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A REVIEW OF CHARGING TECHNOLOGIES FOR COMMERCIAL ELECTRIC VEHICLES

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ABSTRACT

Electric mobility becomes trending issue than ever in transportation sector. The essential part of electric mobility is the use of electric vehicles. Electric Vehicle (EV) is type of vehicle which primarily powered by an electric motor drawing power from a rechargeable energy storage device. EV receives electricity by plugging into the grid and store it in batteries. EV Charger is an electrical device that converts alternating current energy to regulated direct current for replenishing the energy of an energy storage device (i.e. battery) and may also provide energy for operating other vehicle electrical systems. The energy storage device namely battery is heart of an electric vehicle. Therefore, battery charger plays a very important role in the electric vehicle technology. Electric vehicle battery chargers divided into two types: on-board type (in electric vehicle) and off-board type (at a fixed location). In this paper, the charging technologies in commercial vehicles, related standards, charging levels and charging modes are described. Also, EV charging sockets are explained clearly. The whole issues about chargers are presented for commercial EV manufacturers. Consequently, the big picture about electric vehicle charging system could be easily seen in this paper.

Keywords: *Chargers, electric buses, charging methods, charging standards*

INTRODUCTION

EV Charger is an electrical device that converts alternating current energy to regulated direct current for replenishing the energy of an energy storage device (i.e. battery) and may also provide energy for operating other vehicle electrical systems.

There are 3 functions that must be performed to allow charging of the EV battery from an electric supply network. The two of them is electrical functions and other one is mechanical function. First electrical function is rectification process and second one is controlling and regulation of supply voltage according to battery charge acceptance characteristics. The mechanical function is the connecting of the EV to the EVSE and this process is performed by the user [1].

The charging scheme is a combination of the charging and termination methods. The charger has three key functions:

- i. Getting the charge into the battery (Charging)
- ii. Optimising the charging rate (Stabilising)
- iii. Knowing when to stop (Terminating)

The block diagram of EV charging system is given below. Main parts of this system are charger control unit, charging cable and vehicle control unit.

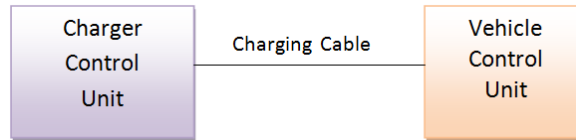


Figure 1 : Main parts of electric vehicle charger

There are many papers about electric vehicle charger in literature. In these papers, mostly the different power electronics topologies of chargers and technical parts of charging technology are underlined [2] [14] [15]. Our paper looks at charging technologies in broad perspective and endeavours to constitute the big picture for EV manufacturers. Also, the charging technologies for commercial vehicles were considered on a preferential basis. Every part of EV charging system are discussed exhaustively in this paper.

THE DIFFERENT EV CHARGING METHODS

EV Charging System is an equipment required to condition and transfer energy from the constant frequency, constant voltage supply network to the direct current, variable voltage EV traction battery bus for the purpose of charging the battery and/or operating vehicle electrical systems while connected.

Generally, there are three main ways of charging: **conductive** charging, **inductive** charging and by **changing the battery**. Using the conductive method the battery is connected by a cable and plugged directly into an electricity provider. The inductive method, in contrast, works through electromagnetic transmission without any contact between the EV and the charging infrastructure. The charging spot is equipped with wires which carry an alternating current, during the EV is at the right place. The alternating current creates an electromagnetic field, which affects the receiver (also consisting of wires) in the EV in a way that a current is induced and charges the battery.

Currently, both the automotive industry and operators of charging stations prefer conductive charging because it is much cheaper and more efficient. Yet there are several R&D projects which focus on the further improvement of inductive charging, because it offers a better way to increase user comfort and could be a key feature for electric mobility.

The third possibility takes into consideration the swapping of discharged batteries with fresh ones in a swapping station. However for this to be possible the dimensions and internal connections for the batteries must be standardized. Each electric vehicle from each manufacturer would have to have virtually the same size, shape and type of battery. As this reduces the OEM's freedom of design and given that the choice of placement of the battery would be severely reduced, most of the manufacturers are considering reject this method [4].

CONDUCTIVE CHARGING

Conductive charging system use direct contact between the EV connector and charge inlet. The cable can be fed from a standard electrical outlet or a charging station. The main drawback of this solution is that the driver needs to plug in the cable, but of course this is only a connection issue [2].

I. The EV Charging Levels

The charging level describes the “power level” of a charging outlet. There are three levels in charging technology [3].

Level 1 Charging : A method that allows an EV to be connected to the most common grounded electrical receptacle (NEMA 5-15R). It is also known as “Home Charging”. The vehicle shall be fitted with an on-board charger capable of accepting energy from the existing AC supply network.

It is a method of EV charging that extends AC power from the electric supply to an on-board charger from the most common grounded electrical receptacle using an appropriate cord set as shown in Figure 2. AC Level 1 allows connection to existing electrical receptacles in compliance with the National Electrical Code [1].

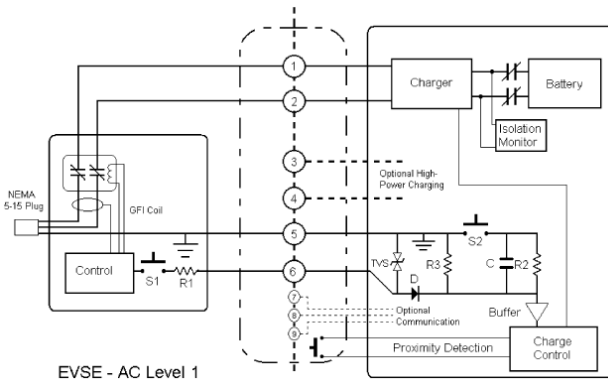


Figure 2 : AC Level 1 System Configuration (SAE_J1772 Standard)

Level 2 Charging : A method that utilizes dedicated AC. EVSE in either private or public locations. The vehicle shall be fitted with an on-board charger capable of accepting energy from alternating current EVSE. It is called as “Fast AC charging”, either 7kW (32A single phase) or 21 kW (three-phase) level.

The primary method of EV charging that extends AC power from the electric supply to an on-board charger from dedicated EVSE as shown in Figure 3. AC Level 2 may be utilized at home, workplace and public charging facilities [1].

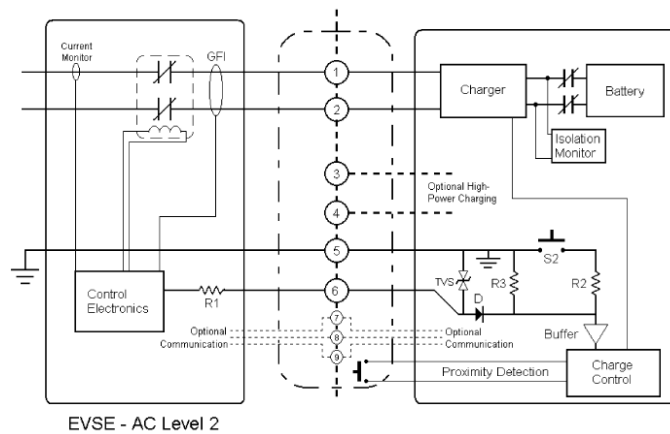


Figure 3 : AC Level 2 System Configuration (SAE_J1772 Standard)

Level 3 Charging : A method that utilizes dedicated direct current (DC) EV supply equipment to provide energy from an appropriate off-board charger to the EV in either private or public locations.

The conductive charging system architecture provides a method to provide energy from an appropriate off-board charger. The power available for DC Charging can vary from power levels similar to AC Level 1 and 2 to very high power levels that may be capable of replenishing more than 1/2 of the capacity of the EV battery in as few as 10 minutes. Level 3 charging is termed as “Fast DC charging”, up to 50kW, which means 20min. charging from empty to 80% full (for DC charging, the last 20% take a very long time, so DC charging is usually measured up to 80%) [1].

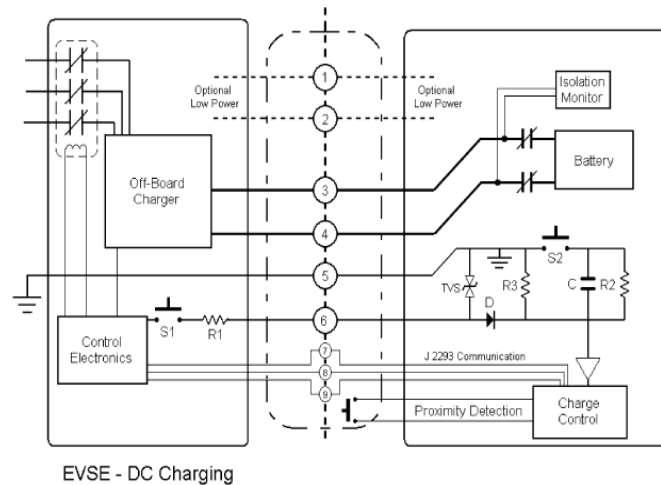


Figure 4 : AC Level 3 System Configuration (SAE_J1772 Standard)

II. The EV Charging Modes

The charging mode describes the safety communication protocol between EV and charging station. These standards are identical worldwide [3].

One method for EV charging is to connect the AC supply network (mains) to an on-board charger. An alternative method for charging an EV is to use an off-board charger for delivering direct current. For charging in a short period of time, special charging facilities operating at high power levels could be utilized [6].

Mode 1 Charging (Household socket and extension cord) : Home charging from a standard power outlet with a simple extension cord, without any safety measures. Although this is what many (private) EV conversions use today, “Mode 1” has been outlawed in several countries [3].

The connection of the EV to the AC supply network (mains) utilizing standardized socket-outlets not exceeding 16 A and not exceeding 250 V AC single-phase or 480 V AC three-phase, at the supply side, and utilizing the power and protective earth conductors [6].



Figure 5 : Mode 1 type connection [5]

The vehicle is connected to the power grid through standard socket-outlets (standard current: 10A) present in residences. To use mode 1, the electrical installation must comply with the safety regulations and must have an earthing system, a circuit breaker to protect against overload and a earth leakage protection. The sockets have shutters to prevent accidental contact [5].

Mode 2 Charging (Domestic socket and cable with a protection device) : The vehicle is connected to the main power grid via household socket-outlets. Recharging is done via a single-phase or three-phase network and installation of an earthing cable. A protection device is built into the cable. This solution is particularly expensive due to the specification of the cable [5].

Mode 2 Charging is home charging from a standard power outlet, but with a special in-cable EVSE (EV Supply Equipment), also known as “occasional use cable”, usually supplied with an EV from the manufacturer. This cable provides:

- In-cable RCD
- Over-current protection

- Over-temperature protection
- Protective Earth detection (from wall socket)

Power will only follow to the vehicle if the EVSE has detected:

- Protective Earth is valid
- No error condition exists (over-current, over-temperature, etc.)
- Vehicle has been plugged in (detected via pilot data line)
- Vehicle has requested power (detected via pilot data line)

Mode 2 charging cables provide a moderate level of safety and are the minimum standard today for charging an EV. Some vehicle manufacturers even make the customer sign an agreement confirming installation of a wall-box at the time of ordering an EV [3].

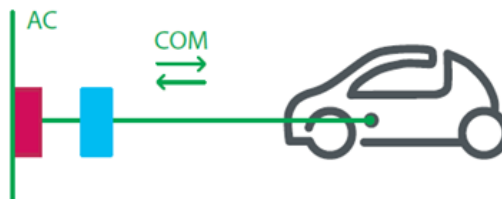


Figure 6 : Mode 2 type connection [5]

Mode 2 charging connection of the EV to the AC supply network (mains) not exceeding 32 A and not exceeding 250V AC single-phase or 480V AC. Three-phase utilizing standardized single-phase or three-phase socket-outlets, and utilizing the power and protective earth conductors together with a control pilot function and system of personnel protection against electric shock (RCD) between the EV and the plug or as a part of the in-cable control box. The inline control box shall be located within 0,3 m of the plug or the EVSE or in the plug [6].

Mode 3 Charging (Specific socket on a dedicated circuit) : The vehicle is connected directly to the electrical network via specific socket and plug and a dedicated circuit. A control and protection function is also installed permanently in the installation.

This is the only charging mode that meets the applicable standards regulating electrical installations. It also allows load-shedding so that electrical household appliances can be operated during vehicle charging or on the contrary optimise the electric vehicle charging time [5].



Figure 7 : Mode 3 type connection [5]

Mode 3 Charging is that wired-in AC charging station, either in public places or at home, allowing a higher power level than Mode 2. The safety protocol is identical to Mode 2 [3].

This charging mode is consists of connection of the EV to the AC supply network (mains) utilizing dedicated EVSE where the control pilot function extends to control equipment in the EVSE, permanently connected to the AC supply network (mains) [6].

Mode 4 Charging (Direct current connection for fast charging) : The electric vehicle is connected to the main power grid through an external charger. Control and protection functions and the vehicle charging cable are installed permanently in the installation [5].

Mode 4 Charging is wired-in DC charging station, either in public places or at home. In DC charging stations, the charger is part of the charging station, not part of the vehicle [3].

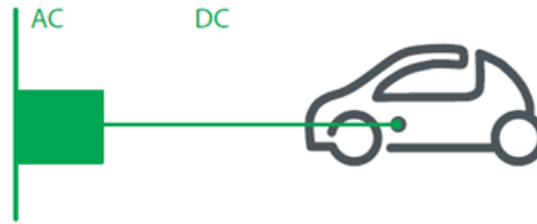


Figure 8 : Mode 4 type connection [5]

This charging mode is consists of connection of the EV to AC supply network utilizing an off-board charger where the control pilot function extends to equipment permanently connected to the AC supply [6].

III. The EV Charging Sockets (Types)

The type of a charging station (or vehicle inlet) describes the actual connector being used. Unfortunately, there are several different world standards. The terminology for sockets are given in below[3]:

- socket : on charging station
- plug : on cable towards charging station
- inlet : on EV
- connector : on cable towards EV

Three types of “electric vehicle” sockets with connectors for the pilot wire can be used for charging electric vehicles [5].

Type 1 (Single phase vehicle coupler) : The connector/inlet pair used in the U.S and Japan, also known as “SAE1772” after the corresponding U.S. standard. As the U.S. and Japan do not have a three-phase power grid, this standard is limited to single-phase and lower power output than Type 2. Also, for Type 1, the charging cable is permanently fixed to the charging station. The SAE J1772-2009 connector, known as the *Yazaki* connector (after its manufacturer), is commonly found on EV charging equipment in North America.

The SAE J1772-2009 coupler specifications have been included to IEC 62196-2 standard as an implementation of the Type 1 connector for charging with single-phase AC. The connector has five pins for the 2 AC wires, earth, and 2 signal pins compatible with IEC 61851-2001 / SAE J1772-2001 for proximity detection and for the control pilot function [8].



Figure 9 : Type 1 charging cables [3]

Type 2 (Single and three phase vehicle coupler) : The connector/inlet and plug/socket pairs used in Europe, also known as “Mennekes” after the company first proposing this standard. Type 2 supports both single-phase and 3-phase charging at higher power rates than Type 1.

For Type 2 charging stations, the charging cable is detachable, so a Type 2 station can charge both, Type 1 and Type 2 vehicles with the correct charging cables. A Type 1 charging station on the other hand can only charge Type 1 vehicles, as the cable is fixed to the station and the usage of adapters is prohibited [3].



Figure 10 : Type 2 charging cables [3]

Type 3 (Single and three phase vehicle coupler equipped with safety shutters) : France and Italy are campaigning for yet another connector/inlet and plug/socket solution, which has “shuttered contacts”, i.e. contacts that are 4 physically covered by a non-conductive cover when not in use. Proponents of Type1 or Type 2 (both non-shuttered) point out that these are safe without shutters, as current can only flow when an EV connection has been detected [3].

The main reasons for preferring the Type 3 connector is given below:

- Among the 3 models proposed (Type 1, Type 2 and Type 3), only type 3 sockets and socket-outlets have shutters.
- These shutters are mandatory in the UK to prevent children (and adults) from contacting live parts.
- Type 3 solutions also include shutters on sockets (male plugs) to anticipate the arrival of ‘Vehicles to Grid’ In this case, the vehicle will act as a power generator. The presence of shutters on plugs will therefore provide the same safety level for people as socket outlets [5].

Type 4 (Fast charge coupler) : Known by the trade name, CHAdeMO, the type 4 connector is used for charging EV in Japan and Europe. It is specified by Japan Electric Vehicle Standard (JEVS) G105-1993 from the JARI (Japan Automobile Research Institute). Unlike types 1 and 2, the type 4 connection uses the CAN bus protocol for signalling [11].

CHAdeMO is the trade name of a quick charging method for battery electric vehicles delivering up to 62.5 kW of high-voltage direct current via a special electrical connector. It is proposed as a global industry standard by an association of the same name and included in IEC 62196 as type 4 [10] .

CHAdeMO is an abbreviation of “CHARge de MOve”, equivalent to “charge for moving”. CHAdeMO is a form of DC Fast Charge, for high-voltage (up to 500 VDC) high-current (125 A) automotive fast charging via a JARI DC fast charge connector. The connector is specified by the JEVS (Japan Electric Vehicle Standard) G105-1993 from the Japan Automobile Research Institute. The connector includes two large pins for DC power, plus other pins to carry CAN-BUS connections. At the moment, CHAdeMO fast chargers have a max power output of 50 kW [12].



Figure 11 : Type 2 charging cables [3]

DC CHARGING

A method that utilizes dedicated direct current (DC) EV supply equipment to provide energy from an appropriate off-board charger to the EV in either private or public locations.

The conductive charging system architecture provides a method to provide energy from an appropriate off-board charger as shown in Figure 6. The power available for DC Charging can vary from power levels similar to AC Level 1 and 2 to very high power levels that may be capable of replenishing more than 1/2 of the capacity of the EV battery in as few as 10 minutes [1].

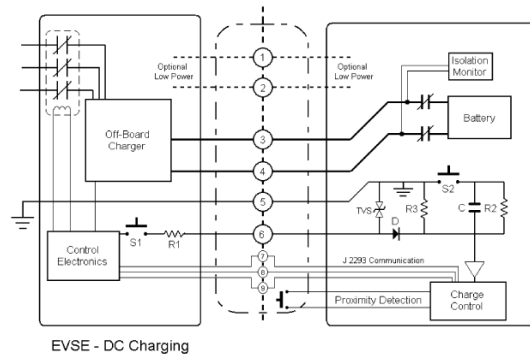


Figure 12 : DC Charging System Configuration (SAE_J1772 Standard)

INDUCTIVE CHARGERS

Inductive charging uses an electromagnetic field to transfer energy between two objects. This is usually done with a charging station. Energy is sent through an inductive coupling to an electrical device, which can then use that energy to charge batteries or run the device.

Induction chargers use an induction coil to create an alternating electromagnetic field from within a charging base, and a second induction coil in the portable device takes power from the electromagnetic field and converts it back into electric current to charge the battery. The two induction coils in proximity combine to form an electrical transformer. Greater distances between sender and receiver coils can be achieved when the inductive charging system uses resonant inductive coupling. Recent improvements to this resonant system include using a movable transmission coil and the use of other materials for the receiver coil made of silver plated copper or sometimes aluminium to minimize weight and decrease resistance due to the skin effect [13].

Advantages of Inductive Charging:

- Protected Connections
- Low infection risk
- Durability
- Increased convenience and aesthetic quality
- No need for cables

Disadvantages of Inductive Charging:

- Slower Charging
- More expensive
- Inconvenience

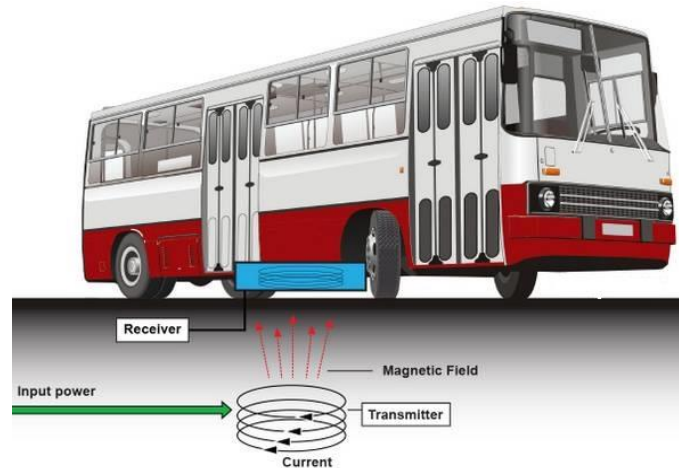


Figure 13: An electric bus charging wirelessly at a station [16]

RESULTS AND DISCUSSION

In this paper, the different EV charging methods are presented. An electric vehicle can be charged with conductive or inductive charging method. Using the conductive method the battery is connected by a cable and plugged directly into an electricity provider. The inductive method, in contrast, works through electromagnetic transmission without any contact between the EV and the charging infrastructure.

Also, the EV charging levels, modes and types are examined in this study. The charging level describes the “power level” of a charging outlet. There are three levels in charging technology. These are Level 1, Level 2 and Level 3 charging.

The charging mode describes the safety communication protocol between EV and charging station. There are four different charging mode namely Mode 1, Mode 2, Mode 3 and Mode 4.

The type of a charging station (or vehicle inlet) describes the actual connector being used. Three types of “electric vehicle” sockets with connectors for the pilot wire can be used for charging electric vehicles. These types are Type 1, Type 2, Type 3, Type 4.

Also, the DC Charging and inductive charging topics are reviewed in this paper. The advantages and disadvantages of inductive charging is given in article.

Finally, very beneficial document about EV Charging technologies is prepared for commercial EV manufacturers. This paper helps manufacturers interpreting the charging levels, modes and types. Also, this paper has a value academically because this paper has different point of view comparison to the papers in literature. The commercial sides of charging technologies are underlined in this paper.

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NOMENCLATURE

EV	Electric Vehicle
AC	Alternative Current
DC	Direct Current
kW	kiloWatt
R&D	Research and Development
EVSE	Electric Vehicle Supply Equipment
NEMA	National Electrical Manufacturers Association
SAE	Society of Automotive Engineers
RCD	Residual Current Device
US	United States
UK	United Kingdom
IEC	International Electrotechnical Commission
CAN	Controller Area Network

JARI	Japan Automobile Research Institute
JEVS	Japan Electric Vehicle Standard
CHAdEMO	CHArge de MOve
OEM	Original Equipment Manufacturer

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