

# Electric Vehicle based on Charging Levels, Modes, and Connectors: A Review

Priya Kapur<sup>1</sup>, Vimlesh Singh<sup>2</sup>, and Yogendra Kumar Awasthi<sup>3</sup>

<sup>1,2</sup>Electronics & Communication Engineering, FET, Manav Rachna International Institute of Research and Studies (MRIIRS), Faridabad, India-121003

<sup>3</sup>Department of Electronics & Communication Engineering, Galgotias University, G. Noida, UP India 203201.  
Email: <sup>1</sup>priyakapur@gmail.com, <sup>1</sup>vimleshsingh@gmail.com [yash\\_ips79@rediffmail.com](mailto:yash_ips79@rediffmail.com)

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**ABSTRACT:** In this paper, standardizations in field of electric vehicles are studied. Firstly, different types of electric vehicles based on their source of energy are studied. Then, different charging methods are discussed along with types of electric vehicle chargers. The electric vehicle chargers are explained on basis of their charging current, levels for EV charging along with modes of EV charging. Finally, the types of EV charging connectors and sockets are explained.

**INDEX TERMS:** AC- Alternating Current, DC- Direct Current, EVSE- Electric Vehicle Supply Equipment, IC-CPD- In Cord-Control and Protection Device

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## I. INTRODUCTION

In present day, there is huge issue of Green House gases because of fuels used by the vehicles. There are lots of climate changes happening and urban air quality is getting worse for which the overuse of crude oils is the main cause. The alternate source of energy to run the vehicles can possibly reduce the pollution levels; hydrogen and electricity are two of them. Without proper infrastructure development none of the alternate fueled vehicles would work. There is need of standardization of charging network and infrastructure.

Most of the vehicles used in the automotive industry are Internal Combustion Engine (ICE). These use gas as the mode to produce power to run the vehicle. Petrol, diesel and CNG are commonly used energy sources. The depleting natural resources of gas, increasing price and continuously increasing mobile pollution due to ICE vehicles has led to think about the other power sources for automotive industry. The various kind of alternate energy sources are being worked upon. Electricity and hydrogen are two of them. For the hydrogen powered vehicle, energy is converted is converted into electricity in the vehicle itself and then used through energy storage devices. In electricity run vehicles, electricity is stored directly in the energy store devices and such vehicles are known as Electric Vehicles (EV). In last one decade, most of the automobile companies and governments all around the world have put lots of effort to transform conventional ICE vehicle into alternate fueled vehicle. The prominently advantages are such as: better energy conversion rate, lesser vehicular noise, lower carbon and greenhouse gas emission, therefore better air quality. Electric Vehicles (EVs) are widely researched and implemented over Hydrogen fueled vehicles. The EVs are mostly fueled by electricity produced by clean energy sources which make them cost effective substitute for ICE vehicles to step towards sustainable development. Most of the countries are targeting to lower the CO<sub>2</sub> levels by 15-30% by 2030 and Net Zero Emission by 2050 which would help to achieve the target of capping global warming by 1.5Co [1] – [3]. The number of EVs sold all around the world increased by 41% by 2020, but due to pandemic the sales decreased by 16% which are expected to increase soon [2] On the average, the 39% of new cars being purchased are Electric Vehicle with Norway being the leader all around

the world. This paper is organized as follows: Section II exhibits the classification of EVs, which are divided into three types based on of the source of energy used, which are expected to work at different three levels. Further the modes of EV charging are explained, followed by types of charger connectors and vehicle socket plugs [3] – [11].

## II. CLASSIFICATION OF ELECTRIC VEHICLES

It is not necessarily that the vehicle runs just on electricity or just on gas. It can run on either one of the gas or electricity or both. Depending upon the designer and usage different type of EVs are explained.

### A. Battery Electric Vehicles (BEV)

Battery Electric vehicles depend totally upon the re-chargeable battery installed in the vehicles. Battery can be recharged by plugging into the EVSE. As for the ICE vehicles engine produces the power and runs the vehicle, in BEV battery is the powerhouse of the vehicle where all the energy is stored and transferred to electric motor to run the vehicle. Other major components of BEV are Battery, Electric motor, Inverter, Drive train and Control module. The AC power from EVSE is converted into DC to be stored in the battery. The accelerator pedal sends the signal to control module to start the drive train. Further, the vehicle electric motor is put into function. To run the electric motor DC power is converted into AC using the inverter. The vehicle speed is varied by the driver by pressing or releasing the accelerator and breaks. Control module is informed about the same which controls the frequency of AC power which controls the electric motor and finally the speed the vehicle. There are a lot of advantages of EV. EVs are easy to drive just as similar as automatic ICE vehicle [6], [12]. There is almost negligible sound when EV is used therefore, no noise pollution. There are no gases emitted from EV while in run, thus no environmental pollution too. Electricity is relatively cheaper than petrol and diesel which saves money. The wear and tear is way less than ICE vehicle, thus another way to save little money. It can also be charged at home. Where there are so many advantages of EV, there are few of the disadvantages too, the electric vehicles are expensive to buy. The charging infrastructure is not expanded well therefore not enough charging points. The drive range is EV is limited and cannot travel longer distance in one charge. It needs frequent charging on longer runs. The charging time of EV is way much higher than refueling ICE vehicle, which is a lot more time consuming [13] – [15]. The basic architecture of BEV is shown in Fig 1(a).

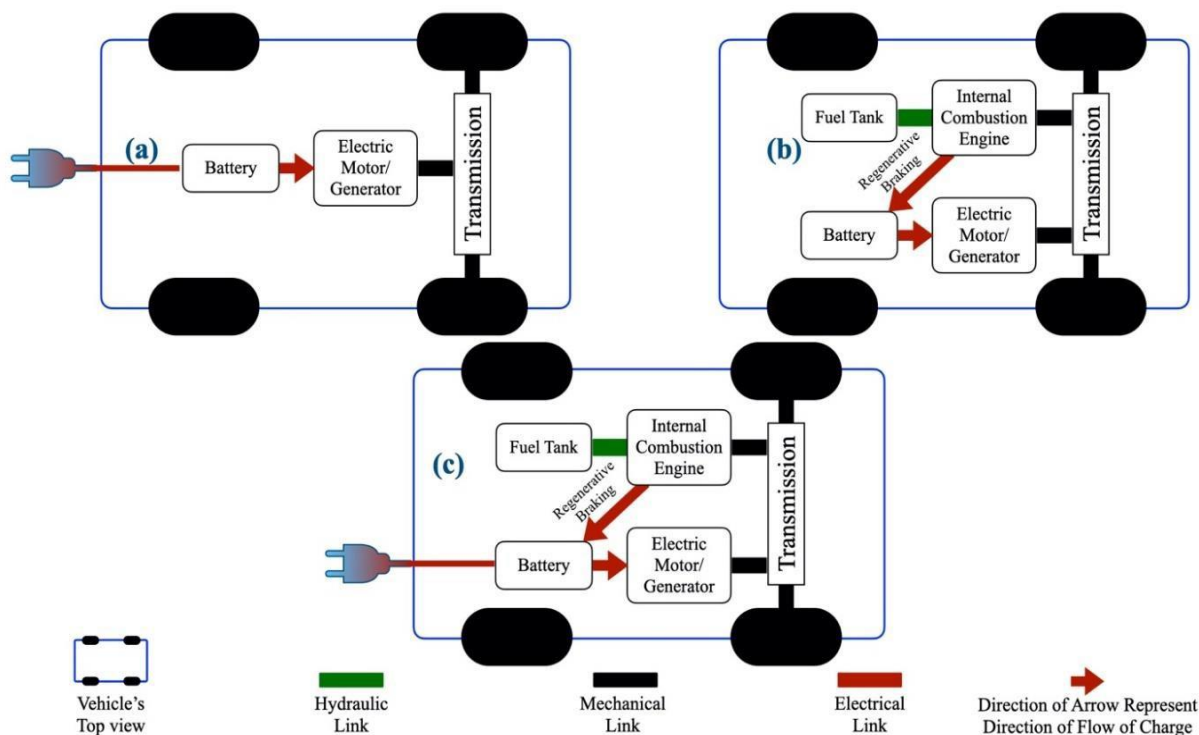
### B. Hybrid Electric Vehicle (HEV)

A hybrid electric vehicle is a type of hybrid vehicle that combines a conventional internal combustion engine (ICE) system with an electric propulsion system (electric vehicle drive train). Modern HEVs make use of efficiency improving technologies such as regenerative brakes which convert kinetic energy into electric energy, which is stored in a battery or super capacitor. HEVs can have both gas-powered engine and electric motor. Generally Braking energy is lost in the form of heat in the brake pads and rotors. But in HEV, energy of battery is charged through regenerative braking system. Regular HEV cannot plug into grid to recharge. In HEV the vehicle when start running from vault, up to almost 100 meters or until the vehicle attains the speed around 20-30 kmph, it runs on electric motor using battery as power source and thereafter, engine is used. This saves a least little of the gas which was supposed to use to run the vehicle originally.

The hybrid type of electric vehicle has lots of advantages such as HEV have superior miles per gallon average than regular gas automobiles. Less of harmful chemical gases are released and these are relatively environment friendly. There is selection of power settings, varying from eco to power for maximum performance. Along with advantages, there are a few disadvantages as higher purchasing cost. The hybrid technology is complex to be manufactured and monitored. Overall Fuel economy on the roads or highways is not much. As the cost of vehicle increases so does insurance rate. Hybrid fuel efficiency decreases in cold weather [15] – [20]. The basic architecture of HEV is shown in Fig 1(b).

### C. Plug-in Hybrid Electric Vehicle (PHEV)

Plug-In Hybrid Vehicles (PHEVs) are becoming so popular because it required fewer amounts of fuels and Crude-oil as compared with normal vehicles. It helps to reduce the Fossil- Fuels & Crude-Oils. It helps financially to the people.[16] – [21] This pioneering modeling and design study established the characteristics and compared well-to-wheel energy use, carbon dioxide emissions and costs of conventional ICE, full hybrid, and plug-in hybrid electric vehicles for simulated driving cycles. Compared to the Conventional and Hybrid-Vehicles the Plug-In Hybrid Vehicles requires less consumption Fuels & Crude-Oils. This Plug-In Hybrid Vehicles produce less amount of emission. It reduces the amount of carbon which will help for Green House gases which will be help to Atmosphere. The different types of EVs' architectures are shown on figure [18] – [23].



**Fig. 1.** Basic architecture of Different Electric Vehicles (EV) types. (a) Battery Electric Vehicle (BEV), (b) Hybrid Electric Vehicle (HEV), and (c) Plug-in Hybrid Electric Vehicle (PHEV).

The basic architecture of PHEV is shown in Fig 1(c). The energy is stored in the storage device which is received in the form of electricity. Usually, the electricity source is the electric grid. From the grid, a connection is made to the EV to transfer the energy. The device used for connection is EV Charger.

The device used for connection is EV Charger. The charger converts the alternating current energy to direct current to be stored in the battery or other storage device. The energy stored in the device is provided to the motor to run the vehicle along with operating vehicle's other operating systems. The energy storage device or battery is one of the main parts of the EVs, thus the EV charger plays a vital role in the EV technology. EV battery chargers are divided into two categories: On-board (fitted in the electric Vehicle) and off-board (fixed at a location).

### III. ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

For any EV to get charged three functions must be performed. First one is mechanical and other two are electrical. Mechanical function is to connect the EV to Electric Vehicle Supply Equipment which is performed by the user [22], [23]. Another two functions are electrical; the first electrical function is to rectify the signal and second process is to control and regulate the supply voltage as per the battery charging capacity characters.

The process of charging is combination of two processes- charging and termination. The charger needs to perform three basic key functions: a. Charging- getting the electricity to battery to charge it, b. Stabilizing- keeping the charge rate optimized, c. Terminating- deciding when to stop the charging process. To decide what kind of charger is needed by the vehicle, the manufacturer needs to understand the different technical parts and the power topologies [7].

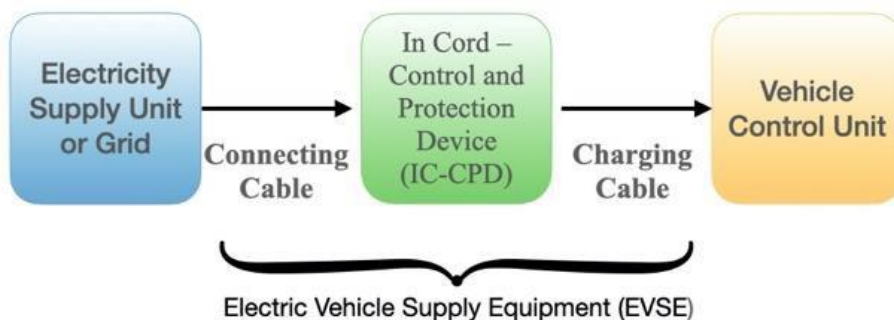


Fig. 2. Main parts of Electric Vehicle Charger.

#### A. Different EV charging methods

The EV user needs to charge the EV to reuse the vehicle after the battery drainage. The most used way is charging the battery and other option is to swap the discharged battery with charged battery. To charge the battery when connected to EV, the charging socket is connected to EV charging system. Electric Vehicle Charging System is the whole system which is required to stabilize and electric energy from alternating current, constant voltage, and constant frequency supply network to the direct current with variable voltage and high current to charge battery.

To charge the battery the charger can connect to EV in two ways of connection i.e., conduction and induction. As the word implies, by conduction means direct contact. When using condition as method of charge the EV battery, charge from electricity gets transferred to electric vehicle through direct connection between the provider and the EV. Whereas induction mean no direct contact. In induction method of charging the vehicle is not connected to charger through cable instead the charge is transferred wirelessly. Inductive method works through electromagnetic transmission of charge.

Currently, most preferred way to charge is conductive charging as it is cheaper and more efficient. Lot of research is going on for improvement of inductive charging as it offers greater comfort for charging the vehicle making it preferable choice for charging in electric mobility.

Both conductive and inductive methods to charge, take long time to charge. Even with the fastest charger, the time taken to EV is much more than refilling the fuel in the ICE vehicle. Closest in terms of time consumption in refilling is the battery swapping. The EV is taken to the battery station and the discharged battery is replaced with the charged one. This is the fastest way that can be done but even it has its drawbacks which will be discussed later.

The current is divided in two forms: Alternating Current (AC) and Direct Current (DC). Throughout the world, energy is transferred in the form of AC. All the homes and office receive AC from electricity grid, so AC is readily available. Therefore, AC can be used to charge the EV easily too. Based on current, the EV charging can be divided into two categories: Alternating Current (AC) and Direct Current (DC).

In AC charging the EV is supplied power in the form of AC and in DC charging the EV is charged through DC. The most used energy storage device is battery. DC is needed to charge the battery which is ultimately stored in it. Battery cannot be charged directly with AC charger as batteries do not support AC supply, so it needs to be converted into DC somewhere prior to charging the battery. This is done at On-Board Charger. DC charger directly provides DC to charge the battery using Off-Board charger. The On-Board and Off-Board chargers can be studied based on various features, availability and charging speeds. Different charging levels in reference to charging power for the On-board and Off-board chargers are shown in fig. 3. The On-board charger is one implemented in the EV, whereas the Off-Board Charger are direct charging units for EVs placed outside of the EV. The on-board charger is an AC to DC converter which when fed with AC from the AC supply conditions the supply by converting into DC and supplies it to the Battery Management System (BMS) of EV and Off-Board Charger are DC chargers which directly interface with BMS for charging the EV battery. The on-board charger has power conversions for different power levels ranging in between 3.3 kW and 22 kW. It can work on both one-phase and three-phase power supply. The power cannot be directly supplied to on-board charger from the supply unit as it may have some fluctuations or instability. To control the instability and fluctuations the charger control unit is used. The charger control unit converts the incoming power as per the requirements of the EV by detecting the feedback from the connection between EV and CCU [24] – [27]. Flow of charge from grid to battery pack in EV through EVSE using On-board charger is shown in fig. 4 (a). The Off-Board Charger are also known as fast chargers and designed to transfer higher range of power which is ranged from 20 kWh to almost 200 kWh as of the developments till now.

The input required for Off-Board chargers is greater than supply available from three phase power supply thus are connected to grid directly. If the vehicles are to be charged only with Off- Board chargers, the weight of EV can be reduced by removing the On-Board Chargers from the machine. To make the EV charging easier from home or office charging sockets, On- board charger is one of the mandatory parts of the EV.

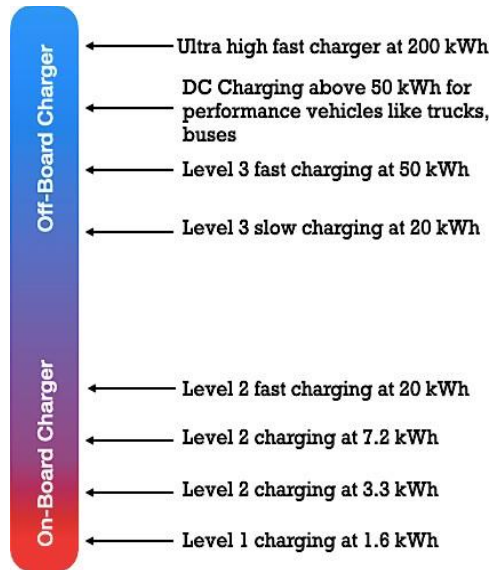


Fig. 3. Charging level in reference to power level for on board and off board chargers.

Different charging levels are shown in reference to On-board and Off-board chargers in figure 3 [27], [28]. Flow of charge from grid to battery pack in EV through EVSE using Off-board charger is shown in fig. 4 (b).

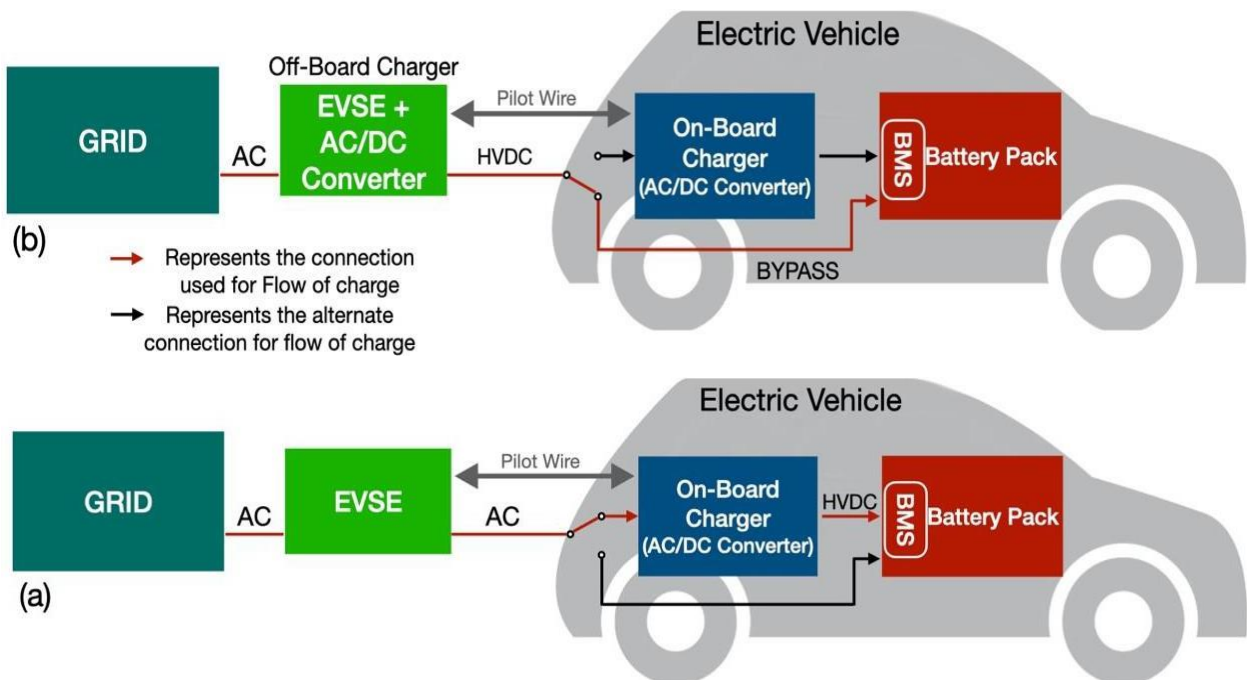


Fig. 4. Charging of EV using (a) On-Board Charger, (b) Off-Board Charger

### A. Conductive Charging

These days most of the charger operators along with automotive industry prefer condition as method to charge the EV as it is cheaper and relatively efficient. In conductive charging the direct contact is made

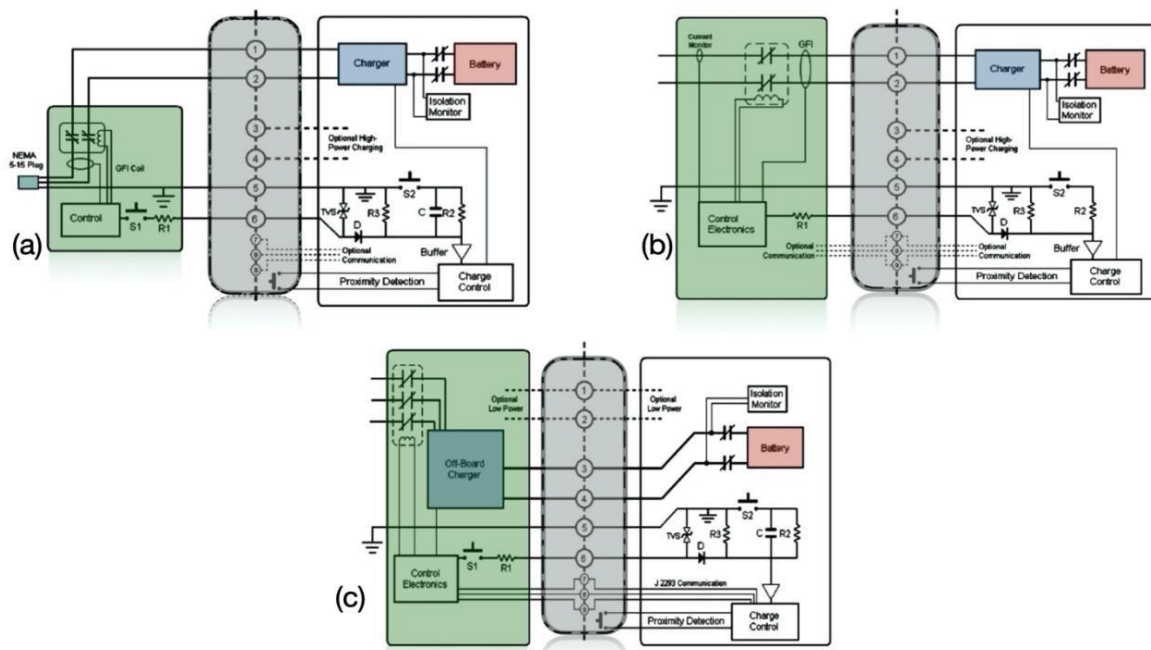
between the EV and supply unit. From a charging station a connecting cable is connected to charging unit which further charges the EV using charging cable. The main drawback is that the connection must be done manually [26] – [28].

### (i) EV charging Levels

The EV charging levels are decided based on power levels at the charging unit outlet. The EV charging levels are divided into three different categories [27], [28].

A level 1 EVSE is residential supply equipment which uses most commonly available AC input of 120V with limited 10A to 12A current with charging capacity of maximum 1.6 kW per hour. It takes 12 to 17 hours to charge a small battery of 24 kWh capacities. 24 kWh batteries run about 180 to 200 km of range. The output from the charger is AC which goes into the on-board charger of EV from where the supply is sent to charge the batteries via BMS. Level 1 charger is the slowest of all the chargers. Level 1 EVSE are most suitable for PHEVs as they have smaller batteries as compared to BEVs. Nissan Leaf is one of the most used BEV which tends to charge using level 1 supply [5], [12], [28]. Architectural design of level 1 EVSE is shown in fig. 5 (a).

A level 2 EVSE is little faster charger than level 1. The input used is 220V or 230V of AC supply. Level 2 can work at single phase and three phases. These can be used at 15A/16A electric socket from where 13A of current can be withdrawn thus making the charging capacity of slowest level 2 EVSE to be 3.3 kW per hour which would take around 7 hours to charge small battery of 24 kWh capacity. Level 2 EVSE is also gives out AC supply just like level 1 EVSE. The AC from Supply equipment goes to the input of EV and charges the battery after getting converted into DC by On-board charger placed at EV. The current rating for level 2 EVSE varies from 13A to 80A along with charging capacity ranging from 3.3 kWh to 20 kWh.



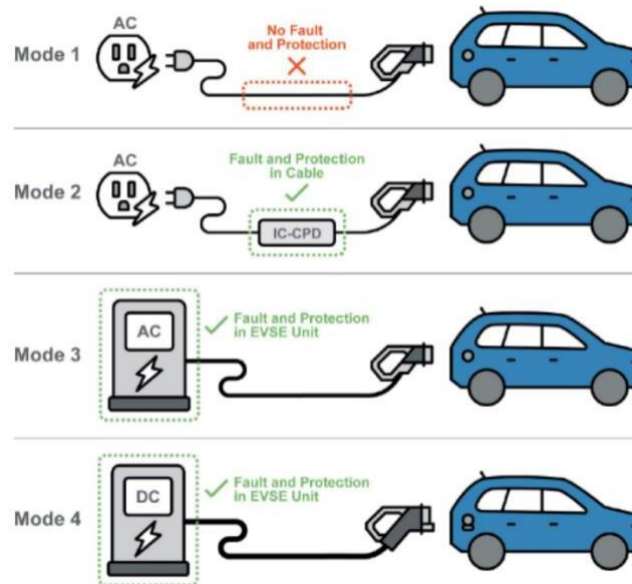
**Fig. 5.** Architectural design of different Charging Levels of EVSE, (a) Level 1, (b) Level 2, and (c) Level 3

The charger with 20 kWh capacities would be the fast one working at three phase AC supply. For a mid-range EV of 350 km to 380 km using 40 kWh batteries, the charger working at 6.6 kWh, or 7.2 kWh would take an overnight to fully charge the battery [27], [28]. Architectural design of level 2 EVSE is shown in fig. 5 (b).

Level 1	Level 2	Level 3
<ul style="list-style-type: none"> <li>• Supply from Household Outlets</li> <li>• 120V, 12-16 A, Single Phase AC</li> <li>• 1.4-1.9 kW Charging Power</li> <li>• Use EV's On-Board Charger</li> <li>• Charge 6-10 km of range per hour</li> </ul>	<ul style="list-style-type: none"> <li>• Supply from household or EV Charging points</li> <li>• 208-240 V, 12-80 A, Single Phase AC</li> <li>• 2.5-19.2 kW Charging Power</li> <li>• Use EV's On-Board Charger</li> <li>• Charge 20-40 km of range per hour</li> </ul>	<ul style="list-style-type: none"> <li>• Supply from Commercial EV Charging points</li> <li>• 208-600 V, 60-400A, at Three Phase AC</li> <li>• Up to 240 kW Charging Power</li> <li>• Use Off-board DC charger</li> <li>• Charge up to 80% battery capacity in 20-30 minutes</li> </ul>

**Fig. 6.** Comparative study of Different levels of EV Charging

A **level 3 EVSE** are fast chargers and are generally connected the electricity grid directly. The output capacity of level 3 can be as low as level 1 or level 2 EVSE i.e., 2 to 20 kWh and as high as 50 kWh. Chargers with higher capacity like 200 kWh are termed as ultra-fast chargers. Even the slow level 3 charger with 20 kWh capacities would charge up small battery of 24 kWh in 1.2 hour.



**Fig. 7.** Different modes for Electric Vehicle Charging

If the battery capacity used in EV is to be increased, the regular level 1 and level 2 chargers are going to take longer time to charge which can go up to days too so there is too much need of fast and efficient charger[22], [28], [29].

All the EVs are no fast DC charger compatible, the compatibility depends upon so many aspects such as battery design and configuration, BMS, charging port compatibility, etc. The fast DC chargers take around 20 minutes to charge empty to 80% of the battery and after 80 %, it takes a long time therefore DC charging is measured up to 80%. Architectural design of level 3 EVSE is shown in fig. 5 (c). Comparative study of EV Charging levels is shown in fig. 6.

### *(ii) The EV Charging Modes*

For efficient performing of EVs all around the world, some standardization is needed. For the same, safety communication protocols between the charging station and EVs have been standardized and called Charging Modes. Four modes are defined as per the connection of EV to the power supply using the various components. The components to be used are supply unit- home supply or grid supply, extension cords, charger control unit, on-board or off-board charger. The home supply can be single phase or three phase power supply coming out from standard 16A socket or specific socket which can bear the current above 16A. The charging modes are defined upon the basis of combinations of some of the components explained above [9]. Different modes of Electric Vehicle charging are shown in fig. 7 along with explanation below:

**Mode 1 charging:** It consists of only two components to make connection from supply unit to EV i.e., regular home socket and cable. The EV can be charged comfortably anywhere effectively as it needs just a cable (with charging head and plug one on each side of charging cable) and supply socket. The maximum can be 16A at the maximum AC of 250 V in single phase or 480 V in three-phase. It is the basic charging form the comfort of home using standard available socket. The electrical wiring must comply with the safety regulations such as have a proper earthing system and have a circuit breaker to prevent against overloading and protection against current leakage [13], [14], [28] – [31]. In the mode 1 charging, EV is connected to 10 A regular home sockets using cable. It is the slowest mode to charge an EV. There is no protection device in case of fluctuations in the supply or the circuit breakage in case of full charging of EV. This mode has been outlawed in several countries.

**Mode 2 Charging:** In mode 2 charging, cable from regular home socket connects to Electric Vehicle Supply Equipment (EVSE) which further charges the EV through on-board charger. The EVSE is a protection device built in between the charging cable and portable in nature. The EVSE is generally sold by the EV manufacturer along with the EV. The EVSE has in-built residual current device which protects EV from over- current, over-heating, and current leakage with device named In Cord –Control and Protection Device (IC-CPD). IC-CPD also controls the fluctuations to protect the EV. EVSE gets feedback signal from the EV regarding the connection, starts charging the EV only when there is valid connection, earth protection, vehicle is plugged in and vehicle has requested for power. The EVSE and EV communicate before charging to establish the connection and start charging, during charging to keep a check on charging and to stop the charging after fully charging to avoid over charging and heating.

The mode 2 charging, cables are moderately safe and are as per the required safety standards. The EVSE is connected to single- phase 250 VAC at maximum of 32A but mostly used is 16A which is readily

available at most of the houses and offices. The supply outlet socket needs to have power and earth conductors to transfer power and provide protection against electric shock [13], [14], [28] – [31].

**Mode 3 Charging:** Mode 3 charging is a conductive charging mode using AC charging station. EVSE is the control unit and is not portable. The power is higher than in mode 2 charging which can be connected to either of single phase or three phase power supply at maximum current can be 80A. When used to the maximum capacity the charging capacity reaches up to 22 kW per hour. It is the fastest mode to charge an EV using AC. The AC supply generally charges the EV up to 95 to 97% of battery capacity and is considered almost 100%.

**Table 1.** Overview of Different Modes for Electric Vehicle Charging

Type	Power	Current	Voltage	Charging time for 30 kWh battery	Safety Equipment used	References
<b>Mode 1</b>	Up to max 3.7 kWh	10A – 16A	1 Phase AC	8-12 h	None	[13], [14], [28]–[31]
<b>Mode 2</b>	3.3 to 11 kWh	13A- 30A	1 Phase or 3 Phase AC	4-8 h	Ic-cpd	[13], [14], [28]–[31]
<b>Mode 3</b>	10 kWh to 43	32A- 63A	3 phase AC	1-2 h	Wall mount IC-PCD	[14]–[16], [28]–[31]
<b>Mode 4</b>	22 kWh to 240 kWh	400A-3225A	DC	5-30 min		[16], [28]–[31]

The mode 3 EVSE is not a portable one but instead is wall mounted with high current supply mostly with the mains and charges the EV through on-board charger. The Mode 3 EVSE communicates with EV just like mode 2 charging EVSE but with better communication, judgment-, and charging power. This is the only charging mode that meets all the electrical installation standards. This type of EVSE is optional to buy from EV manufacturer or other EVSE manufacturer as it is an expensive product as compared to mode 2 EVSE. Due to highpower capacity, it optimizes the charging time which is the good enough reason to buy additional equipment to charge the personal EV [14] – [16], [28] – [31].

**Mode 4 Charging:** Mode 4 Charging is an OFF-board charger with DC connection charging which is usually termed as fast DC charger. DC charger directly charges the battery using DC by-passing the on-board charger. DC chargers are connected directly to the grid to receive high power to charge the EV faster. The controls and protection are permanently mounted along with the cable at the installation site. This kind of charger is not suitable for home charging but instead for charging stations as it withdraws high current and voltage which may add load to the residential grid and ultimately may lead to power line collapse in the area. The EVs have special charging connectors to identify the DC charging or AC charging which are explained ahead [16], [28] – [31].

### **B. Inductive Charging**

Without the direct connection, the current can be transferred between two objects using electromagnetic field (EMF) and this process is known as induction. The same process can be used to charge the EVs too and is known as inductive charging. It is done only at the charging stations. From the electrical device the charge is transferred through inductive coupling to EV to charge the EV battery or run the EV. The

alternating EMF is produced at the induction coil at the inductive charging station from the electric current and the portable device (here EV) receives power from the EMF using coil and converts it back into electric current to charge the battery. The sender and receiver coils, when come in proximity, from an electrical transformer. With the use of resonant inductive coupling in inductive charging system, the distances between send and receive coil can also be increased. According to recent research and developments, various materials are being used such as silver-plated copper or aluminum to decrease the weight and resistance of the resonant systems while using the movable transmission coil [32] – [37]. The inductive charging is durable form of charging where the connections are protected with low infection risk. As there are almost no cables needed, the charging convenience and quality are maintained or even increased. Along with positive qualities, there are few negative aspects too such as, the speed of charging is lower, and it is expensive way to charge the EVs. Building inductive charging stations is inconvenient at this moment of time from station when connected to socket. Connector: the charging head on the cable towards EV which when connected to EV socket supplies the charge to EV to charge it. EV Socket: on the EV to which connector gets connected and supplies the power. In Type 1, Type 2, CHAdeMO, and CCS the connector on cable side is female connector and, on the EV, socket is male [4], [5], [7], [9]. The Socket and connector correspond to each other i.e., the connector used on the charger side must be the corresponding as the socket used in the EV.

### ***A. Type 1 Connector***

This type of connector/socket pair is used widely in Japan and USA named as “SAE J1772/2009” or Yazaeki connector (named after the manufacturer), found majorly in North American Continent. Type 1 coupler is AC coupler which is compatible with only single-phase power supply and doesn't support three-phase supply. Thus, it can be used in either of level 1 or level 2 charging. Level 1 charging uses 120V with maximum current of 16 A with output power up to 2 kW. Level 2 uses 208V to 240V single phase with current maximum up to 30 A with power up to 7.4 kW. Type 1 coupler has five pins: three main bigger pins (two pins for AC supply, one pin for earth), and last two smaller pins for compatibility functions like proximity detection and pilot function control [16], [29] – [32], [38] – [41].

First small pin is Proximity Pin (PP). It tells about the EVSE about the type of cable connected to the socket as for different number of electrical currents, different thickness cables are to be used. Second small pin is Control Pilot (CP). It is responsible for bidirectional communication between EV and EVSE. It also checks the amount of current the EV needs to charge the battery of EV. COMBO1 or CCS 1 type of connector coupler is derived from type 1 connector coupler.

### ***B. Type 2 Connector***

Types 2 connector/ socket pair is majorly used in Europe, was proposed by company named “Mennekes” thus named too after them. Type 2 couplers can transfer higher power than type 1 counterpart thus can be used in both mode 2 and mode 3 charging. It is also compatible with three phases along with single phase power supply. Therefore, maximum voltage can be up to 480V, and current up to 300A. COMBO 2 is derived from type 2 connector. Type 2 coupler has 7 pins in total: five main pins (four pins as AC conductors, one pin for earth), two pins for compatibility functions like proximity detection (PP) and a pilot function control (CP) as explained in type 1 connector [16], [29] – [32], [38] – [41].

### ***DC-EV Connectors***

The DC connectors are mostly found at the charging stations and within the fleet chargers. Rapid DC charging rate starts from 50 kW, whereas ultra-fast charge at the rate of 100-150 kW or even range up to 350 kW. Just like AC connectors, DC connectors also vary across different areas and manufacturers.

### ***C. CHAdeMO Connector***

CHAdeMO was invented in Japan. “CHAdeMO” is an abbreviation of “CHArge de MOve,” equivalent to “charge for moving,” and is a pun for “O **cha demo** ikaga desuka.” In Japanese, meaning “Let’s have a cup of tea while charging.” [42] It is official DC charger connector in Japan for fast charging and used by Nissan and Mitsubishi in North America. The original CHAdeMO connector can transfer 62.5 kW power through DC current through 2 pins held side by side. It can work at 500 V, and 125 A. New version CHAdeMO 2.0 can work at much higher than previous version, it can work at 1000V and 400A at maximum power of 400 kW. The data signals are transferred using the CAN (Control Area Network) protocol which is used as CP and communicates between EV and charging system. Level of battery before and during charging and maximum capacity of battery are few points communicated between EV and charging station. It is not feasible for EV to charge on DC all the time, so there is need to supply AC charging to EV. Therefore, combined charging system is developed [16], [29] – [32], [38], [39].

### ***D. Combined Charging System Connector (CCS)***

As the name suggests, combined charging system connector, consists of both DC and AC connectors. CHAdeMO is combines with both Type 1 and Type 2 to result in CCS 1 (COMBO 1) and CCS 2 (COMBO 2) respectively. CCS 1 is used majorly in North America whereas; CCS 2 is most widely used in EU, Asia [39]. Over the mains, the communication protocol changes to internet protocol i.e., the charger communicates through IP data. The CCS connector means that EV is compatible with both AC EVSE through top half of CCS and DC charger through bottom half of CCS connector. COMBO 1 and COMBO 2 can be used in mode 2, mode 3 and in mode 4 by using part function and complete unit as per needs of the user [16], [29] – [32], [38], [39].

### ***E. GB/T Connector***

The largest share in EV market is held by China and the charging connector named GB/T (Guobiao standard) is different from whole of the world and is available in both AC and DC mode. AC-GB/T is effectively an inverse of type 2 charger connector, as connector on cable side is female connector and, on the EV, socket is male in type 2 charger and in GB/T connector on cable side is male connector and on the EV socket is female. Type 2 charger uses PP/CP (proximity pilot and control pilot) whereas GB/T uses CC/CP (charging confirmation and control pilot) signals. Though connector is seven-pin interface and is capable of handling three-phase supply, but the implementation is mostly limited to single-phase supply. In the DC-GB/T total of nine pins are present. Two are for mains (DC+ and DC-), two for charging communication (S+ and S-), and two for charging confirmation (CC1 and CC2), one for protective earth (PE) and last two pins for auxiliary DC power (A+ and A-). DC- GB/T can easily work at high voltage of 750-1000V with current of 80/125/200/250A [43] – [45].

Connector Type	Type 1	Type 2	CHAdEMO	CCSI	CCS2	GB/T (AC)	GB/T (DC)	Tesla
Country	USA, Japan	Europe, India	Japan	America	Japan, India, Europe	China	China	America
Type of current	Single Phase AC	Single/Three Phase AC	High Power DC	Single Phase AC and High Power DC	Three Phase AC and High Power DC	Single Phase AC (Three Phase Reserved)	High Power DC	Single/Three phase AC, High Power DC
Voltage	120/240 V	480 V	Up to 1000 V	120/240V(AC); 50-1000V(DC)	480 V(AC) 50-1000V (DC)	380-430 V	Up to 950 V	240 V (AC) up to 410 V
Current	32 A(max)	63 A(max)	400 A	80A(AC/DC)	63A (AC) 400A(DC)	32 A	250 A	63A (AC) 800A (DC)
Power	3.3 -7.6 kW	30 kW	400 kW	19.2 kW (AC); 80 kW (DC)	44 kW (AC) 400 kW (DC)	22 kW	237.5 kW	22-43kW (AC) 250kW
Sockets and Connectors								
Reference	[16], [29] – [32], [38] – [41]	[16], [29] – [32], [38] – [41]	[16],[29],[31], [32],[38],[39], [42]	[16], [29], [31], [32], [38], [39]	[16], [29], [31], [32], [38], [39]	[43] – [45]	[43] – [45]	[45] – [47]

Fig. 8. Overview of different connector types

### F. Tesla Connector

Over a short period of time, Tesla has become the hot selling brand of EV. The Tesla EVs have fast speed and long-distance range for which the Tesla EV battery also needs to be extraordinary powerful. For the same reason, Tesla has designed special EV charger connector to charge the EV. The charger connector has both AC and DC supply unit from the single charging connector, but the designs are divided into two types, Tesla Type 1 for North America, and Tesla Type 2 for European Union. For communication between EV and charger, Tesla connector also use CAN protocol just like CHAdEMO. It can also switch to digital protocol instead of analog protocol. As per the recent developments, the Tesla is shifting to type 2 models from type 1 model to maintain the uniformity all around [45] – [47]. All standardized EV charging Connectors are overviewed in Fig. 8.

### V. CONCLUSION

In this paper, different types of EV and EV charging methods have been presented. The EVs are classified based on range, charging and combination of battery and engine/motor used. The EV chargers are classified into conductive and inductive charging depending upon the connection of charger to the EV. In conductive charging the EV is connected using the cable and inductive charging EMF is used to transfer the charge without any contact between EV and charger. Further the charging levels are explained followed by charging modes. Lastly the different charging connectors are presented.

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