Review on Charging Methods and Charging Solutions for Electric Vehicles

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Abstract: Electric Vehicles (EVs) are gaining popularity due to low maintenance cost and zero emissions. The range of the EVs depends on the energy stored in their batteries which can be charged by using a normal (AC) charger or a fast (DC) charger. The batteries in EVs can be used as storage devices in Vehicle to Vehicle (V2V) and Vehicle to Load (V2L) technologies. Fast chargers have an important role in EV applications. Hence this article comprehensively investigates the state of the art of EV charging methods and charging solutions for EV applications. This article presents an overview of charging methods and charging solutions for electric vehicles.

1 Introduction

Using petrol and diesel for transportation results in CO_2 and Nitrogen Oxides emissions. Hybrid Electric Vehicle (HEV) is a low-emission vehicle and Electric Vehicle (EV) is a zero-emission vehicle. Electric vehicles in the form of two-wheelers, three-wheelers, cars and buses are being used and the percentage of electric vehicles in the total number of vehicles is increasing gradually [1]-[5]. The central government and many state governments are encouraging the use of electric vehicles by in the form of input subsidy and lower taxes on electric vehicles. However, increasing number of electric vehicles will bring new issues to power systems such as overloading and power quality [6]-[11]. Leading technology companies like Siemens, ABB Etc are in the forefront of introducing the recent developments in EV chargers into the market. The main contributions of this article can be summarized as follows:

Investigate the EV charging methods in terms of type of charger, rating, and other options such as Vehicle to Vehicle and Vehicle to Load.

Discussing the differences in AC and DC chargers in terms of charging current, charging time and power rating.

2 Chargers used in India

Charging time for mid-range Electric SUV Most of the cars in India use CCS2 charging standard. AC charger installed at a home or office will have a rating of 7.2 KW and above. Depending on the battery capacity and condition, this charger can charge the battery (SoC 0% to 100 %) in 7 to 9 Hours [12]. DC charger installed in a commercial location will have a rating of 50 KW and above. It can charge a battery (10% SoC 80% SoC in 30 minutes to 50 minutes [13]-[15]. Connecter for CCS2 on the car side is shown in Fig. 1. & Fig. 2.

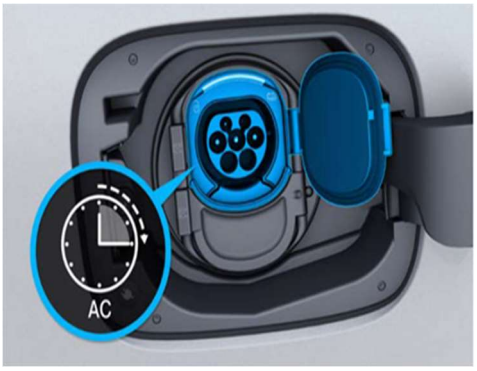

Fig. 1. CCS2 charger connecter for AC

Fig. 2. CCS2 charger connecter for AC /DC

2.1 Specifications of CCS2 charger

AC charger with a three-phase AC input is available in the power range of 4.3 KW to 20 KW and DC charger is available up to a power level of 400 KW [16]-[18].

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Typically, the battery capacity and the range of the car increases in the high-end segment. Cars in this segment can support AC charging up to a power level of 11 KW and DC charging up to a power level of 350 KW.

3 Electric Cars in India

Mahindra introduced the e-Verito in 2016 with a battery capacity of 266 Ah. It had a range of 140 KM. It was possibly the only car to use a 3-phase Induction motor. It was discontinued later. All electric cars available currently use the Permanent Magnet Synchronous Motor (PMSM).

3.1 Electric cars in the mid-range segment

Tata Motors, MG Motor, Mahindra, Hyundai and BYD are the key players in the mid-range EV market in India. Prospective car buyers now prefer Sports Utility Vehicles (SUVs) over other types. Electric SUVs dominate the product portfolio of many EV car companies [19]-[22].

Table 1. Electric SUVs in mid-range

Brand	Electric SUV		
	Model	Battery	Range
Tata	Nexon	40.5 KWh	465 KM
MG	ZS EV	50.3 KWh	461 KM
Mahindra	XUV 400	39.4 KWh	456 KM
Hyundai	Kona	39.2 KWh	452 KM

3.2 Electric cars in the high-end segment

Volvo, BMW, and Mercedes-Benz have a strong presence in the high-end EV market in India. Electric SUVs sold in this segment have a battery with higher capacity, increased range and sometimes two motors to drive the vehicle. One at the front axle and the other at the rear axle.

Table 2. Electric SUVs in high-end

Brand	Electric SUV		
	Model	Battery	Range
Volvo	C40 Recharge	78 KWh	530 KM
Mercedes - Benz	EQE	90.6 KWh	550 KM
BMW	iX	71 KWh	425 KM

3.3 Vehicle to Load

The Electric power in the battery can be used to power small appliances and other electric loads that can be used in the car. Depending on the battery capacity and the current SoC of the battery, there is a limit on the maximum power that can be used.

Fig. 3. Vehicle to load inside an Electric Vehicle

Fig. 4. Vehicle to load outside an Electric Vehicle

Vehicle to Vehicle charging

In Vehicle to Vehicle charging, a fully charged EV can be used to charge the battery of another EV with a lower SoC.

Fig. 5. Vehicle to Vehicle charging.

4 Charging and fast charging

Charging the vehicle using the supplied AC charger takes about 9 to 10 hours. The supplied charger is either installed at a home or office location and some manufacturers give a portable charger (2.8 KW supplied with Hyundai Kona) that can be plugged into a 15 A wall outlet. It will take 19 hours for a full charge. A portable charger is shown in Fig. 5. Some companies provide Roadside Assistance (RSA) for electric cars stalled with a fully discharged battery.

Fig. 6. Portable charger with a rating of 2.8 KW

Fig. 7. Roadside Assistance vehicle for charging

4.1 Charging time for mid-range Electric SUV

Charging time for the vehicle depends on several factors such as power rating of the charger, maximum charge acceptance level of the battery, SoC of the battery and its temperature.

Table 3. Charging time for mid-range Electric SUVs

Brand	**Electric SUV**		***AC Charging time (7.4 KW, SoC 10% to 100%)***	***DC Charging time (50 KW, SoC 10% to 80%)***
	Model	***Battery***		
Tata	Nexon	40.5 KWh	6 Hours	56 Minutes
MG	ZS EV	50.3 KWh	9 Hours	60 Minutes
Mahindra	XUV 400	39.4 KWh	6.5 Hours	50 Minutes
Hyundai	Kona	39.2 KWh	6 Hours	57 Minutes

High-end electric SUVs support a higher charging power level in both AC and DC charging. They also have a higher battery capacity. This higher battery capacity is needed for driving two electric motors at two axles [23]-[25]. This is summarized in Table 4 below:

Table 4. Charging time for high end Electric SUVs

Brand	**Electric SUV**		***AC Charging time SoC 10% to 100%)***	***DC Charging time (SoC 10% to 80%)***
	Model	***Battery***		
Volvo	C40 Recharge	78 KWh	8 Hours (Using a 11KW Charger)	30 Minutes (Using a 150 KW Charger)
Merced es-Benz	EQE	90.6 KWh	9.5 Hours (Using a 11KW Charger)	32 Minutes (Using a 100 KW Charger)
BMW	iX	71 KWh	7.25 Hours (using a 11KW Charger)	31 Minutes (Using a 150 KW Charger).

Charging and fast charging
Destination Charger
Most EV charging solutions providers offer AC Destination, DC Destination, DC Fast and DC high power chargers. A Destination charger is used at a home, apartment, office, business parks, complexes, hotels, sports institutions, and shopping centers. A fast charger is used at a city charging point, shopping center, and fast charging station on a highway [26]-[28]. AC Destination chargers from three different manufacturers are compared in Table 5. Mode 3 charging is AC charging. The AC Destination charger is shown in Fig. 8. DC destination charger is shown in Fig.9.

Table 5. AC Destination chargers

	ABB	SIEMENS	Beny
Charging mode	Mode 3	Mode 3	Mode 3
Power rating/ current	1-Phase: 7.4KW/32A 3-Phase: 22KW/32A	1-Phase: 7.4KW/32A 3-Phase 22KW/32A	1-Phase: 7.4KW/32A 3-Phase 22KW/32A
Input voltage	1-Phase: 184-276V 3-Phase: 320-480V	1-Phase: 230V 3-Phase: 400V	1-Phase: 230V 3-Phase: 400V

Fig.8 AC Destination charger

DC Destination chargers are available at higher power ratings. They follow Mode 4 charging. They include options for energy meter and payment calculator. Most

of the destination chargers can power up multiple charging points by using dispensers. This cost and space-saving solution can be flexibly installed on the floor, on the wall or under the roof. Some of DC Destination chargers are compared in Table 6.

Table 6. DC Destination chargers

	ABB	SIEMENS	Beny
Charging mode /connector	Mode 4 /CCS2	Mode 4 /CCS2	Mode 4/ CCS2
Power rating/ current	24KW/ 60A	100KW/ 125A	30KW/ 250A
Output voltage	150V to 920V DC	100V to 1000V DC	150V to 1000V DC
Input voltage	3-Phase: 400V	3-Phase: 400V	3-Phase: 380V

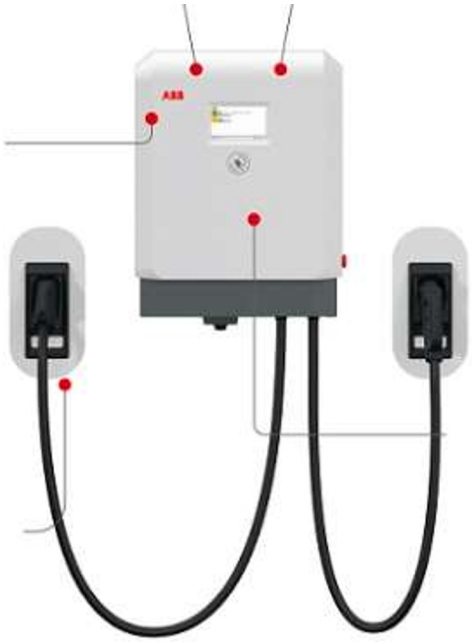

Fig. 9 DC Destination charger

4.2 Fast and High-Power Chargers

Most of fast chargers are of modular design in 175-350 kW range and ideally suited for highway corridor and EV fleet operations. Typical DC high power charging is shown I Fig. 11. They have cable retraction system with long cables. The output voltage range is from 150 to 1000V DC supporting todays and next generation EVs. Output current can be as high as 500A. Most of them use dynamic DC power sharing technology as illustrated in Fig.10 to save costs and scalable installation with integrated galvanic isolation. They come with integrated cooling system and connection to standard 400 V AC grid.

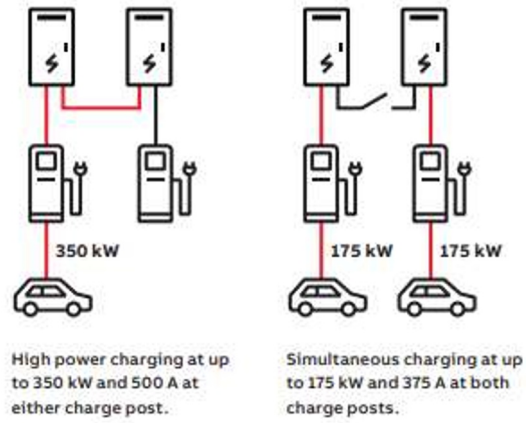

Fig. 10 Dynamic DC power sharing

Table 7. DC Fast chargers

	ABB	SIEMENS	Beny
Charging mode / connector	Mode 4 /CCS2	Mode 4 /CCS2	Mode 4/ CCS2
Power rating/ current	175KW/ 500A	300KW/ 400A	240KW /250A
Output voltage	150V to 920V DC	150V to 1000V DC	150V to 1000V DC
Input voltage	3-Phase: 400V	3-Phase: 400V	3-Phase: 380V

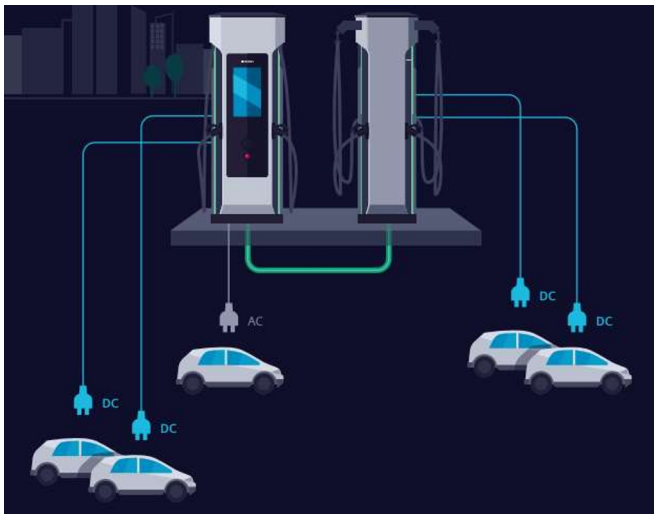

Fig. 11 DC high power charging

5 Conclusion

The market for electric vehicles is directly correlated with the recent developments in batteries, fast charging, and electric drive modules. Electric Vehicles are evolving with batteries using newer technologies like solid-state batteries and Sodium-ion batteries, higher capacity up to 114 KWh, support for higher power levels of 11 KW in AC charging and up to 350 KW in DC charging and as a result; increase in range up to 650 KM. Charging processes now automatically adapt to the connected vehicles to fulfil two goals. It always seeks to

use the full charging power available, and to use it based on the actual power request from each car(s) connected.

At the end of 2022, there were 27 lakh public charging points worldwide, more than 9 Lakh of which were installed in 2022. Globally, more than 6 Lakh public AC chargers were installed in 2022, 3.6 lakh of which were in China. The countries with the largest number of fast chargers are Germany (over 12000), France (9700) and Norway (9000) [29]. In this paper an overview of charging methods and charging solutions for electric vehicles are presented.

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