A REVIEW OF CHARGING TECHNOLOGIES FOR BATTERY ELECTRIC VEHICLES

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Abstract—**As electric vehicles (EVs) gain popularity around the world, heavily electrified mobility looks to have a bright future. With long-variety electric motors turning into a reality, the time-consuming and inconvenient procedure of charging an EV is slowly turning into a primary hurdle for clients, as many clients fear that their EV will also run out of energy at some point on a journey. This paper gives a review of different charging technologies for EVs, such as wired charging technologies, wireless charging technologies, V2V and V2G. To begin, there are two categories of wired charging technology: AC charging (indirect charging) via On board charger and DC charging (direct charging) via an off-board charger. Wireless charging technologies for electric vehicles are then thoroughly discussed in this paper. In summary, this paper provides a comprehensive review of the current state of EV charging technology and the key future developments in the charging field that will make an EV owner's charging experience much less time-consuming, effective, and convenient.**

Keywords—**Battery Electric Vehicles(BEV),AC charging,DC charging, off-board charger, on-board charger (OBC), Vehicle to Vehicle charging (V2V), Vehicle to Grid charging (V2G), wired charging, wireless charging.**

I. INTRODUCTION

Growing concern about carbon dioxide (CO2) emissions, greenhouse gas consequences and the rapid depletion of fossil fuels increases the need to develop and implement new green, sustainable options for ICE-driven vehicles. The transportation sector is responsible for about 24% of the total CO2 that results from the combustion of fossil fuels. For this reason, in the last decade, EVs have attracted increasing interest because of their promising capabilities, together with free-pollutant gases, no greenhouse gas emissions, and excessive efficiency [2]. Moreover, the electric motor that drives EVs utilizes 80 to 85% of the total energy that is supplied through the batteries, compared to the 12–30% that ICE-based vehicles utilize. It is estimated that by 2022, there will be over 35 million EVs in the world [5].

However, future improvements to the charging system have proven difficult due to the fact that a number of factors must be considered when researching these systems, such as an optimal structural design with fewer components, safety precautions, high efficiency, quick charging, and so on. These charging technologies can be classified into two categories: wired charging (contact charging) and wireless charging (non-contact charging) (contactless charging).

To begin, wired charging technologies necessitate a direct cable connection between the EV and the charging system to achieve charging, and they may be further classified into AC and DC charging technologies. AC charging is also referred to as level 1 or level 2 charging. An in-car inverter converts alternating current (AC) to direct current (DC), which is then used to charge the battery at either level 1 (120 volts) or level 2 (240 volts) (240 volts). In short, it uses the on-board charger to charge the battery (OBC). Before it enters the vehicle and charges the battery, the DC charging system converts the AC from the grid to DC [18].

Wireless charging technologies can be classified into three groups: near-field charging technologies medium-field charging technologies and far-field charging technologies. Wireless charging is less expensive than wired charging and does not require a direct connection to the batteries of electric vehicles. The first two charging technologies that is near-field

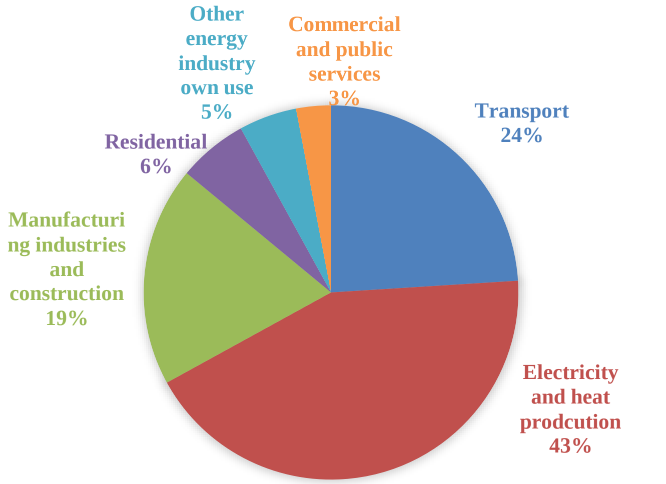

Figure 1. Sector-wise CO2 emission from fuel combustion

charging and medium-field charging are the most dominant and currently used charging technologies for EVs. They can charge the batteries wirelessly by converting grid-frequency AC (50/60 Hz) into a high-frequency AC (up to 600 kHz), which is then delivered via a transmitter pad and received by a receiver pad attached to the electric vehicle being charged. Far-field charging technologies, on the other hand, are seen as the charging method of the future for electric vehicles. However, one of the biggest disadvantages of wireless charging solutions is that they are inconvenient to use [2].

EVs are traditionally charged from the grid (G2V), using single-phase or three-phase chargers. V2G technology can also be used as a grid backup energy unit. As a result, when total energy demand is high, EVs can discharge during peak hours. Bidirectional power electronic converters, which are fundamental components of EV chargers, support G2V and V2G, the main functionality of EV chargers.

Many consumers are concerned about an emergency circumstance in which their electric vehicle's battery runs out and they don't have access to a charging station. As a result, EV solutions must be devised. If EV owners can charge their cars from other EVs, which is referred to as vehicle-to-vehicle charging (V2V) in this article, their fears of having a flat battery will be greatly reduced, opening the road for the EV market to grow. In V2V, an electric vehicle can link to another in an isolated mode and transfer energy from one battery to another according to the vehicle's settings [6].

The rest of this article is arranged as follows: The classification of charging technologies in BEVs is shown in Section II. The third section delves into the most current developments in the wired charging method. Section IV examines future developments in the charging system, while Sections V and VII discuss wireless charging technologies and V2X charging technologies, respectively. Section VI discusses wireless charging standards for electric vehicles. Finally, concluding observations are given in section VIII.

II. CLASSIFICATION OF CHARGING TECHNOLOGIES IN BEVS

The classification of wired and wireless charging technologies for BEVs is presented in this section. The overall classification for both charging technologies is shown in Fig. 2, which is done in a systematic manner. [1] [2].

The wired charging technology can be achieved in two ways, as shown in the *fig 2*:

1. AC charging system (1φ OB slow charging and 3φ OB
   fast charging)
2. DC charging system (off-board fast charging and off-board rapid charging)

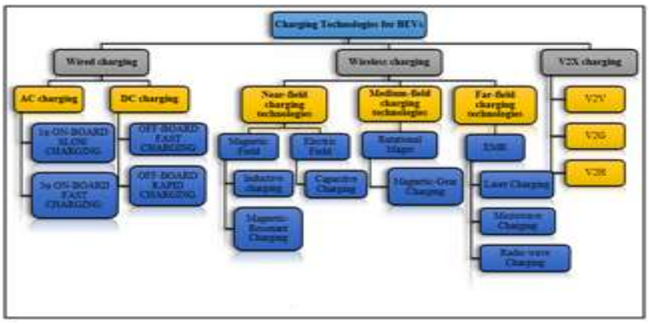

Figure 2. Overall classification of charging technologies for BEVs

The available wireless charging technologies are:

1. Near-field charging (inductive charging, magnetic resonant charging, and capacitive charging)
2. Medium-field charging (magnetic gear charging)
3. Far-field charging technologies (laser charging, microwave charging, and radio wave charging)

Furthermore, within the near future, the concept of vehicle-to-X (V2X), which transmits electricity from an on-board battery to infrastructure, is predicted to spread [3]. The available V2X charging technologies are:

1. Vehicle to Vehicle(V2V)
2. Vehicle to grid (V2G)
3. Vehicle to home (V2H)

While the wireless charging and V2X has existed, it has still not been standardized yet. Each method will be explained in detail as we proceed through the paper.

III. WIRED CHARGING TECHNOLOGY

This section extensively discusses the classifications of wired charging technologies for BEVs. As shown in Fig. 1, the wired-based technologies are classified primarily based on the input voltage type supplied to the BEV's inlets; i.e., AC-charging technologies and DC-charging technologies.

EVSE

Electric vehicle supply equipment (EVSE) is the basic unit of the EV charging infrastructure. The electric vehicle supply equipment (EVSE) provides electric power to recharge the battery of an EV. EVSE are commonly referred to as "EV charging stations" or "EV charging points" [5]. The EVSE accesses power from the local electricity supply and utilizes a control system and wired connection to securely charge EVs. An EVSE system enables diverse functions like user authentication, authorization for charging, information recording and exchange for network management, and data privacy and security. It is recommended to use EVSEs with a minimum of basic control and management functions, for all charging purposes. Conductive charging, or plug-in (wired) charging, is that the mainstream charging technology in use. Requirements for EVSE for conductive charging depend upon elements, which include vehicle type, battery capacity, charging methods, and power ratings [8].

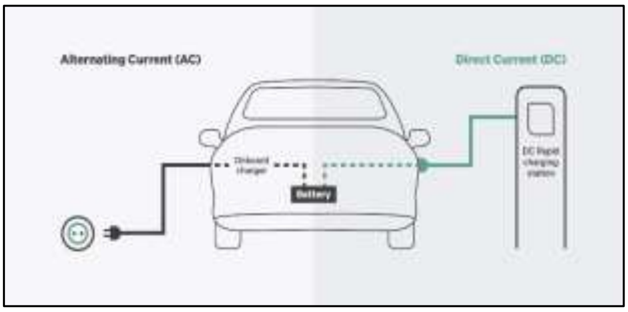

Figure 3. AC and DC charging system for EV [19].

1. AC CHARGING

When charging an electric car with alternating current, the car's on-board system (also called the on-board charger) is used, and it takes care of the conversion of outlet current into battery current. It therefore receives alternating current and converts it into direct current, which is then sent to the car battery.

The AC power is supplied by the on-board charger, which includes a rectifier that converts AC to DC power. The power control unit then controls the charging power delivery to the battery by adjusting the voltage and current of a DC/DC converter. The battery charging is controlled by the power control unit, which is coupled to the BMS (Battery management system). The BMS keeps track of important battery parameters like voltage, current, and temperature. Following that, it sends signals to the power management unit, which regulates the charging power delivered by the DC/DC converter. If the battery operating limits are exceeded, just like the voltage or current, the BMS triggers the protection circuit within the on-board charger, thereby isolating the battery if needed for its secure operation.

It is classified into two groups: 1φ OB slow charging and 3φ OB fast charging.

A) 1φ on-board slow charging

1φ OB slow charging typically requires multi-stage conversions (i.e., AC-DC and DC-DC), which inherently leads to low-voltage ripples and a comparatively high power rating. Thus, it is widely used as an OBC inside BEVs, such as for level 1 AC charging (i.e., input voltage: 1φ 120 or 220 V, charging power: below 2 kW, and battery voltage (VB): DC 240 ~ 325 V) in a number of BEV models on the market [2].

a) Level 1 Charging

Level 1 charging systems are standard on vehicles and therefore are portable and do not require the installation of charging equipment. At one end of the provided cord is a standard, three-prong household plug. On the other end is a connector, which is also used to plug the vehicle in. Depending on the battery technology used inside the vehicle, Level 1 charging typically takes 8 to 12 hours to completely charge a fully depleted battery. The most common place for level 1 charging is at the vehicle owner's home, where it is normally charged overnight [7].

b) Level 2 Charging

Level 2 equipment offers charging through a 240V AC plug and requires installation of home charging or public charging equipment. These units require a dedicated 40-ampere circuit. However, unlike Tier 1, Tier 2 car chargers require a 208–240 volt, 40-ampere circuit. The Level 2 charging system is well matched with all electric vehicles and plug-in electric hybrid vehicles. Level 2 chargers have a cord that plugs directly into the vehicle in the same connector location as Level 1 equipment. Depending on the battery used in the vehicle, level 2 charging normally takes 4 to 6 hours to completely charge a fully depleted battery. Charging time can increase in cold temperatures. Level 2 chargers are commonly found in residential settings, public parking locations, places of employment, and commercial settings [7].

These 240-volt chargers need to be professionally installed and have an output current of up to 32 amps. There are a few variations depending on the version you purchase and the kind of vehicle you drive, but you can expect to refuel about five times faster than a Tier 1 charger [13].

B) 3φ on-board fast charging

Compared to the 1φ OB slow charging technologies, the 3φ OB fast charging technologies can provide a faster charging capability due to their medium power rating (about 20 kW); i.e., they can charge the battery up to 80% within a charging time ranging between 2 ~ 3.5 h. Consequently, they will be used for an OBC inside BEVs like level 3 (i.e., input voltage: 3φ 280 ~ 420 V, charging power: up to 50 kW, and battery voltage (VB): DC 320 ~ 400V. Dual-active-bridge (DAB) topologies are the most commonly used for these charging technologies. This approach is more practical for almost all BEVs in the market due to its easy application [2].

2. DC CHARGING

DC chargers are designed to quickly charge electric vehicles. It is essential for high mileage, long distance driving, and large fleets. They operate at level 3 charging power with an output ranging from 50kW to 350kW. DC chargers are implemented as off-board chargers rather than on-board chargers because, with high power operation, the AC/DC converter, the DC/DC converter, and the power control circuits become larger and more expensive, which makes it impractical to integrate them as an on-board charger. Therefore, in order to avoid taking up space within the vehicle, they are set up as off-board chargers, which can be shared by many users [1]. Most Level 3 chargers provide an 80% charge in 30 minutes, although cold weather can lengthen the time required to charge [7].

Older vehicles had limitations that only allowed them to charge at 50kW on DC units (if they were ready to at all). However, more modern vehicles are now coming out that can accept up to 270kW. Because battery size has increased considerably since the first EVs hit the market, DC chargers have been getting better outputs to match, with some now being capable of up to 350kW [10].

Currently, in North America, there are three sorts of DC fast chargers present: CHAdeMO, Combined Charging System (CCS), and Tesla Supercharger. All major DC charger manufacturers provide multi-standard units that offer the ability to charge via CCS or CHAdeMO from the same unit. The Tesla Supercharger can only service Tesla vehicles. However, Tesla cars are able to make use of different chargers, especially CHAdeMO for DC speedy charging, through an adapter [10].

It can be classified into two groups: off-board fast charging and off-board rapid charging.

A) *Off-board fast charging*

The power flow for DC charging from the DC charger to the EV battery is initiated by converting the AC power provided by the AC grid to DC power with the help of a rectifier inside the DC charging station. The presence of the rectifying unit in the charging station enables this technology to directly charge a BEV’s battery. As a result, they can achieve an overall reduced size and weight of the driving system. Then the voltage and the current of a DC/DC converter are appropriately adjusted by the power control unit [1] [2]. Whenever there's a fault condition or wrong connection among the charger and the EV, the safety circuits and the protection interlocks are used to de-energize the EV connector and stop the charging process. The BMS plays the key role of controlling the voltage, the current and communicating with the charging station in the event of an unsafe situation [1].

These types of charging technologies are particularly well known for their fast charging (specifically, for their charging times below 1 hour). Nowadays, reputable companies such as Tesla, BMW, Nissan, and Hyundai have begun to provide fast DC charging stations that are capable of charging batteries within an hour. Off-board fast charging technologies primarily feed the battery with a three-phase power source with a power level ranging from 20 to 120 kW, a charging time of less than an hour, and a battery voltage of DC 320–450 V [2].

B) *Off-board rapid charging*

An extended form of fast charging technology can be found in the so-called rapid charging technologies, which use more power and charge current.

With these charging approaches, the charging time is faster, such that the battery of BEVs with DC 320 ~ 500 V can be charged up to 80% within 15 min. One of the most well-known rapid chargers, which is manufactured by Tesla, is fed by DC 480 V and 250 kW. As of March 2020, Tesla successfully operated around 16,013 superchargers at 1,826 charging stations worldwide for different BEV models such as the Model S, 3, X, and Y.

As an example, the Model S has an 80 A charging current, and the battery takes about 20, 40, and 75 minutes to charge up to 50%, 80%, and 100%, as for 85 kWh.

IV. FUTURE DEVELOPMENTS IN EV CHARGING

The charging technologies are being constantly improved in order to provide a much better and less time-consuming EV charging experience. As the electric car market is being established in many countries, key developments are being made to ease the main drawbacks customers think about: charging time and experience. The main technological developments we might experience in the future are as follows:

V. WIRELESS CHARGING TECHNOLOGY

Charging an electric vehicle without involving cables directly related to the vehicle’s system is known as "Wireless electric vehicle charging station (WEVCS) technology". Wireless electric charging technology for electric automobiles has lately been developed to help batteries in charge themselves. The transformer’s operating concept has played an important role in developing the basic basis for an electric vehicle charging or wireless charging system. The most significant benefit of a wireless charger is that it makes charging an electric vehicle extremely convenient [9].

Wireless charging systems for EV can be distinguished into two categories,

1. Static Wireless Charging
2. Dynamic Wireless Charging

1. Static Wireless Charging (SWCS)

As the name indicates, when the vehicle is static or parked, it gets charged. So here we could simply park the EV at the parking spot or in the garage, which is incorporated with WCS. A transmitter is fitted underneath the ground and a receiver is arranged in the vehicle underneath. To charge the vehicle, align the transmitter and receiver and leave it to charge. The charging time depends on the AC supply power level, the space between the transmitter and receiver, and their pad sizes [11]. This static wireless charging is best built in areas where EVs are parked for a certain time interval.

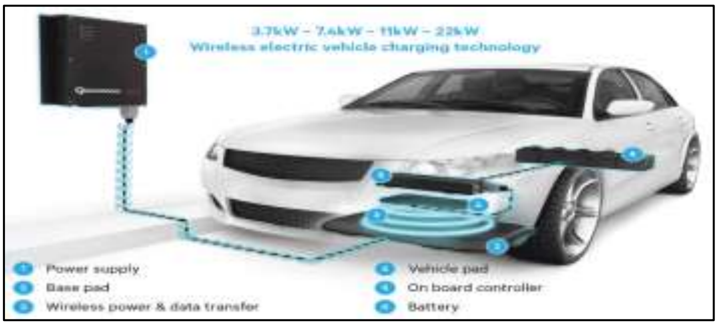

Figure 4. Static Wireless Charging [11]

2. Dynamic Wireless Charging System (DWCS)

As the name indicates, when the vehicle is in motion, it gets charged. The power will be transferred over the air from a stationary transmitter to the receiver coil in a moving vehicle. With the help of a dynamic wireless charging system, the EV's travel range could be improved with the continuous charging of its battery while driving on roadways and highways. It reduces the need for large energy storage, which further reduces the weight of the vehicle [11].

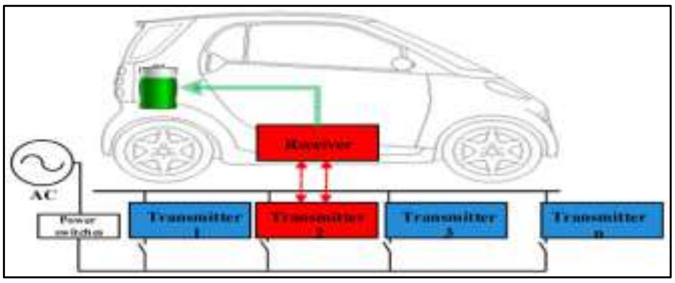

Figure 5. Dynamic Wireless Charging [11]

The next section thoroughly discusses the classifications of wireless charging technologies for BEVs. Beyond wired charging technologies, wireless charging technologies are recently attracting substantial attention due to their advantages, which are discussed below. Wireless charging technologies can be subdivided into three groups according to the transmitted distance: near-field charging technologies, medium-field charging technologies, and far-field charging technologies [2].

1. NEAR-FIELD CHARGING TECHNOLOGIES

The near-field charging technologies for BEVs include inductive charging, magnetic-resonant charging, and capacitive charging, which are described in detail below.

a) Inductive charging

Inductive or wireless chargers work on the phenomenon of IPT, i.e., transferring power from the utility grid to the EV by means of mutual inductance. It requires no physical contact between the utility grid and the EV. Moreover, they'll or might not require isolation transformers for safety purposes, so their size is reduced as compared to the conductive chargers. However, inductive chargers are comparatively less efficient due to misalignment of the power transferring coil [5]. Here, wireless transmission of power is achieved by mutual induction of magnetic fields between transmitter and receiver coil. When the main AC supply is applied to the transmitter coil, it creates an AC magnetic field that passes through the receiver coil, and this magnetic field moves electrons in the receiver coil, causing an AC power output. Firstly, an AC output is rectified and then filtered to charge the EV's energy storage system. The power transferred is determined by frequency, mutual inductance, and the distance between the transmitter and receiver coils [11].

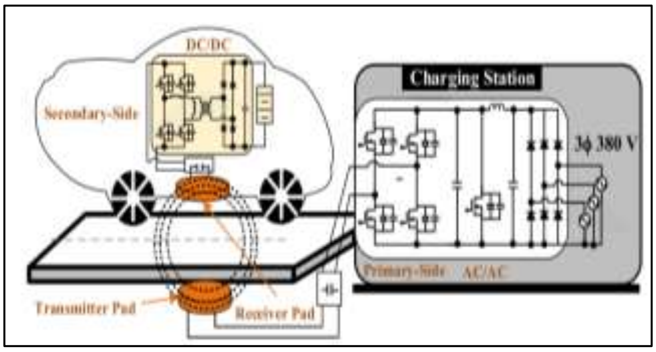

Figure 6. Inductive charging topology [2]

In these systems, achieving maximum power transfer with high efficiency is one of the essential considerations during both the design stage and operation. In addition, to ensure the long lifetime of the battery, it is very vital to regulate the EV power bus voltage. This is accomplished by controlling the switching frequency and conversion ratio of both the primary-side (i.e., a high-frequency (HF) AC-AC converter at the transmitter pad) and secondary-side converters at the same time (e.g., a full-bridge, dual-active bridge DC-DC converter, etc., at the receiver pad). The development of an appropriate power pad is one of the most important steps in the creation of a reliable and efficient wireless power transfer (WPT) system for charging BEV batteries.

These types of charging technologies have the capability of transferring the power between 3 ∼ 60 kW for a short distance of 4 ∼ 10 cm, respectively, with a maximum efficiency of 90% for the distance of 4 cm [2] [5].

b) Magnetic-Resonant charging

In contrast to inductive charging, MR charging is more effective as the resonant frequency gets magnified by adding compensation capacitors, thus resulting in a long transmission distance capability (i.e., 1 ∼ 5 m). The power range achieved by MR charging can reach up to 100 kW.

Phase 1: simple residential systems; phase 2: parking spaces; phase 3: on-street parking; and phase 4: dynamic charging systems are the four phases of charging technologies that can be implemented as a future technology for highways.

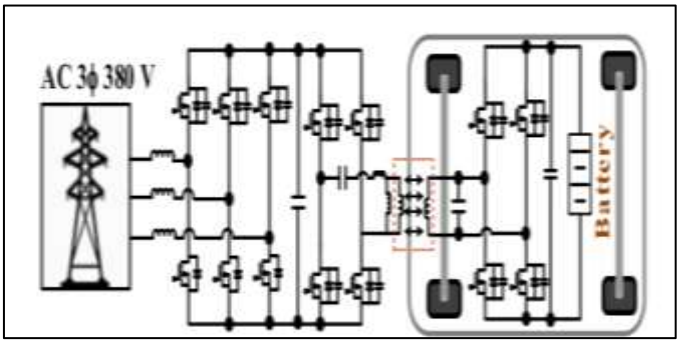

Figure 7. Magnetic-Resonant charging topology [2]

Moreover, the Oak-Ridge national laboratory has recently demonstrated an MR-based wireless charging system with an output of 120 kW, which is equivalent to that of a Tesla supercharger. It can transfer high power (i.e., 100 kW) over a medium range (i.e., 1 m) with a high efficiency of 90%. Qualcomm also constructed a 100-meter test track in France that is embedded with a 20 kW wireless charging system. Therefore, MR charging has attracted more interest as compared to inductive charging due to its promising features, which were mentioned earlier.

c) Capacitive charging

Capacitive charging can be generated by means of the electric field, where two metallic plates are integrated with both the transmitter and receiver pads which are connected to the power source or load as shown in the fig 8.

Wireless energy transfer between transmitter and receiver is accomplished by means of displacement current caused by the variation of the electric field. The AC voltage is first supplied to the power factor correction circuit to improve efficiency and to keep the voltage levels and to reduce the losses while transmitting the power. Then it is supplied to an H-bridge for the high-frequency AC voltage generation and this high

frequency AC is applied to the transmitting plate, which causes the development of an oscillating electric field that causes displacement current at the receiver plate by means of electrostatic induction [11].
The AC voltage at the receiver side is converted to DC to feed the battery through the BMS by rectifier and filter circuits.
Frequency, voltage, size of coupling capacitors, and air-gap between transmitter and receiver affect the amount of power transferred. Its operating frequency ranges from 100 to 600 KHz [11].

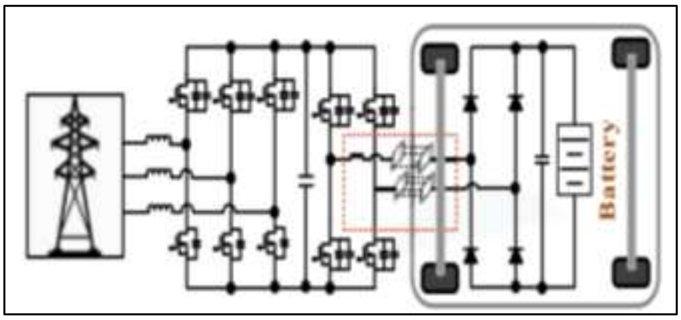

Figure 8. Capacitive charging topology [2]

Because the capacitor's two plates act like two capacitors connected in parallel, an electric field can be generated between them, resulting in the induction of electrical current in the receiver pad. This induced current is equivalent to the rate of change of the electric field between the transmitter and receiver pads. Thus, power converters such as resonant-based converters can be utilized to increase the rate of the electric field by elevating the frequency provided by the utility grid. Their power transfer capability, distance, and maximum efficiency can reach up to 7 kW, 12 cm, and 80%, respectively [2].

2. MEDIUM-FIELD CHARGING TECHNOLOGIES

The principle of medium-field charging technologies makes use of mechanical force as the main energy-carrying medium. They can be implemented in charging applications with a low power range of 1.5 ~ 3 kW. The working principle of this charging technology depends on the mechanical interaction between two synchronized permanent magnets (PMs), which are placed side by side. They can transfer a power of 3 kW over a medium range (i.e., 15 cm). As of late 2009, some well-documented studies had provided magnetic gear-based totally charging prototypes that could switch 1.6 kW over five cm with 81% efficiency [2].

3. FAR-FIELD CHARGING TECHNOLOGIES

This section discusses the far-field charging technologies for BEVs, which use electromagnetic radiation such as laser charging, microwave charging and radio wave charging.

a) Laser charging

For this sort of charging technology, the energy is transmitted via a resonating beam with a frequency that may attain as much as 3.59x1014 Hz, which is generated by a distributed laser charging (DLC) transmitter and received through a DLC receiver [2].
The received beam is then fed to a DC/DC power converter to regulate the output voltage for battery charging purposes. According to JAXA, the institute is working on a laser-based system capable of transferring 10 MW over a distance of up to 10 km with a maximum efficiency of 37%. *Fig. 9 (b)* shows one of the future technologies of wireless charging via laser with the help of the satellite.

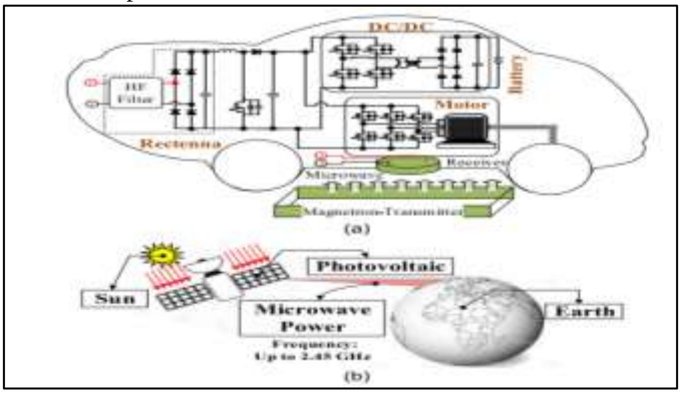

Figure 9. a) Laser charging topology [2] b) Future technology of laser charging with the help of the satellite [2]

b) Microwave charging

Microwave charging technology was examined in applications involving the delivery of power over a far distance (i.e., a hundred km), which includes platforms based on balloons, helicopters, experimental airplanes, experimental cars, etc.
In 1975, the US Jet Propulsion Laboratory achieved the maximum amount of transmitted energy using microwave charging technology. Specifically, 30 KW of power was enclosed from a parabolic dish with a diameter of 26 m to a rectenna (i.e., a rectifying antenna) 1.54 km away with 85% efficiency; the second one was examined by N. Kaya, in which two objects located in space successfully achieved energy transmission. Then, the first wirelessly powered airplane was released in Canada in 1987 through a ground-based microwave emitter.

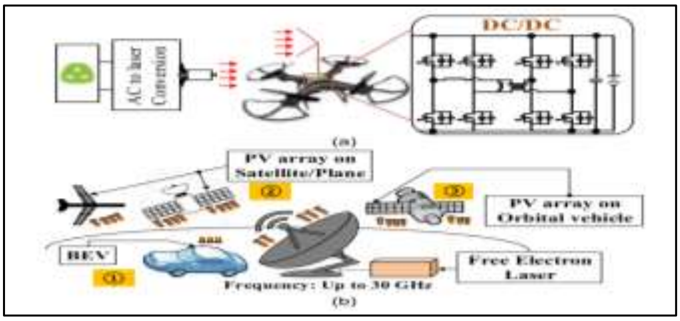

Figure 10. (a) Microwave charging for BEV. (b) Future technology of microwave charging for a satellite vehicle [2].

However, this technology is not yet practically applicable in BEVs. The main limitation of this type of charging technology is that the loss of communication between the transmitter pad and receiver pad will cut off the charging process. They also need large antennas, direct line-of-sight transmission paths, and complex tracking mechanisms [2].

c) Radio wave charging

The next type of far-field charging technology is radio wave charging, which is based on electromagnetic field (EMF) propagation. For this kind of charging technology, the power transferred from the transmitter may be captured through a rectenna that consists of a high frequency (HF) filter (allows high frequency (up to 30 GHz) components to pass), a rectifier (which is used to rectify the HF sine wave), and a low frequency (LF) filter (which only allows low frequency components to pass). The rectifier feeds a chopper DC to give the battery with the necessary DC voltage and charging current, as shown in Fig. 13. Unlike laser and microwave charging systems, radio wave charging efficiency is currently too low, and it therefore requires intensive research in order to attain the needed power efficiency for BEV charging. Furthermore, in order for a radio wave charging system to maintain adequate charging capabilities, an operator must guarantee that the charging connection is not disrupted, as any interruption results in no charge [2].

VI.WIRELESS CHARGING STANDARDS FOR ELECTRIC VEHICLE

Wireless charging allows electric vehicles to charge without the use of a plug. It will not be a good thing if each manufacturer develops its own wireless charging standards that are incompatible with other systems. As a result, in order to make wireless electric vehicle charging more user-friendly, Standards are being developed by a number of international organizations, including the International Electro Technical Commission (IEC), the Society of Automotive Engineers (SAE), Underwriters Laboratories (UL), and the Institute of Electrical and Electronics Engineers (IEEE) [11].

- WPT for Light-Duty Plug-In EVs and Alignment Methodology is defined by SAE J2954. According to this standard, level 1 has a maximum input power of 3.7 kw, level 2 has a maximum input power of 7.7 kw, level 3 has a maximum input power of 11 kw, and level 4 has a maximum input power of 22 kw. When aligned, the minimum target efficiency must be better than 85%. Allowable ground clearance is up to 10 inches, with a 4-inch side-to-side tolerance. Magnetic triangulation is the most preferred alignment method for staying within charging range in manual parking and finding parking locations for autonomous vehicles.
- EV/PHEV Conductive Charge Coupler is defined by the SAE J1772 standard.
- Communication between Wireless Charged Vehicles and Wireless EV Chargers is defined by the SAE J2847/6 standard.
- EV Inductively Coupled Charging is defined by the SAE J1773 standard.
- Use Cases for Wireless Charging Communication for PEVs are defined by the SAE J2836/6 standard.
- For WEVCS, UL subject 2750 defines Outline of Investigation.
- EV WPT Systems General Requirements are defined in IEC 61980-1 Cor.1 Ed.1.0.
- WPT-Air Fuel Alliance Resonant Baseline System Specification is defined by IEC 63028 Ed.1.0.

VII. V2X CHARGING TECHNOLOGIES

With the increasing investment from the auto industry, electric vehicles are becoming part of our daily lives. However, charging an EV is an issue, as it requires frequent charging and longer waiting times compared to traditional gasoline-based vehicles. Typically, an EV is charged at residential or public charging stations. As the number of electric vehicles on the market is increasing, one potential solution is to exploit the V2X (Vehicle to Anything) charging system [12].

The three types of V2X charging systems are vehicle to vehicle (V2V), vehicle to grid (V2G), and vehicle to home (V2H).

1. VEHICLE TO VEHICLE (V2V) CHARGING TECHNOLOGY

The ability for one electric vehicle to charge another vehicle is known as V2V charging. Power from one battery transfers to the other vehicle battery according to the setting in the vehicle. Power electronic units in both vehicles, as well as a charging connection that connects the two vehicles, make this power transfer possible

V2V Charging has a wide range of utility applications because it allows one EV owner to assist another EV owner who has run out of the battery charge on the roadside and needs a “jump-start.” To begin with, two vehicles, each with its own on-board power electronics system that allows the car to receive and distribute power via standard charging ports. Most electric vehicles on the market today can only receive, not distribute, an electric charge [4] [16]. Future electric vehicles will need on-board power electronics to manage power flow in both directions in order to enable bi-directional power transfer. Future electric vehicles will need on-board power electronics to regulate bi-directional power flow in order for this bi-directional power transfer to be possible. In order for this bi-directional power transfer to exist, future electric vehicles will need to have on-board power electronics to manage the power flow in bi-directions.

The V2V connection can be used to enable communication between the EVs. SAE J1772, this connector has three power lines (L, N, and G), a proximity detector that prevents the cars from moving while they transmit charging electricity and a control pilot enables communication with each other [6].

When the EV chargers detect and admit a V2V connection, the grid-connected mode's control system is instantly switched to the V2V operation's control diagram. As a result, the V2V operation can be activated. The V2V operation can be carried out while the mandatory safety standards are met by using the proximity detecting port and the control pilot.

There are currently just a few EV chargers on the market that have a unidirectional front-end converter. However, V2V operation necessitates the use of bidirectional converters in EV chargers, which appears to be a constraint for the suggested V2V operation. Unidirectional EV chargers, on the other hand, can still participate in V2V operation while receiving charging assistance from another EV having a bidirectional charger [6].

Figure 11. A Nissan Leaf is transferring energy to a Tesla Model S through a conductive charging cable [4].

2. VEHICLE TO GRID (V2G) CHARGING TECHNOLOGY

Typically, electric car charging is a one-way "Grid-to-Vehicle" energy transfer. The energy stored in electric vehicle batteries is solely utilized for driving. EV charging is now a two-way street thanks to bi-directional V2G charging points. Fully charged vehicles have the ability to feed stored energy back into the grid when the grid's power consumption surges.

Vehicle-to-grid is beneficial to grids in terms of balancing them, especially when renewable energy sources are included. It is also cost-effective because users can sell extra power from their cars to power the grids at a uniform price. These benefits are compelling enough to pursue [15].

The following is the V2G charging protocol:

- The EV and the charger exchange information about the EV and set the maximum charging current limit depending on the EV's and charger's power ratings.
- Once charging begins, the EV and charger negotiate and set a charging and discharging current set point based on battery variables such as state of charge (SoC), temperature, and so on.
- In the case of V2G, the charger can request a current modification, which the EV must accept. ISO 15118 is used for communication. If the request is approved, the EV's current set point is changed, and the charger is required to charge or discharge the EV according to the negotiated set point [16].

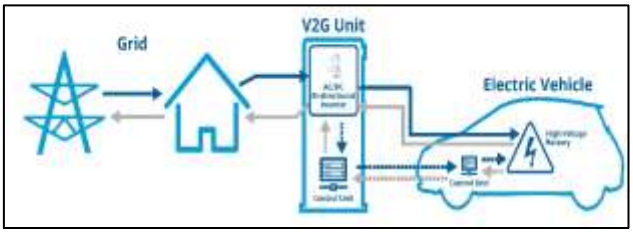

Figure 12. Vehicle to Grid (V2G) charging technology [20].

3. VEHICLE TO HOME (V2H) CHARGING TECHNOLOGY

V2H transfers electricity from your electric car battery to your distribution board or an energy storage system such as the Tesla Power Wall. During periods of high demand or increased electricity use, the vehicle offers a supply.

Power is sent to appliances, plugs, and devices when V2H feeds your distribution board, with load management controlling the distribution. Power is supplied to a big battery back incorporated into your home when V2H feeds an energy storage device, which stores energy for later delivery [17].

Only Japanese electric vehicles now support V2H, hence only CHAdeMO fast-charging ports can handle V2H. However, the current car-to-grid communication interface standard can extend V2H capabilities to CCS fast charging outlets.

Solar panels are being put in modern homes to save electricity expenditures. Conventionally, people have an inverter in their home that comes with a battery pack in order to store electricity and use it when needed; however, the electric car eliminates the battery pack because the car can store electricity and be used when needed, saving money that would have been spent on the battery pack.

In comparison to standard home storage batteries, electric cars have a greater battery capacity. When compared to home storage batteries, this means that one can go longer without electricity. Also, must consider that the car cannot constantly remain at home because it must be used for other purposes.

There are many examples where using V2H has been proven to be advantageous, but there are others where it makes no difference or is even more expensive in the long run. As of now, there is no way of knowing whether it is truly beneficial or not. When all electric cars allow V2H charging, it may become helpful to everyone in the near future.

Limitation for V2X charging technology

- All EVs on the market do not have bi-directional on-boarding chargers that facilitate EV discharging, which is a limitation for V2X charging technology.
- The communication protocol for AC charging via CP and PP has no provision for initiating V2X. In V2X mode, the charger acts like a master and requests the EV to discharge the required amount of current. However, in the present AC charging protocol, the EV is the master, and this type of V2X request cannot be enabled.

- EV batteries lose charge capacity and power capabilities as they age and go through charge cycles. V2H and V2G add additional charge cycles, so logic indicates that V2G activities reduce battery life.

VIII. CONCLUSION

This paper provides a comprehensive review of different charging technologies used in EVs. The way we transmit power to charge our electric vehicles might change drastically in the upcoming years, which will indirectly help with the broad adoption of EVs. Starting from the wired charging technology used in various regions of the world to working on wireless and V2X technology, these initiatives in future development will immediately increase the convenience of owning an EV. Unlike other research articles on charging technologies for BEVs, this review paper discussed in detail the currently appealing and available charging technologies for BEVs, such as wired charging technologies and wireless charging technologies. Wired charging systems are further divided into AC and DC charging methods depending on the way in which the EV battery is connected to the utility grid. Afterward, the classifications of wireless charging technologies for BEVs have been very well investigated, along with their commonly employed topologies. The main advantage of owning an electric-powered vehicle is the ability of electricity to be used as a commodity. Since the whole world has moved on to electrification, one can use their EV as a powerhouse and charge other devices during an emergency by using V2G technology. Also, the V2V function enables an EV to be charged by another EV in an emergency when there is no access to a charging station. This function will become useful when the number of EVs grows and the demand for roadside charging assistance subsequently increases. Since an EV can be charged anywhere, the option to charge an EV while moving, such as dynamic wireless charging technology, is also something tech companies have been working on to make the ownership experience of an EV more or less convenient than gasoline-powered cars. In short, this paper shows us the scope of a future where the traditional charging methods being used in current times will be improved more as our auto industry gets increasingly electrified on a global scale. In conclusion, there is still a long way to go to charge the battery of an EV in a more convenient, efficient, and stable manner.

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