Technical and legal considerations and solutions in the area of battery charging for electric vehicles

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Abstract. The issue of protecting health of residents of urbanized areas from the effect of excessive particulate matter and toxic components of car exhaust gases imposes the need of introduction of clean electric vehicles to the market. The increasing market availability of electric vehicles, especially in the segment of short-range (neighborhood) vehicles is followed by development of new and advanced infrastructure solutions. This also applies to the increasingly popular hybrid vehicles PHEV (Plug-in Hybrid Electric Vehicles). However, problems with the existing designs are primarily associated with limited driving range on a single battery charge, the density of charging stations in urban and suburban area, energy system efficiency due to increased electricity demand and the unification of solutions for charging stations, on-board chargers and the necessary accessories. Technical solutions are dependent on many factors, including the type and size of battery in the vehicle and access to power grid with increased load capacity. The article discusses the legal and technical actions outlined in the above directions. It shows the available and planned solutions in this area.

1. Introduction

The need for the wider popularity of electric vehicles seems obvious and is primarily due to the necessity of reducing the impact of transport on environmental pollution and warming the earth's atmosphere. The rapid development of this type of vehicles, however, faces difficulties both of a technological nature, as well as from the legislation. The main concern of potential buyers of electric vehicles refers to the uncertain range of EVs. This problem is also related to the development of both home and public charging stations, especially fast charging stations. A dense network of quick charging stations could reduce the current imbalance of replenishment of energy time in conventional vehicle (refueling) and electric vehicle (charging). Another issue is associated with unification of standards for charging, so that the users can be sure the possibility of recharging their vehicles, regardless of the brand.

2. The European Standards of EV battery charging equipment

IEC 62196-1 (PN EN 62196) 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 [1].
The standard is applicable to vehicle computer, plugs, socket-outlets, connectors, inlets and cable assemblies for electric vehicles, charged via conductive connection. The operating voltage of such a system cannot exceed 690 V AC and current to 250 A, and 600 V DC and current to 400 A.

IEC 62851 (PN EN 61851) **Plugs, socket-outlets, vehicle couplers and vehicle inlets – Conductive charging of electric vehicles** [2].

The standard defines four modes of charging batteries:

*Mode 1*: Slow charging from a household-type socket-outlet. In Europe, this means single-phase 16 A 230 V, 3 kW socket. EV can be equipped with a cable for connecting the socket and the vehicle.

*Mode 2*: Slow charging from a household-type socket-outlet with an in-cable protection device.

*Mode 3*: Slow or fast charging using a specific EV socket-outlet with control and protection function installed.

*Mode 4*: Fast charging using an external charger.

IEC 61851-1 also describes the pilot signal which communicates the charging requirements by means of PWM method [3].

The EU and US road signs indicating a charging station are shown in Figure 1. Table 1 lists the standard charging parameters.

![Figure 1. Road signs indicating a charging station- EU left, US right](image)

**Table 1** Details of charging modes

| Charging Mode | AC grid type (phases) | Maximum current [A] | Maximum power [kW] | Estimated charging time [h] | EV connector type |
|---------------|-----------------------|---------------------|---------------------|-----------------------------|------------------|
| Mode 1        | 1 or 3                | 16                  | 3.7                 | 5.5                         | A, B             |
| Mode 2        | 1 or 3                | 32                  | 22                  | 1.0                         | A, B             |
| Mode 3        | 1 or 3                | 63                  | 44                  | 0.5                         | A, B, C          |
| Mode 4        | DC                    | up to 400           | up to 200           | 0.1 (CC phase only)         | C                |

Assuming the energy demand of about 0.2 kWh/km energy capacity of 20 kWh is enough to cover the distance about 100 km [4]. EV’s can be connected to power supply by one of three ways:

A- Connection EV – grid using a fixed connection of supply cable and plug to EV,
B- Connection EV – grid using a releasable connection between EV and AC supply device,
C- Connection EV – grid using the supply cable and EV connector permanently attached to the supply equipment; this is only solution for Mode 4 charging.

In all charging systems is mandatory PE (protective earth) connection, while the connection CP (pilot connection) is required in systems mode 2, 3.4.

IEC 61980 Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements

The regulations included in IEC 61980 standard apply to equipment the wireless electric power transfer (WPT) to the Electric Vehicle energy storage. The technologies considered here include:
- inductive power transfer (MF-WPT, electric energy transferred through the magnetic field),
- capacitive power transfer (EF-WPT, electric energy transferred through the electric field),
- microwave power transfer (MW-WPT, electric energy transferred through electromagnetic waves in range 1 GHz to 300 GHz),
- infrared power transfer, (IR-WPT, energy is transferred through electromagnetic waves in range 300 GHz – 400 THz).

The standard describes the following issues:
- the characteristics and operating conditions,
- the specification for the required level of electrical safety,
- requirements regarding basic communication for safety and process matters if required by a WPT system,
- requirements for basic positioning of the primary and secondary devices, efficiency and process matters if required by a WPT system
- specific EMC requirements for WPT systems
- as well as others.

3. Pilot signal

Electric Vehicle Charging Equipment (EVSE) transmits input PWM signal with a frequency of 1 kHz and a voltage of 12 V into the EV controller. The EV driver to pin CP is accompanied by a system of diodes and two resistors: 2.74 kΩ and 1.3 kΩ. When the charger plug is powered and current loop PWM signal CP-PE is closed permanently by a 2.74 kΩ resistor, this results in a decrease in the voltage to 9 V. After the procedure is initiated by EV driver charging, accompanied by the parallel resistor 1.3 kΩ, which gives the result of the resistance of 880 Ω and fall voltage is 6 V. EVSE controller by changing the PWM duty cycle informs the EV controller about the maximum charge current. Pilot signal circuit is shown in Figure 2. Table 1 lists the PWM pilot signal meanings.
4. Fast Charging Systems

The development of rapid-charging is related to the appearance of the electrochemical battery technology which can provide high charge current values (above 1C) [5]. The use of such batteries in mass-produced vehicles (Mitsubishi, Toyota, Nissan) enabled the Japanese EV’s manufacturers to introduce DC fast charging system called CHAdeMO. The fast charging system was developed by SAE and later adopted by several European producers called CCS (Combo Charging System). The system forms a combination of connector DC fast charging systems and charging AC mode 1 and 2. The manufacturer of popular EV called Tesla has initiated and is successfully developing a worldwide network of fast charging stations Superchargers dedicated to Tesla electric vehicles. China is developing one of the largest network of EV quick charging stations in cooperation with ABB. The network is based on the Terra 53Z DC fast chargers.

4.1. CHAdeMO fast charging system

CHAdeMO quick charger is designed to feed an input power of 62.5 kW and can charge the battery at a voltage of 50 V to 500V. The system uses a dedicated connector charger for each specific vehicle. For digital communication it applies CAN protocol. Fast charge is based on the CC (Constant Current) principle in a first charging phase (up to 80% of target SOC) and the controllers provide CV (Constant Voltage) loop to complete the process (80% to 100% SOC). View of the CHAdeMO connection is shown in Figure 3.

| PWM Duty Cycle | Maximum charge current |
|----------------|------------------------|
| 16%            | 10 A max               |
| 25%            | 16 A max               |
| 50%            | 32 A max               |
| 90%            | Fast Charging Mode     |

4.2. CHAdeMO interface pins designations:

5, 6 - (-) charging current, (+) charging current,
8, 9 - CAN Bus
1 - GND

Figure 3. CHAdeMO charging interface.
4.1.1. The procedure for digital communication
After a connector is used to couple the charger plug with the EV socket, the charger transmits the initiation of the charging process signal to the computer in the EV. EV controller connects via CAN and transmits input about battery parameters in the EV to the computer in the charging station, including: required battery voltage, battery capacity, maximum charging time, etc. The computer in the charging station checks the compatibility of EVCS/EV connection. Then EVCS computer transmits the following EVCS parameters to the vehicle controller: the possible values of voltage and current, and the EV controller checks and closes the connection when it has completed the process of coupling settings. This signal is transmitted to EVCS. EVCS approves the connection and performs insulation test, then sends the signal confirming the completion of the preparatory procedure. After receiving this signal, the computer turns on the main contactors in EV, and then calculates the optimum battery charging parameters, taking into account the battery current state of charge and transmits a signal (every 100 ms) with the desired value of the charging current. The charging current is continuously monitored.

4.2. Tesla Superchargers
Each Tesla Electric Vehicle (EV) is equipped with an on-board charger, capable of single-phase socket charge rated at 40 A or 3 x 16 A three-phase current input. Such a garage should be equipped with Wall Connector device [6], which is compatible with Tesla EVs and is capable of power input of at a rate of 48 A or 72 A through a dedicated connector cable. In the first case, charging 60 minute charge cycle offers vehicle range of 48 km to 55 km (depending on the vehicle model), and in the second case from 74 km to 84 km. Of course, this requires an adequate electrical installation and layout of the garage. In EV’s, Tesla uses advanced Lithium-Ion batteries with a maximum charging current of 1.75 C, which means that the battery with energy capacity of 60 kWh could be charged by device of power 105 kW. Tesla made a significant step forward in the field of fast charging EV batteries. This was possible as a result of introducing a system of free life fast charging batteries for all Tesla vehicle owners. The total cost of charging the battery is included in the vehicle price. The current network of Tesla quick charging stations includes 628 locations equipped with 3738 chargers called Supercharger. Each station is typically equipped with 4 to 12 superchargers. Stations are located mainly in the US, Canada and Europe, as well as in Japan, China and Australia. The geographical distributions of the stations is such that another one is within the range of the vehicle after the battery is fully charged. Of course, in case of the lack of supercharging station in a given location, it is possible to charge traditionally through an on-board charger if a single-phase grid slot is available. Of course, such a charge cycle is much more time consuming. In Poland, there is currently only one station with 4 superchargers in operation, whereas in the nearest future 5 further new stations are planned, at such distances from each other that they will be within the Tesla vehicle range. Stations are open 24 hours a day. The maximum capacity of a single supercharger is 120 kW. The design of a supercharger is such that it is design by analogy to on-board chargers operating in parallel. Thus, a 120 kW supercharger includes 12 standard chargers with a capacity of 10 kW connected in parallel. Tesla Supercharger example performance is shown in Fig. 4.
Tesla EVs are equipped with a Lithium-Ion battery with the rated power capacity of 60 kWh, 70 kWh, 85 kWh or 90 kWh, which naturally affects the vehicle range varies from 370 to 555 km. The procedure for charging the battery from the state 10% SOC to 80% SOC is fast. 80% SOC gives the opportunity to get you to the next charging station. Further loading (from 80% SOC to 100% SOC) requires a much longer time due to the reduced charge current in this range. This is due to the need to protect the battery from early wear. Therefore, the actual charging time is variable. Computer installed in the Tesla vehicle communicates the message to start charging with the station controller, and the latter decides on the appropriate charging parameters of the state of battery charge current load charging station and the current climate. Due to the fact that charging is faster for a low SOC than for a higher state of SOC, the selection regarding the charging parameters has to take into account the driving range. It might be the case that the complete (and longer) charging is not necessary in given circumstances. Many external factors can affect the actual charging parameters: outdoor temperature, grid limitations, the number of simultaneously loaded vehicles at the station and many others. The loading procedure is simple. A vehicle is parked in a designated spot, after connecting the cable to the vehicle, and station controllers and the vehicle communicate and check the compatibility of the connection. Subsequently, charging starts and the progress of this process can be monitored by a special application on a smartphone. Most of the stations use between 20 to 40 minutes for this, and thus the potential waiting time is not long.

4.3. CCS (Combined Charging Solution)

The idea of CCS was demonstrated during the 15 International VDI Congress in 2011 by European car manufacturers (Audi, BMW, Daimler, Ford, GM, Porsche and VW). This system (also called a combo) is a universal solution, which allows both low-power (1 or 3 phase for the home grid) as well as a fast DC charging. This standard applies PLC (Power Line Communication) protocol to control the charging process and the exchange of information between the EV and EVSE. The design of the CCS connection is shown in Figure 5.
4.4. China Fast Charging System

Stations Terra 53Z 50 kW can recharge the batteries with current up to 125 A with a voltage of 220 V to 550 V DC. The battery charge is completed within 20 min and can ensure the increase of the vehicle range of about 100 km. Digital communication based on GSM and Ethernet. Table 3 gives an example with parameters of EV charging. The design of the China GB standard connection is shown in Figure 6.

| Electric Vehicle | Battery energy capacity [kWh] | On-Board Charger Power [kW] | Range [km] | Range after 30 min. Fast charging [km] (est.) | Specific Energy Consumption [kWh/km] | Recharging Time (230 V AC) [h] (est.) | Remarks |
|------------------|--------------------------------|-----------------------------|------------|---------------------------------------------|-------------------------------------|--------------------------------------|---------|
| Nissan Leaf      | 24                             | 3.3                         | 161        | 120                                         | 0.149                               | 8.0                                  |         |
| i-MiEV           | 16                             | 3.3                         | 100        | 73                                          | 0.160                               | 7.0                                  |         |
| Tesla 60         | 60                             | 10                          | 370        | 270                                         | 0.162                               | 7.5                                  | 40 [A]  |
| Tesla 70         | 70                             | 10                          | 432        | 315                                         | 0.162                               | 9.1                                  | 40 [A]  |
| Tesla 85         | 85                             | 10                          | 510        | 370                                         | 0.166                               | 10.0                                 | 40 [A]  |
| Tesla 90         | 90                             | 10                          | 555        | 400                                         | 0.162                               | 10.5                                 | 40 [A]  |
| Toyota Prius PI (model 2017) | 8.8                     | 3.3                         | 35         | 0.25                                        | 0.25                                | Electric Mode                        |         |
5. Wireless Charging Systems

Qualcomm system [7] is composed of a wall power supply, transmitter pad, receiver pad, on-board charging controller and a battery. The transfer of energy between the transmitter and receiver pad is carried out wirelessly. These systems are designed to match the power of 3.3 kW to 20 kW. A single induction coil has a rectangular shape with rounded corners (Circular Rectangular) or double bipolar (Bipolar or DD). The DD model provides more focused magnetic flux and more compact transmission and reception coil as well as demonstrates 50% higher power density. CR coils require more precise positioning. The position tolerance for the transfer of full power to the coil CR is 75 mm in the lateral direction and 100 mm in the longitudinal direction, while the 100 mm coil DD in the lateral direction and 150 mm in the longitudinal direction. The vertical spacing between DD coils in the range of 160 to 220 mm provides adequate power transfer. In the case of CR coils, after 220 mm spacing is exceeded, it is followed by a significant decrease. The Halo System operates at a frequency of 85 kHz. This ensures EMC compatibility. The development of Halo technology was utilized as a technique of charging EV battery during normal drive, and called Dynamic Electric Vehicle Charging (DEVC). For this purpose, special street lines are equipped with transmission pads, which are longitudinally spaced every 2 m [8]. This is designed for slow moving vehicles like taxis or buses.

6. Conclusions

The increase in popularity of electric vehicles is limited by the low accessibility of public charging stations. In addition, the lack of universal, global standards, which would normally offer users confidence in the possibility of charging EVs, discourages potential customers from buying such cars. One solution to the problem of charging stations could be the application of more than one standard. However, this makes the design of energy conversion and control system considerably more complex. The result is a higher cost of such multi-system solutions. The appearance of fast charging and technologically advanced batteries on the market reduces the charging time of conventional and electrical vehicles. The range of today’s electric vehicles gradually approaches that of the conventional vehicles. The strategy of building networks and developing brand dedicated fast battery charging stations adopted by some vehicle manufacturers can also increase the attractiveness of buying an electric vehicle.

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