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Charging infrastructure of electric vehicle - An Overview

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Review Article

Charging infrastructure of electric vehicle - An Overview

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Abstract

Since fuels like petrol, coal, and diesel are non-renewable sources of energy, there will be a deficiency of fuels in the future because of the increasing demand for mobility. The latest vehicles for the gasoline and petrol engine technology yield substantial greenhouse gas emissions and therefore create environmental issues. Electric vehicles will give a solution to this problem. Plug-in electric vehicles are implemented, to achieve environment-friendly transport and reduce greenhouse gases. Apart from the advantages, defects such as wear and tear of devices, electric spark, and carbon deposition make electric vehicle's wired charging less efficient. To make power transfer more flexible, in recent years the trend is to eliminate these cables i.e., by transfer of power without the use of any cables or wires. Wireless transfer is based on the induction principle. Features like the ease of charging, no exposed wires and fearless transmission of power in adverse environmental conditions make wireless charging more attractive. Plug-in electric vehicles often face the problems such as slower charging rate, size, weight, low energy storage capacity, etc. Wireless power transfer technology can resolve all these above problems. This paper reviews the battery-charging infrastructure from wired to wireless charging. Advantages and disadvantages of each technology for EV charging are also discussed, and wireless charging technology for Connected Autonomous Electric vehicle (CAEV) is discussed.

Keywords: CAEV, dynamic WPT, plug-in EV, static WPT

Introduction

Interest in electric vehicles has recently grown due to some reasons like energy availability, environment conservation, increase in oil prices, etc. When compared to internal combustion (IC) engine vehicles, the electric vehicle has so many advantages. Some of them are noise free, pollution free, high performance vehicle and its speed can be directly controlled from the rotor. It produces uniform power and speed, while in an IC engine vehicle power production is not uniform. For an electric vehicle (EV), the battery pack is the power source. This DC power is then converted into AC by using inverter configurations, which will turn the driver wheels of the EV. So, the battery plays an important role in the operation of an EV. The battery pack is made up of a common Li-ion connected in series and parallel to generate the power needed for the EV to run. Coolant is transferred through a metallic inner tube or through the space between the cells to reduce thermal hotspot and result in greater battery life. The cells are arranged as detachable modules, which makes them more reliable [1]. Why Li-ion battery? These batteries can store a large amount of energy in the given mass, self-discharge is less, and have a lifespan of up to three years or 300 to 500 charge cycles. When a battery in an EV runs out of charge, it can be recharged again by using several methods. paper is giving a comparison between various charging technologies of an EV from wired to wireless charging.

Charging Technologies

A. Wired charging

Wired charging and wireless charging are the two technologies, which are used to charge an EV. Wired

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charging is based on the conduction principle. Here a metal contact is operating between the charging inlet of the vehicle and supply equipment. It is the popular way of the charging method. An EV, which uses wired charging technology, is termed a plug-in EV. Plug-in EV requires a power electronic system between the power grid and high voltage battery pack which is located within the vehicle. This electronic system can split into two: A charging station and chargers. The charging station (electric supply equipment) consists of conductors, EV connectors, attachment plugs, power outlets, and apparatuses, which are required for delivering energy to the EV. There are two types of charging systems mostly available, which are AC and DC. In AC systems, the battery is powered by an AC charger via vehicle on-board charger, while in DC systems, the vehicle battery is charged directly by a DC charger. While explaining the battery charger types, it is also classified into two, off-board and on-board battery chargers with unidirectional and bidirectional power flow. Onboard chargers are available for charging from the utility outlet at household plug or office, etc. and it is designed for lower power consumption. Off-board, chargers are the fastest and they interface directly with EV. It is designed to transfer higher Kilowatts of power and it can improve the vehicle's overall efficiency. In addition, it removes the significant weight of EV [2].

Ways of charging EVs also can be categorized into four types, which are mode 1, mode 2, mode 3, and mode 4 charging. Mode 1 is the slowest charging method and mode 4 is the fastest one. Mode 1 charging uses a single-phase supply i.e., standard AC 110 volt (US) and 230 V (Europe and most of the world). An EV with an on-board charging electronics can use mode 1 charging by allowing the vehicle user to connect his vehicle into a socket in his garage. Since it is home-based charging method, it is the most comfortable and cheapest way of charging. However, it will take 7 to 15 hours for charging purposes. The maximum current for mode 1 charging is 16A. However, in the case of mode 2 charging, it uses 230V/440 Volt that is not exceeding 32A, installed primarily in public areas like shopping centres, city parks, etc. Mode 3 charging is the powerful and fastest charging, which can charge the battery within 30 minutes. It uses a 3-phase AC supply and an off-board charger. Such charging methods are usually used for heavy vehicles, like electric buses, installed in public and industrial areas. Mode 4 charging is a different approach to charging since; AC power is converted into DC in the charging station itself [3]. Mode 1 and mode 2 charging typically use case A connection. Case A connection of an EV to the AC mains utilize a cable and the plug is permanently attached to the EV. Case B uses a flexible cable arrangement with a connector to be connected into the EV inlet and a plug to be inserted into the supply socket to connect the EV to the power supply network. Case B connection is used for mode 3 charging. Case C connection has a connector cable, which must be inserted into the inlet of the electric vehicle. It is fixed permanently to a charging station. Mode 4 charging uses a case C connection. Apart from the advantages of plugin EV, it has so many drawbacks also. The main drawback of wired charging is battery-charging issues due to battery stations mounted over a long distance. Small driving range, long charging times and regular charging, and difficulties with messy wires and safety issues in the wet surroundings are also major disadvantages of the wired system. Such drawbacks can be solved by charging the vehicle's battery without the use of wires and this is called wireless charging.

B. Wireless charging

Wireless power transfer technology system supplies electrical energy to the vehicle without any wired connection between them. This energy transfer is achieved through a magnetic coupling of coils, which is based on Faraday's law of electromagnetic induction. A typical wireless charging system consists of three stages. First of all, grid AC power is converted to DC power using AC to DC converter. Then by using an inverter, DC power is converted into high frequency AC power. This high-frequency current generates an alternating magnetic field in the primary coil and this magnetic field induces an emf in the secondary coil. The AC power obtained at the receiver is rectified to charge the battery. The primary coil is on the road and the secondary coil is on the EV. To ensure safe and stable operation, battery management systems, communications, and power control are also added to the system. The design of a magnetic coupler is an important part of a wireless power transmission system because it affects the transferring of power from transmitter to receiver [4].

The wireless transfer can again be classified into static wireless transfer and dynamic wireless transfer. In a static wireless charging system, EVs are charged wirelessly when it is parked at home or workplaces. Plug-in chargers can easily be replaced by the static wireless charging system; it solves safety problems associated with an electric plug. The primary coil is fixed beneath the ground and the secondary coil is placed on the EV. Charging time relies on the distance between the coils, size of EV, source power, etc. Charging of EV by using static wireless power transfer is shown in Fig 1. A good number of modelling methods of EVs are available namely vehicle annual mileage model, short period model, etc. Short-period models represent the class of models of daily vehicle patterns. This label is intended to highlight that vehicle usage is modelled typically as it evolves over a single day or few days and not in as a single summary metric covering a longer period of time (e.g., a year). It is again categorized into three models namely summary travel statistics model, activity-based approach and Markov chains model of vehicle state. The activity-based approach is based on activity-based models and direct use of activity travel schedules.

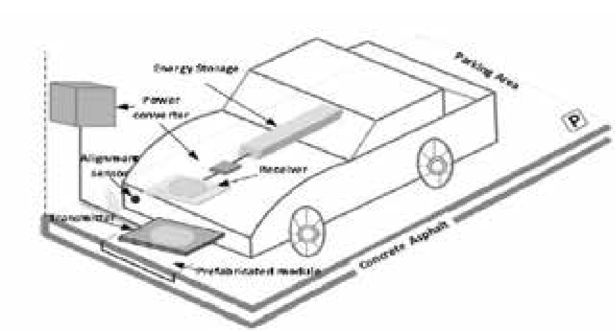

Fig. 1. Static wireless power transfer

There are so many methods used for wireless power transfer in which inductive wireless power transfer technology is the commonly used one [5]. The secondary coil of the vehicle and the primary ground coil is coupled by using a magnetic resonant coupling. The primary coil is also known as the charging paddle or inductive coupler is inserted into the vehicle charging port and the secondary coil receives that power and charge battery. This is the traditional way of inductive power transfer, which is shown in Fig 2. Then resonant inductive power transfer was introduced. Here receiver receives the power via varying magnetic fields. Additional series-parallel compensations are provided to obtain resonance conditions and to reduce losses. To improve the efficiency of the magnetic resonant coupling, the secondary side of the coupler is connected by a DC-DC converter. Resonance operation on the IPT (Inductive power transfer system) system is used to improve the energy transferred between coils. Leakage inductance between coils leads to power loss and thereby a reduction in efficiency. To avoid this problem, reactive current compensation is used between the coils. This will minimize the leakage

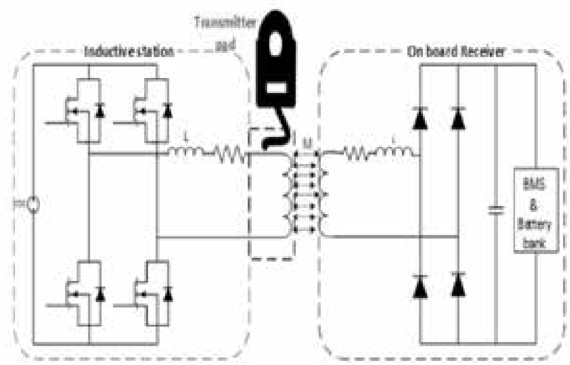

Fig. 2. Traditional Inductive power transfer`

An alternative option for transferring power wirelessly is capacitive wireless power [6]. It uses advanced geometric and mechanical structures of coupling capacitors as shown in Fig 3. In low-power applications, capacitive wireless charging is very useful. Instead of using coils or magnets, coupling capacitors are used to transfer power from the transmitter to the receiver section. Through some power factor correction, the supply AC voltage is applied to the H bridge converter. The high-frequency AC, which is the output of the H bridge converter passes through coupling capacitors to the receiver side. The AC voltage received is converted into DC by using rectifiers for the battery charging. To reduce the impedance between the transmitter and receiver, inductors are added in series with coupling capacitors. When the distance between transmitter and receiver (plates of coupling capacitor) is less, then capacitive power transfer shows excellent performance. But normally, the air gap between transmitter and receiver is large so the application of capacitive power transfer is limited because of the low performance.

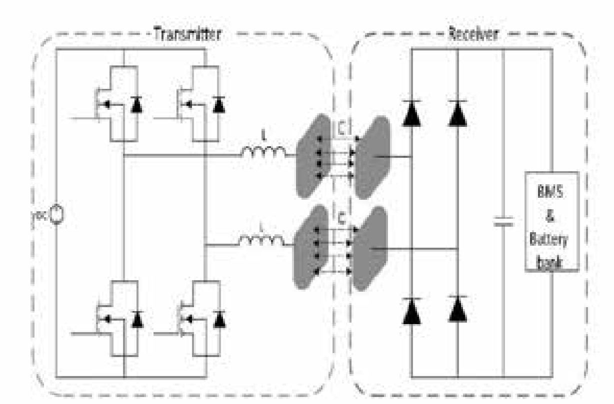

Fig. 3. Capacitive wireless power transfer

Magnetic gear wireless power transfer is another useful method used for transmission of power, which is shown in Fig 4. In comparison to other coaxial cables, this system is based on two synchronized permanent magnets located side by side. Because of the current source applying on the transmitter side, it produces a mechanical torque on the primary permanent magnet. It leads to the rotation of the primary permanent magnet, which in turn induces a torque on the secondary permanent magnet. The main permanent magnet acts as a generator and the secondary permanent magnet receives and supplies power to the battery. Power transfer capacity is inversely proportional to the separation axis of a permanent synchronized magnet.

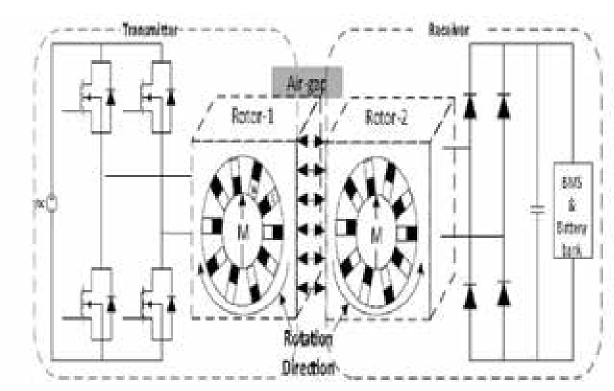

Fig. 4. Magnetic gear wireless power transfer

When supply is provided, entire equipment begins to work and creates a magnetic field. Even though the vehicle is absent, the magnetic field is generated and it causes magnetic radiation problems and wastage of energy. So, to reduce energy wastage, microcontroller-based wireless charging is used. PIC microcontroller associated with the IR sensor and MOSFET is used in the receiver section. Active low signals are transmitted to the MOSFET switch, by the activation of the IR sensor due to the presence of the vehicle. It turns ON the supply and then the transmitter transfers power to the receiver circuit. On the other hand, when the vehicle is absent, supply will be cut-off, due to the dissemination of active high signal. Therefore, energy wastage can be avoided and thereby an increase in efficiency occurs.

C. Dynamic Wireless charging

Dynamic wireless charging is a promising technology, which can help to foster EV adoption. In dynamic wireless charging, when driving in normal traffic, EVs could be powered to expand the driving range of EV. By using smaller size batteries, the size and weight of EV will also improve. The use of such a system however depends on the development of infrastructure. Not only that, but it is limited by cost also. In such a system, power is transferred via the magnetic field embedded in the road. This comes from electrical wires buried beneath the road surface, named track. A pictorial representation of dynamic wireless charging systems is shown in Fig 5.

Dynamic power transfer track can be classified into two parts namely, the elongated track and segmented track. As the name says, the elongated track consists of one long transmitter track linked to a power source. Since the inductance is large,

Fig. 5. Dynamic wireless charging

a compensation capacitor should be installed along with the track and it will have the problem of magnetic radiation. This will lead to additional constraints in the design and its coupling coefficient is low this will bring a reduction in efficiency.

Segmented track eliminates issues such as magnetic radiation, low coupling coefficient problem but it introduces synchronization problem between receiver and track. It consists of many small transmitters so the cost will also increase [7]. During design time, coils cannot be placed too near because of the negative mutual inductance effect and it cannot be placed too apart because when the vehicle moves away from the transmitter, power transfer will reduce. Thus, care should be taken while placing transmitter coils; the separation between them must be optimized.

Dynamics wireless charging technology, a newly introduced method for increasing the efficiency of wireless charging is based on a multi-parallel primary coil [8]. Centralized power supply rail mode usually is a long rail coil, which has one or more pick-up mechanisms. In the case of EV, for the supply of enough electrical energy, guideways will be generally so long, and it will have a high-frequency current, which increases secondary and primary leakage inductance. Large potential drop lowers system efficiency and makes the system responsive to the changes, which affects its stability also. Thus to reduce the energy loss, it uses wireless power transfer using the multi parallel primary coil. Here, the transmission rail is connected by a multi-stage parallel connection to the transmission bus. If EV passes over the transmission guide rail, it is in working condition and all others are in standby mode.

The main drawback of dynamic wireless charging is that its installation cost is too high. As a solution for this problem, new terminology named Mobile Energy Disseminator was introduced for transferring power wirelessly, which is represented in Fig 6. It enables power exchange between the vehicles when they are moving. The main advantage of this method is that the installed infrastructure is only utilized effectively for design. Hence, there is no problem with having a high cost; it will make the system cheaper. It exploits inter-vehicle communication. Buses or heavy vehicles that act as mobile charging stations are called mobile energy disseminators (MED) [9]. The busses which take MED's role are ordinary city busses that follow their predefined routes. Therefore, there is no requirement for extra heavy vehicles as MED. Buses are repeatedly moved at prescribed routes that are already scheduled and it will make EVs meet them at the specified location. When the bus completes its round trip or exhausts its energy inventory, it will return to the charging point where it will again be fully charged. By using co-operative mechanisms based on dedicated short-range communication, vehicle search MED within the range and schedule a charge appointment while in motion. These MEDs use inductive power transfer technology for transferring the power. When vehicles interact with one another, route selection algorithms are essential for information exchange [10].

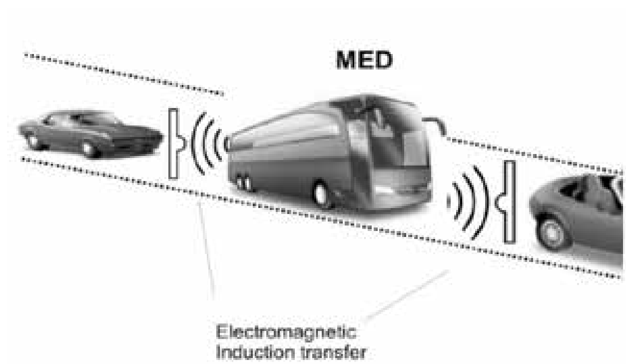

Fig. 6. Wireless transfer using MED

D. Wireless charging system for connected autonomous EV

Connected and autonomous electric vehicle (CAEV) is a mix of the connected, electric, and autonomous vehicles. A connected vehicle is a vehicle, which allows it to communicate with objects and vehicles nearby. An autonomous vehicle is a vehicle, which is capable of driving itself without human involvement.

Typically, CAEV is an electric vehicle with sensing capabilities especially sensing their surroundings and navigating with no or little human involvement. Here also inductive power transfer technology (IPT) is used. When the vehicle is in the parking space, static IPT is used and dynamic IPT is used when it is on the move. In the static wireless charging system, CAEV communicates wirelessly, for their recharging process with the base controller of the charging station. It essentially has a contact base controller and a charging pad for the inductive power transfer [11]. The charge management system of CAEV consists of the wireless charging station, control centre, SecCharge server,etc. SecCharge server is intended to facilitate the provision of proper coordination of charging services to CAEV. Here the vehicle, (client) initiates a request to the server and the web server provides the appropriate command, which is required for the charging process. HTTP is used for client-server communication.

E. State of charge

State of Charge (SoC) is the level of charge of an electric battery relative to its capacity. The units of SoC are percentage points. The lifeline of a battery is depending on the depth of discharge. So many research works are going based on the SoC of a battery, imbalance in the battery, etc.

Most electric vehicles can cover up to 100 km with 15 KWh. Li-ion battery's nominal voltage rating is 3.6 Volt.

Power output produced is large in the case of EV compared to IC engine.

Tesla model's P100D will cover 60 mph in 2.28 seconds.

It uses an induction motor and Li-ion battery for its operation.

The following four types of batteries are commonly used today in EVs:

- Lead acid
- Nickel Cadmium (NiCd)
- Nickel Metal Hydride (NiMH)
- Lithium-ion (Li-ion)

Lithium-ion batteries have higher specific energy relative to the other battery types. In the future, technology innovations with Li-ion and other battery technologies are expected to result in batteries with much higher specific energy and lower costs.

F. Major impact of E-vehicle

Emphasizes the importance of government incentives and coordination between industry and academia.

The target of 400,000 passenger battery electric cars (BEVs)by 2020 avoiding 120 million barrels of oil and four million tons of CO2.

In India, installation of a fast-charging station will cost almost 25 lakh whereas installing a slow charger can cost Rs 2-3 lakh depending on the technology. India will deploy both CHAdeMO and Combined Charging System (CCS) fast charging technologies, besides the existing Bharat Standard, at its public electric vehicle charging stations.

Conclusion

This paper presents a basic overview of the charging infrastructure of EVs. There are plenty of great benefits to EVs over conventional petrol/ diesel vehicles. On the other side, there are some controversies about choosing EVs due to their charging issues. Many research works are still going on to improve battery technology and the efficiency of EVs. This paper reviews charging technology from wired charging to dynamic wireless charging. The advantages and limitations of each technology for EV charging are also mentioned. In addition to this, the wireless charging technology of CAEVs is also mentioned in this paper.

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