version not compatible with original).

The Type 3 or SCAME connector was developed for electric car manufacturers in Italy and France (Schneider Electric, Legrand, and Scame), but was not supported by the European Commission. This connector is available in single-phase and three-phase versions – Type 3A and Type 3C, respectively. The main difference from the Type 2 connector was the use of touch blinds, but in the second edition, this option was added for Type 2. If the AC connectors are numbered, the letters are used to indicate DC.

The AA connector or better known as CHAdeMO was developed in Japan by a group of large companies (TEPCO, Nissan, Mitsubishi, Subaru, etc.). This connector has two power contacts and eight to control the charging station. Control is via the Controller Area Network Bus (CAN bus) is an interface or digital communication system to control the electrical devices of the vehicle. The main purpose of using the network of controllers is to collect, analyze and control data obtained from all devices installed on the car. The latest versions of this connector support current up to 400 A.

The three-part GB/T or GBT connector according to Chinese standard GB/T 20234 [15-17] is used only in Chinese-made electric vehicles. The GB/T 20234.2 standard applies to AC connectors (slow charging). This connector looks very similar to the European Type 2 connector but is technically completely incompatible with it. Charging stations with GBT connectors are rare in Europe and the USA.

Generalized information on the types of connectors for charging electric vehicles on AC is given in Table. 2. The type of connectors for charging electric vehicles on AC are shown in Fig. 3.

Table 2

Types of connectors for charging of electric vehicles on AC

Characteristic	Type 1 (J1772)	Type 2 (Mennekes)	AA (CHAdeMO)	GB/T (slow)
Voltage	up to 230 V	up to 400 V	up to 500 V	up to 750 V
Current	up to 32 A	up to 63 A	up to 125 A	up to 200 A
Power	up to 7,4 kW	up to 43 kW	up to 63 kW	up to 150 kW
Connection mode	single-phase, three-phase			
Application	USA, Japan	China, Europe, USA	Japan, USA, Europe	China, rarely the USA, Europe
Standard	IEC 62196-2		-	GB/T 20234.2

Fig. 3. Type of connectors for charging of electric vehicles on AC:
a – Type 1 (J1772); b – Type 2 (Mennekes); c – AA (CHAdeMO); d – GB/T (slow)

Type 1 and 2 connectors are used to recharge the electric vehicle from charging stations operating in charging modes 2 and 3.

The International Standard IEC 62196-1 [12] applies to accessories with a rated operating voltage not exceeding 1500 V DC at a rated current of not more than 400 A. The standard IEC 62196-3 [14] applies to accessories that include controls with a rated operating current voltage up to 1500 V DC and a rated current up to 250 A.

The Combined Charging System (CCS) connectors are the first (EE or CCS Combo 1) and the second (FF or CCS Combo 2) type for DC charging. They are the same as the first and second connectors for AC charging but have two additional contacts for the positive and negative contacts of high-power DC. These types of connectors can be used for both slow and fast charging. CCS Combo connectors are not the same for Europe, the US, and Japan: Europe uses CCS Combo 2 connectors compatible with Mennekes connectors, and CCS Combo 1 connectors for the US and Japan, which are similar to the J1772 connector. The CSS Combo 2 connector is the most common type of connector on fast-charging stations in Europe, along with the CHAdeMO connector.

If the L1 and N contacts remain on the Combo 1 connector but are not used during charging, the L1, L2, L3, and N power contacts on the Combo 2 connector are completely removed. Control is by transmitting a high-frequency modulated signal also known as PLC (Power Line Communication) without PWM, and not through common contacts PP (Proximity Pilot) and CP (Control Pilot). PP is presence contact, which gives a signal prohibiting movement when connecting the power supply; CP is PWM, charging mode control – maximum current, start, and end. These types of connectors have appeared relatively recently, but have become widespread for their versatility – on-board connectors for electric vehicles allow you to use both standard connections for types 1 or 2 for AC and DC charging via CCS Combo connectors.

With the help of a power cable with CCS connectors, the electric car is connected to stationary charging stations on DC of much higher power than on AC. The DC voltage is applied almost directly to the battery, bypassing the onboard charger, but without bypassing the onboard controller of the electric vehicle.

It is worth noting the EV charging stations of the Tesla Supercharger type [9], which differ from the considered stations in the separation of use. These EV charging stations charge the batteries up to 50% of the volume for 20 minutes, up to 80% for 40 minutes, and up to 100% for 75 minutes. The connectors for such EV charging stations differ in shape depending on the region of use: it has three contacts in the USA and five contacts in Europe. This significantly complicates the operation of electric vehicles imported from the USA to European countries.

GB/T or GBT DC connectors are similar to the same AC connector and are used for Chinese-made electric vehicles. Standard GB/T 20234.3 [17] applies to DC connectors (for fast charging). It is also very rarely used in the USA and Europe.

Generalized information on the types of connectors for charging electric vehicles on DC is given in Table. 3. The type of connectors for charging electric vehicles on DC are shown in Fig. 4.

Table 3

Types of connectors for charging of electric vehicles on DC

Characteristic	Type 1, EE (CCS Combo 1)	Type 2, FF (CCS Combo 2)	Tesla Supercharger	GB/T (fast)
Voltage	200–500 V	200–500 V	480 V	up to 750 V
Current	up to 200 A	up to 200 A	up to 250 A	up to 200 A
Power	up to 100 kW	up to 100 kW	up to 120 kW	up to 150 kW
Application	USA, Japan	Europe	USA, Europe	China, rarely the USA, Europe
Standard	IEC 62196-3		-	GB/T 20234.3

a *b* *c* *d*

Figure 4 – Type of connectors for charging of electric vehicles on DC:
a – Type 1 (CCS Combo1); b – Type 2 (CCS Combo2); c – Tesla Supercharger; d – GB/T (fast)

6. Discussion of the comparative analysis results

The charging speed of any battery depends mainly on the strength of electric current and voltage. Each such battery has a maximum charging current and, if exceeded, it can affect not only the loss of battery capacity but even lead to its complete failure. The larger the capacity of the battery, the more time it takes to charge it, and the higher the current and voltage, the faster the charging process. One of the important characteristics of a rechargeable battery is its degradation – a natural process that constantly reduces the amount of energy it can conserve.

The analysis of charging modes of electric vehicles showed that four internationally standardized modes are used, three of which use AC with single-phase and three-phase connections and only one – DC. The maximum charging power on AC is up to 43 kW, while on DC – up to 250 kW. When charging on DC, the fastest charging is provided. There are four standardized cases of connecting charging stations to electric vehicles. Three cases of cable connections can be used on AC, only the third case – on DC, and the fourth case – when wirelessly charging an electric car. The Technical Committee IEC TC 69 develops international standards for power and energy transmission systems for electric motors and battery-powered trucks.

Analysis of the principles of use of charging stations showed that they classify portable, wall, and stationary stations. National standards introduce road signs for electric vehicles, and a European standard establishes harmonized identifiers for the power supply of electric vehicles. There are several standardized protocols for the interaction of the EV charging station and the control server, which are designed to optimize energy resources and energy production systems. International standards apply to the highest level of communication in wired and wireless technologies.

A comparison of existing types of connectors for charging electric vehicles has shown that there is no single standard for them. Moreover, the types of connectors are quite different and depend on the country or region: North America, Europe, China, and the United States. The standardized interface between the charging station and the electric car remains one of the most acute problems. The European standardization organizations CEN and CENELEC have set up a special group, but so far, no consensus has been reached on the choice of a single standard interface. The main technical characteristics of the existing standardized types of connectors show that for both AC and DC they are used for voltages up to 750 V and currents up to 200 A. The maximum power for them on both AC and DC is up to 150 kW.

In addition to the comparative analysis, the question of the metrological support of charging stations remains unanswered. The presence of public EV charging stations is one of the most important success factors for the widespread use of electric vehicles [18]. To ensure reliable accounting of electricity consumption of electric vehicles during charging, it is necessary to assess the compliance of electricity meters used in EV charging stations [19].

The issue of international and regional standardization of DC electricity meters for use in EV charging stations remains relevant. International Standard IEC 62053-41 [20] applies only to static watt-hour meters of accuracy classes 0.5 and 1 for measuring electrical energy in DC systems, and it applies only to its standard tests. This standard applies to electricity metering equipment (electricity meters) designed to measure and control electrical energy in electrical networks with two poles and voltages up to 1500 V DC. Such electricity meters can be used at public EV charging stations for DC electric vehicles.

International standards of IEC are transformed into European standards of CENELEC without changes. However, standards are commonly used as a means of verifying compliance with EU law, such as the Measuring Instruments Directive (MID) [21]. If the product meets the standard stated in the Official Journal of the EU, the manufacturer may consider that it complies with the relevant EU legislation. Therefore, the relevant international standards must be adapted to meet the requirements of the relevant EU regulation. In many cases, this means only the addition of a special ZZ appendix, which establishes a link between individual articles of EU law and clauses and sub-clauses of an international standard.

However, in some cases, it is still necessary to prepare a special European standard. European standards EN 50470 have been developed for active electricity meters. A draft of standard EN 50470-4 [22] is being developed for active DC electricity meters, work on which began in late 2021. This standard will apply only to static watt-hour meters of accuracy classes A, B, and C for measuring electrical active energy in DC systems and applies only to its standard tests. The implementation of this standard can ensure the conformity assessment of DC electricity meters used in EV charging stations.

8. Conclusions

The urgency of the global energy transition is constantly growing, so the topic of EV charging stations is steadily gaining interest in recent years. The issue of standardization of both the EV charging stations and their components remains unresolved, so it is important to establish their main components and their technical characteristics. The main components of EV charging stations include charging modes, cases of its connecting to electric vehicles, the principles of its use and protocols of interaction, and connectors for charging electric vehicles. It is established that the main problem area of the introduction of EV charging stations is its metrological support. The solution to this problem is to ensure international and regional standardization of DC electricity meters for use in EV charging stations and to assess their compliance.

References

[1] IEC 61851-1:2017. Electric vehicle conductive charging system – Part 1: General requirements.

[2] Directive 2014/94/EU of The European Parliament and of The Council of 22 October 2014 on the deployment of alternative fuels infrastructure.

[3] T. Anegawa. “Safety Design of CHAdeMO Quick Charging System”. World Electric Vehicle Journal, vol. 4, 2016, pp. 855–859.

[4] M. Badawy, N. Arafat, S. Anwar at all. “Design and Implementation of a 75 KW Mobile Charging System for Electric Vehicles”. 2013 IEEE Energy Conversion Congress and Exposition, 2013, 7 p.

[5] IEC 62752:2016 In-cable control and protection device for mode 2 charging of electric road vehicles (IC-CPD).

[6] Teslapedia. Supercharging, Apr 3, 2015 [online] Available: http://teslapedia.org/model-s/tesla-driver/supercharging/

[7] IEC 61980-1:2020. Electric vehicle wireless power transfer (WPT) systems – Part 1: General requirements.

[8] IEC TS 61980-2:2019. Electric vehicle wireless power transfer (WPT) systems – Part 2: Specific requirements for communication between electric road vehicle (EV) and infrastructure.

[9] IEC TS 61980-3:2019. Electric vehicle wireless power transfer (WPT) systems – Part 3: Specific requirements for the magnetic field wireless power transfer systems.

[10] EN 17186:2019. Identification of vehicles and infrastructures compatibility – Graphical expression for consumer information on EV power supply.

[11] ISO 15118-1. Road vehicles – Vehicle to grid communication interface – Part 1: General information and use-case definition.

[12] IEC 62196-1:2014. Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles – Part 1: General requirements.

[13] IEC 62196-2:2016. Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles – Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories.

[14] IEC 62196-3:2014. Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles – Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers.

[15] GB/T 20234.1-2015. Connection set for conductive charging of electric vehicles – Part 1: General requirements.

[16] GB/T 20234.2-2015. Connection set for conductive charging of electric vehicles – Part 2: AC charging coupler.

[17] GB/T 20234.3-2015. Connection set for conductive charging of electric vehicles – Part 3: DC charging coupler.

[18] C. Mester. "Charging stations: a practical, Europewide approach to legal metrology". METinfo, vol. 28, No 2/2021, METAS, Switzerland.

[19] C. Mester, M. H. D. van der Wiel. "E-vehicle charging". OIML Bulletin, Vol. LXIII, No. 2, April 2022, pp. 29–34.

[20] IEC 62053-41:2021. Electricity metering equipment – Particular requirements – Part 41: Static meters for DC energy (classes 0,5 and 1).

[21] Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to the making available on the market of measuring instruments (recast).

[22] prEN 50470-4. Electricity metering equipment – Part 4: Particular requirements – Static meters for DC active energy (class indexes A, B, C).