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A Review on Contactless Charging for Electric Vehicles

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ABSTRACT
The limited and depleting supply of fossil fuels made the scientists around the world to look for alternatives. One such alternative is the use of Electrical Vehicles instead of conventional internal combustion engines, which are major consumers of fossil fuels. This fast emergence of electric vehicles worldwide has brought up the need for design of effective and convenient charging methods and systems for their batteries. The commonly used plug-in charging method has some limitations such as safety and operation in certain weather conditions. Researchers are in continuous search of new technology that can overcome these limitations and make the EVs more economical. Therefore, a novel method to charge the battery through induction, without any physical contact has been proposed. This paper presents a literature review on the Contactless Power Transfer technology used in EV charging. A possible future technology to improve the range using roadway electrification and in-motion power transfer concepts, which will further help in reduction in the size and cost requirement of the battery. This will help in reducing the range anxiety and will result in better satisfaction of the customer's needs and expectations.

1. Introduction

The transportation sector has been the largest consumer of fossil fuels worldwide and thus the most important factor in reducing fossil fuel demand. At present, the world is undergoing a transformation in automobiles that use internal combustion engines to electric vehicles, hybrid electric vehicles and hydrogen fuel cells vehicles. However, electric vehicles are known to be advantageous than the hydrogen fuel cells vehicles due to their greater wheel efficiency, less cost and overall weight. As the cities around the world are pushing away from petrol-diesel powered vehicles to help provide cleaner cities, given the intense urbanization which is occurring globally, the electric vehicles have gained the most attention. And because of the higher efficiency and the cost competitiveness of the electric vehicles, the development of electric vehicles has gained significant momentum over the past decade. One major problem with electric vehicles is the limited range – travel distance per charge. Hybrid electric vehicles are being recommended to extend the vehicle range until the advancement of technology and charging infrastructure build up to make the electric vehicle range acceptable.

Generally, the batteries of the electric vehicles are being charged through direct plug-in to a power outlet, which is raising concern in terms of the esthetic look of the vehicle at the time of charging, safety and operation of the charging systems under the adverse weather conditions such as snow and rains. Such conditions possess risks of electric shock to the individual handling the charging cords at the time of plugging and freezing of the charging cord to the vehicle in snow causes it difficult to unplug it from the automobile.

In recent decades, contactless or wireless power transfer has been an area of intensive research to facilitate the use of electric products in our lives. Typical examples include cordless charging of mobile phones, robots, smart watches, ones, robots, smart watches, implanted medical devices and home appliances. These widespread applications and constant increase in demand for contactless power transfer systems arises from their convenience and possible reduction in charging downtime that are otherwise major problems for wired chargers.

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Most of the risks with the plug-in method of charging the electrical vehicles can be minimized by the implementation of contactless power transfer technology that uses the electrical concept of electromagnetic field to transfer electric power to the onboard system to charge the battery without any physical contact with the vehicle.

The plug-in method of charging the vehicle requires the vehicle to be idle throughout the charging time as the electric vehicles do not have the provision of instantaneous or fast refueling(charging) as in automobiles using internal combustion engines. This time can be reduced by roadway electrification. The concept of roadway electrification enables the vehicles to draw power directly from the power utilities or the grid to power the propulsion motors and simultaneously charge the onboard batteries, which results in increase in the driving range of the electric vehicle per charge without requiring additional onboard storage batteries. Hence, it will also help in reducing the capacity requirement of the storage batteries and improves the cost effectiveness of the batteries.

2. Contactless Power Transfer Technology

This method uses a non-ionizing wireless charging system for EVs through near-field magnetic coupling. The basic operating principle of contactless power transfer system is similar to the working of the transformer. The alternating current utility power initially passes through an electromagnetic interface stage, and get boosted to direct current power with a power factor of nearly unity, which is similar to conductive charging system. An optional BUCK stage can be used to tune its output to required level, which achieves smooth start/stop of the charger and continuous tuning of the output power. In the inverter stage, the DC power is converted into high frequency AC power, which

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then resonates in primary compensation network and the primary coil. The high frequency AC power is transferred to the secondary coil placed on the vehicle through the mutual inductance between the primary and secondary coils. The secondary compensation network, along with the secondary coil can be tuned to have same resonant frequency in order to maximize the transfer efficiency. The high frequency AC power thus received is rectified to DC power in the rectifier stage and filtered by the filter network. Finally, the DC power is available to charge the onboard batteries.

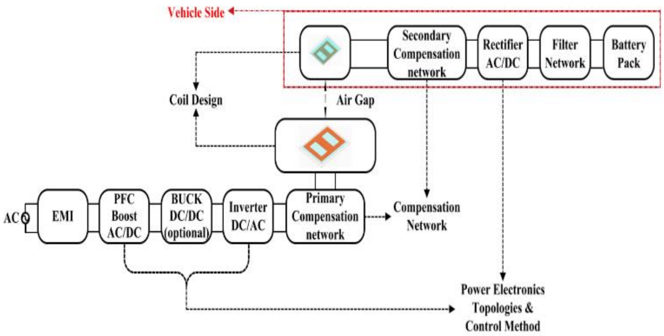


Fig. 1. A non-ionizing radiative contactless charging system for EVs.

To generalize the performance of operating parameters, a few important areas are listed below:

1. Power Level – This directly determines how long it will take for the batteries to fully charge.
2. Maximum Charging Distance – Allows the vehicle chassis to meet ground clearances.
3. Efficiency – The efficiency should be measured from AC mains to DC battery to be comparative with plugin charging systems.
4. Charging Tolerance – The relative ease of vertical and horizontal alignment for a normal driver when parking.
5. Size and Weight – Must be easily installable into a vehicle.

Three main parameters of a CPT system are the operating frequency, the transferred power and the length of each primary winding. In more detail, design considerations can also refer to the other system parameters, e.g. geometry of the windings, the resonance coupling topology, constant or varying frequency control [1] [2]. However, in this paper there is a macroscopic approach of CPT system design and these parameters go out of the scope of this research.

The operating frequency of the CPT system affects mainly:

1. The power transfer efficiency of the CPT transformer
2. The efficiency and the losses of the inverter supply
3. The maximum length of the winding due to electromagnetic reflection (to be analyzed further)

The length of the primary windings affects:

a. The number of inverters required by the total system
b. The required power capability of each winding, as every winding should provide the required power to all the cars driving on top of it
c. The inductance of the winding and as a result the capacitance needed for resonant mode coupling

The power capability of the primary windings affects:

a. The resistive losses of the system
b. The length of the winding, as every winding should provide the required power to all the cars driving on top of it.

The effects of increasing or decreasing each parameter are summarized in the table below.

Table 1: Parameter of CPT system and their advantages/disadvantages

Parameter	Increase ↑	Decrease ↓
Frequency (f)	(+) greater efficiency (+) (after a threshold) efficiency becomes constant, independent of load	(+) lower switching losses (+) greater possible maximum primary winding length
	(-) more switching losses (-) higher cost of inverter	(-) lower efficiency (-) efficiency dependent on load
Power (P)	(+) longer primary is possible, as more cars can be powered per winding (+) less inverters	(+) lower losses (inverter & ohmic) (+) systems already tested
	(-) higher power capability of inverter (-) higher losses (-) real systems have not been built	(-) less cars can be powered per winding (-) many inverters are needed (due to shorter windings)
Length of primary (L)	(+) less inverters (lower system cost) (+) possible advantages concerning construction issues	(+) less cars can be powered per winding (+) increased efficiency
	(-) real systems have not been built (-) greater power also in order power all cars driving on top	(-) many primaries are needed, so many inverters as well

3. Types of Contactless Charging

Contactless/cordless charging system of am electric vehicle charges the onboard batteries by electromagnetic field to transfer the electrical energy. This methodology of electric vehicle can be classified into two categories:

1. Static contactless charging
2. Dynamic contactless charging

3.1. Static Contactless Charging

In this type of wireless charging, the batteries of the electric vehicle are charged while the vehicle is being parked where the transmitter with primary coil is installed below the ground along with its circuitries. The receiver with the secondary coil is mounted on the underside of the vehicle receives the AC power through the magnetic field produced by the primary coil which is then rectified into DC power to charge the battery pack.

The charging duration of the electric vehicle depends on the charging pad sizes, power supply level and the air gap between the transmitter and the receiver elements. The gap between the transmitter and the receiver coils is approximately 150 – 300mm. The receiver element is provided with battery management system and wireless communication network to receive and provide feedback form/to the primary side to enable auto cut off mechanism to prevent the battery from over charging and for other safety measures.

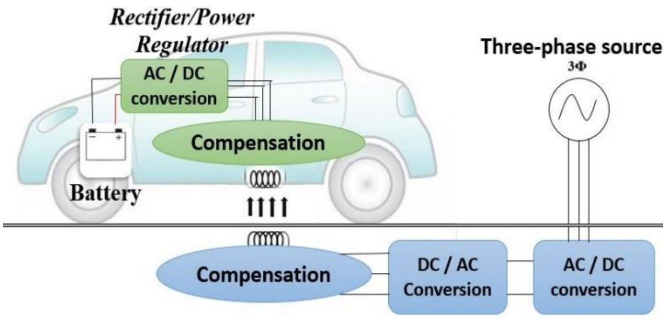


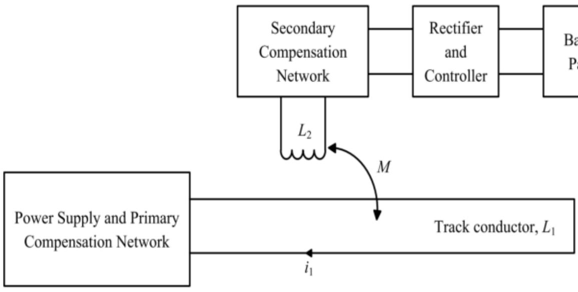
Fig. 2. A static contactless charging system for EVs.

This type of contactless charging is well suited for public transport applications, where it can be used to charge the bus while waiting at the station and also the mass transit applications, where it can be used at parking areas at shopping mall, commercial buildings, etc. An automatic guidance system can be installed in the vehicle to help the driver to align the vehicle directly above the primary coil for better power transfer efficiency of the charging system. An exchange of data between the transmitter of the charging station and the receiver of the vehicle can be established through short range communication methods, which allows charging stations to adjust the charging procedure according to the battery and the user.

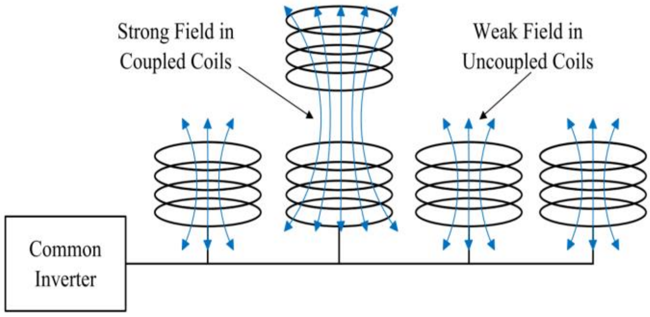
3.2. Dynamic Contactless Charging

Dynamic contactless charging method will enable charging of the batteries while the vehicle is still in motion. This is made possible by the concept of roadway electrification. In this methodology, a lane of the chosen road is electrified from the grid.

The roadway electrification can be done using two kinds of coil structure. The first structure uses a single primary coil throughout the length of the track. One coil side carries the magnetizing current in forward direction while the second coil side forms the return path. This coil is powered through a high frequency AC power source. In a single-coil design for the primary coil, the drawback is that when the conductor(L_1) is not covered by the receiver coils(L_2), it not only generates a redundant EMF, but also results in low efficiency of the whole system.



(a)



(b)

Fig. 3. Typical coil configurations for dynamic charging systems with (a) single-coil design for primary coil and (b) segmented-coil design for primary coil.

The second method consists of multiple coils along the length of the track in order to improve the magnetic coupling of the primary and the secondary coils. The usage of multiple coils also increases the coupling height of the magnetic field produced by the primary coil.

With the proposed coil structure, the system was able to transfer 2–5 kW wirelessly at a relatively high efficiency [3,4]. However, the height of magnetic flux generated by the circular coil is limited. In order to solve this problem, Budhia et al. [5] developed the solenoid coil structure, which improved the magnetic flux path. It was reported in [6] that a 3 kW wireless charging system using a solenoid coil structure was built and a DC-DC efficiency of 90% was achieved with an air gap of 200 mm. In addition, the solenoid coil structure performs well in wireless power transmission with a large air gap. Park et al. [7] optimized the solenoid coil shapes and demonstrated a wireless charging system that delivered 1.403 kW power at an air gap of 3 m.

The performance of the solenoid structure is fairly good, but there is a severe drawback. This structure generates double-sided flux and half of the flux that is produced towards the lower end of the coil is not used in transferring power. In addition, the unused flux may couple with the metal body of the vehicle and steel buried under the ground. This will lead to generation of electromagnetically induced EMFs in the metal bodies resulting in circulating eddy currents causing a power loss which in turn greatly decreases the efficiency of the system. In order to have a single-sided flux path and a larger charging zone than the circular coil structure, a bipolar coil structure known as a DD coil structure was developed in [8]. The bipolar coil structure shows excellent system efficiency at the desired power level with good tolerance to horizontal misalignment. Nguyen et al. [9] simulated the bipolar coil structure with the same size but different aspect ratios (ratio of width and length of a rectangular geometry). They built a wireless charging system employing the bipolar coil structure with the optimized aspect ratio to transfer 8 kW with a DC-DC efficiency of 95.66% at an air gap of 200 mm. Even when the horizontal misalignment increased to 300 mm, the system DC-DC efficiency was still as high as 95.39% [9].

4. Application and future influence

Contactless Charging of Electric Vehicle, approach revolutionizes the changes in electric vehicle industry. The recent trends suggest a rise in interest for electric cars in comparison to electric two-wheelers and internal combustion engine vehicles or petrol/diesel cars

At a fundamental level, electric vehicles comparatively offer a lower operating cost compared to conventional internal combustion engines. On average, electric vehicles are 75-80% cheaper from fuel and maintenance perspective, which is an important factor for many consumers who have high usage. This reality holds true across factors because it's materially cheaper to charge a battery compared to refueling a conventional liquid fuel tank. The electric vehicles comparatively induced with dynamic charging technique takes lesser time than the electric vehicles which are charged statically. With reduced new battery capacity using dynamic contactless charging system electric vehicles can be charged under motion. Comparatively, with wireless charging system range and cost setbacks of plug-in charging systems can be minimized. With the growing impact of fuel-driven vehicles on the environment, electric vehicles are critical in cutting transport emissions and cleaning up the air. With more people opting for electric mobility, the new technology can also be rolled out broadly for public use. This in turn would help everyday drivers of electric cars charge more conveniently on the go.

5. Conclusion

Contactless power transfer technology has the potential to revolutionize the road transportation from the automotive industry. With the advancement of electric vehicle technology, contactless charging technique is expected to increase significantly by next decade. The main agenda of this paper is to give an overview of different methods on contactless charging of the batteries of the electric vehicle through induction principle. These contactless charging methods will have a greater impact on the preferences of the public to opt for the electric vehicles due to the cost and range advantages over the automobiles that employ internal combustion engines.

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