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CHARGING OF ELECTRIC VEHICLE IN-MOTION

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Abstract: Electrification of vehicles plays an important role to overcome environmental issues and acts as an alternative to CO2 emission from the internal combustion engines. Some of the hurdles in implementing EV are limitations in charging systems like, lack of charging stations, time-consuming in charging, heavy onboard batteries, less drive range and high prices of vehicles. At present, wireless mode of charging is preferred compared to other modes of charging systems. Development in wireless power transfer technology helps us to construct electrified roads and charge electric vehicles while moving. In this paper, we will review on move charging technology, different cores controllers and converters used in wireless power transfer. On move charging system overcomes problems like range anxiety and heavy on battery in EV. It also focuses on the safety concerns of electric vehicles like EMI exposure, fire hazards and metal object detection. Limitations and improvements in wireless charging system of EV batteries is also discussed.

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Keywords: EV, Wireless charging, dynamic charging, inductive charging, MOD system.

I. INTRODUCTION

Rising oil prices and global warming has led to the development of electric vehicle. EV was introduced in the mid of 19 centuries. According to International Energy Agency, it is predicted that number of Electric Vehicle on road will be almost 145 million by 2030[7]. Despite its slow speed, EV had many advantages over IC Engines like zero-emission, quiet moving vehicle, good drive ability, low maintenance and gearless drive. As EV's are a solution to environmental problems, the developing Electric Vehicle markets needs for more effective and stable system to optimize the battery technology. Currently available chargers are plug-in type where the vehicle needs to be plugged in after a short drive, hence a long drive is not possible [2]. This can be made possible by wireless charging of electric vehicles, to free users from wires.

In static charging transmitter coils or charging coils are placed underneath the ground in public charging stations, shopping malls, workplace, traffic signals lay-by's, and rest areas along highways,etc [1]. In dynamic charging, EV's are charged on move as the roads are electrified and hence range anxiety problem is solved. Dynamic charging adopts to inductive method of power transfer. The current transportation infrastructure is mainly adopted for ICE engines to implement dynamic charging technology we need to reform the existing roadway infrastructure to support more electric vehicles which make long drives possible [2]

Improvements in EV technology helps power transfer between G-V or V-G, similarly it can power local loads at home thus energy consumption from power grid can be reduced.

II. DYNAMIC CHARGING FUNDAMENTALS

A. History of dynamic charging

Dynamic charging system history began in 1976 at Lawrence Berkley National Laboratory, where technological viability was evaluated. In 1979 Electric bus project Santa Barba started a 4.3 m length lane with a coil size of 1m using switched capacitor tuning for regulated power [19]. Partners for advanced transit and highway [PATH] in 1992 initiated an IPT station for an electric bus along the roadway to analyze the economic and environmental factors. They also explained 60-kW with 60% efficiency power transfer with an air gap of 7.6cm. Due to its size, high cost and low efficiency it cannot be imposed commercially [1]. In 1996 German Italy Company, along with the University of Auckland designed a prototype capable of charging an electric bus of 60 kW operating at a frequency of 15-20 kHz, with an air gap of 40mm and efficiency of 90% but the vehicle with such an air gap and efficiency can be maintained only if the secondary winding is lowered during charging[1].

In 2009 Korea's Advanced Institute for Science and Technology (KAIST) developed a electric vehicle with contact, having a power rating of 3kW for which efficiency was found to be 80% and for 60kW rating without mechanical moving coil efficiency was 72%. Further researches were carried out to reduce electromagnetic field, minimize the weight of pick-up coil, increase output [15]. In 2016 Utah state University developed a 50kW wireless power transfer system for an electric bus which over an air gap of 15-30cm at 20 kHz frequency transferred power of 50kW with an efficiency of 90% [15]. Certain standards is set by the society of automotive engineers (SAE) for transmitter and pick-up coils, operating frequency, airgap, power ratings, efficiency, control strategies, magnetic and electric fields which could be useful for the design of WPT [4]. There is a wide array of researches going on in the area of WPT.

B. Structure of Dynamic charging System

Figure 1 shows several stages of charging electric vehicle. The main power supply or other renewable sources like solar wind is converted using AC/DC converter into DC, then into high-frequency AC power through suitable compensation topology and fed to the transmitter. The receiver side is the onboard system where the secondary coil or pick-up coil receives power from the transmitter using compensation networks it is then rectified regulated and stored in the battery pack of the vehicle [4]. In dynamic wireless charging the vehicle receives the required power through flux developed in pick up-coil while it is in motion. Based on the energy-carrying capacity wireless power transfer can be classified into electromagnetic field, electromagnetic radiation and electric field [19]. In electromagnetic type based on the distance of field, it can be inductive power transfer IPT or coupled magnetic resonance laser, microwaves, and radio waves emission. Power is transferred through the air having a frequency of about GHz to THz. In an IPT power is transferred through a small air gap at low frequency [22].

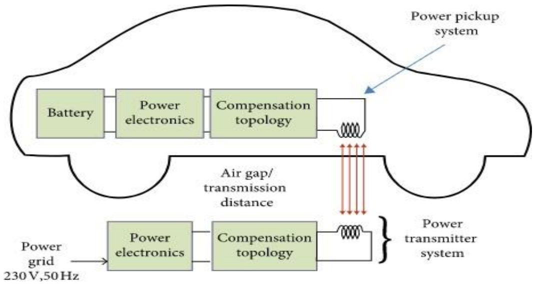

Fig. 1 Configuration of EV charging system

In electric field type capacitive power transfer method is used where the power level and operating range is low hence flux guiding and shielding components are not required [2]. This paper gives a brief review of compensation topologies, coil design, converters and some safety considerations of inductive power transfer [20].

III. COMPENSATION TOPOLOGIES

To improve the power conversion process, efficiency, and to reduces the inductive impedances in the primary side capacitors are connected along the primary and pick coils in a series and parallel manner to achieving approximately resistive impedance and unity power factor. A compensation network is used on the pick-up coil side, to increase the transferred power to the load [5]. The high frequency AC power is supplied to the high frequency rectifier through the C/LC filter hence a regulated DC power is fed to the electric vehicle battery [6]. The leakage flux will produce reactive power which is compensated by capacitor which therefore improves the efficiency and power conversion process. Compensation circuit can be classified into 4 types based on the capacitor connection as is shown in Figure 2. An AC voltage is produced at the receiving coil in the figure below by a high-frequency current in the primary coil that causes a fluctuating magnetic field. A compensation network that resonates at a high frequency can transfer a lot of power. In order to charge the battery, the obtained AC transmitted power is rectified and sent to a DC/DC converter [14].

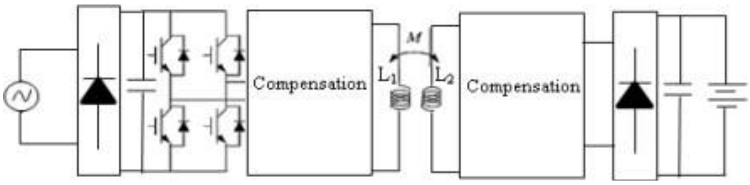

Fig. 2 Typical WPT system

There are two common compensation topologies: Series-Parallel-Series (SPS) and Parallel-Parallel-Series (PPS). A capacitor C1 is connected in series with the primary coil of the PS compensation circuit when using the series parallel series topology, whereas capacitor C2 is connected in series with the pick-up coil side of the PP compensation circuit when using the parallel-parallel series topology. New topologies can be presented, depending on the merits of the current remuneration. PPS topology, which is similarly user-friendly, can transfer maximum power over a greater distance than PP topology, even if the circuit has a misalignment situation. SPS topology is introduced to overcome some of the drawbacks of the PPS compensations technique as the air gap widens and the leakage magnetic flux grows. This design facilitates the transfer of rated power with a maximum misalignment of up to 25% between the connected inductor coils. SPS techniques is preferred over other methods for WPT systems because it operates with more misalignment while being safer than PS [24].

IV. COIL DESIGN FOR INDUCTIVE POWER TRANSFER

Coil design is an important factor in wireless power transfer systems as it influences the power conversion level, overall performance and the efficiency of the entire system [6]. The configuration of the coil must increase the coupling coefficient; reduce leakage flux, high-quality factor, and high misalignment tolerance. The two basic types of coils are unipolar and bipolar. Flux lines go from the North Pole and enter the south pole around the coil edge in a unipolar coil. Simple topologies for the coil include circular, square, and spiral. The flux lines of a bipolar coil enter the coil face where the south pole is located after leaving the north pole. Thus, flux lines are constrained to the area around the coil. The coupling coefficient is increased by using ferromagnetic cores to direct magnetic flux [4]. Due to their bulkiness, ferrite cores such the E-type, U-type, and pot cores were determined to be inappropriate for wireless power transfer. As a result, researchers proposed many ferrite core types, including the single-sided circular core, the Double D Quadrature (DDQ) core, and the Rectangular H-shaped core [10].

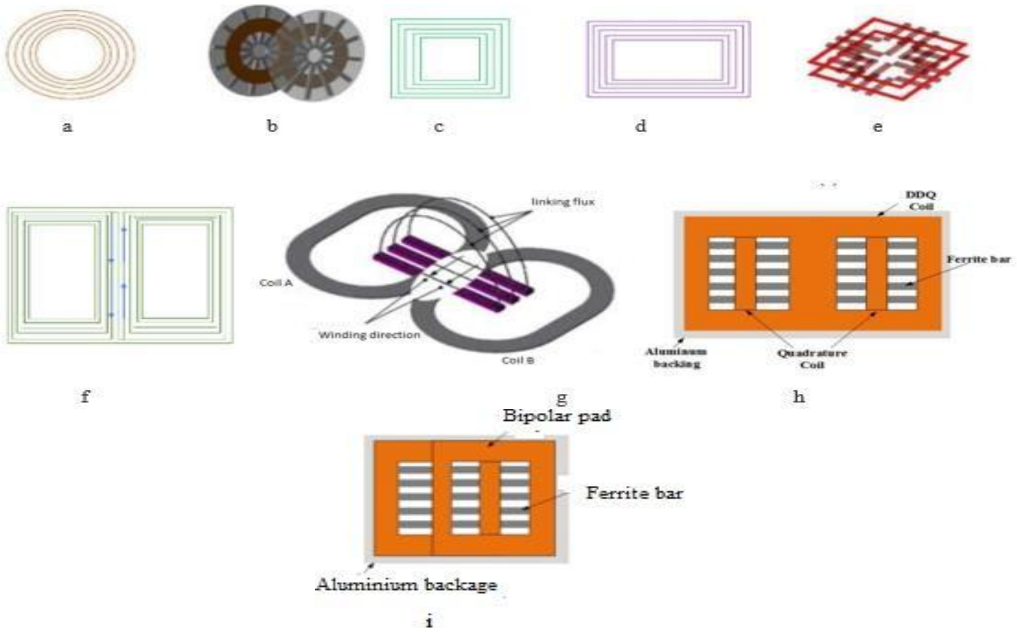

Fig. 3 (a) circular spiral coil (b) circular core with ferrite core (c) square coil (d) Rectangular coil (e) Rectangular coil withferrite bars (f) Double D coil coreless (g) DD coil with ferrite bars (h) Double D Quadrature (DDQ) (i)Bipolar coil [3]

TABLE. 1 Comparison between different coils

Properties	**circular coil**	**rectangular coil**	**DD coil**	**DDQ coil**	**bipolar coil**
Magnetic Flux	one- side	2sided	double - sided	2 area	double- -area
Ferrite material	more	less	Less	less	less
Misalignment tolerance	poor	high	medium	high	high
Effect of shielding	Small	medium	large	large	large
EMF Exposure	High	Low	Low	low	Low

Out of many couplers, bipolar coil is the most preferred. Bipolar coils have advantages like high misalignment tolerance, coupling coefficient and less EMF exposure when compared to circular coils [15]. Hence coil geometry design contributes to IPT charging system as Table 1.

V. POWER ELECTRONIC CONVERTERS AND CONTROLLERS

The power electronics converter provides power to the electrified roads. There is a need for high-power and frequency converters [2].

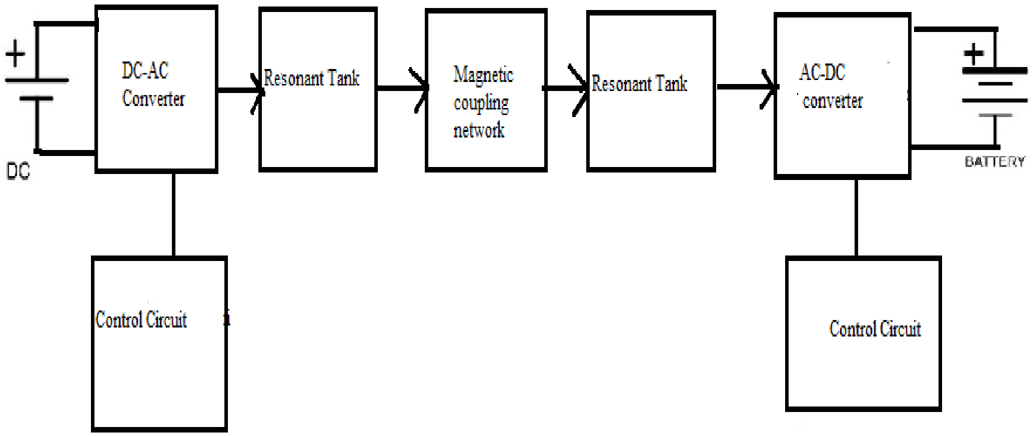

Fig. 4 Block diagram IPT system

The DC supply via a DC/AC converter is converted to AC voltage resonating at high-frequency which is transferred via magnetic coupling circuit to the pick-up coil. This AC is rectified using converter circuit to charge the vehicle battery. The control circuit on both side of the coil ensures whether the inverter is operating at resonant frequency and converters output is maintained constant for proper charging of battery.

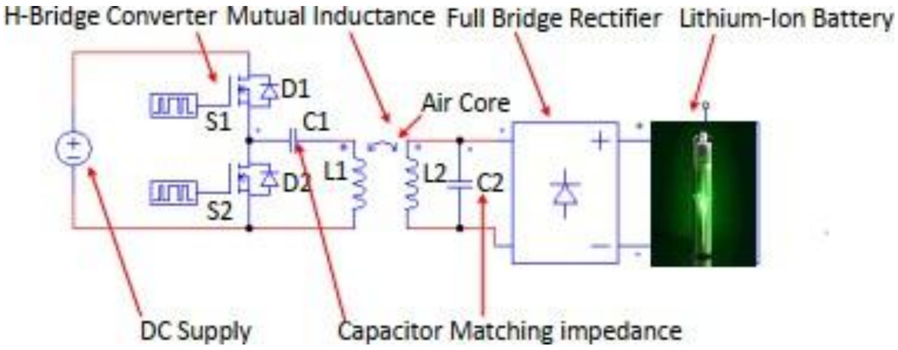

Fig. 5 circuit diagram of H-bridge Converter in WPT charging

In order to achieve optimal efficiency, the H-bridge offers fixed voltage (FV) or constant current (CC) regulation, as well as impedance matching [25]. To control the charging power for numerous electric vehicles, power converters use sophisticated circuit topologies and various control topologies. The inverter's input voltage, duty cycle, and switching frequency all affect how much power is sent to the pick-up coil. To achieve maximum efficiency and power transfer, the front end converter can manage the primary coil voltage by varying the DC voltage, switching frequency, and duty cycle [6].

The disadvantage of dynamic wireless charging is that the primary coils buried in the road are only in touch with the pick-up coil for a brief period of time, necessitating high misalignment tolerance and electronics with high power ratings. [25] To get around this, use a single, lengthy primary cable or lumped charging pads made up of tiny segmented coils. One power source powers the entire track in a long charging lane system while maintaining constant current to individual sections through direct connections, as shown in Figure 6a below. However, this system has drawbacks because a high voltage line runs through it, posing safety risks and EMI problems. [25]. Double ground pads are supplied by the full-bridge inverter in the system depicted in Figure 6b's segmented coil track, but the system's cost rises as the number of charging stations rises.

In Figure 6c the direct connection is replaced by extending high- frequency lines in Figure 6d, bidirectional switches are connected in parallel a particular ground coil which is switched on and off hence minimizing power loss. This system is complex and costly due to more converters and controllers. In Figure 6e the system is similar to Figure 6d but the switches are connected in series the disadvantage in this system is when a fault occurs the entire system is disconnected. Thus, various topologies of controllers were reviewed in dynamic wireless charging system [25].

VI. METAL OBJECT DETECTION HEALTH AND SAFETY MEASURES

One of the major concerns in commercializing wireless EV is its safety measures on human exposure in EMF and sensitivity to a foreign metal objects. A human body can withstand a magnetic field of 28.3μT [18]. Aluminum shield can be used to reduce leakage flux. Different ferrite bars, coil positions, control strategies, and misalignment tolerance are considered in the design of a dynamic wireless charging systems.

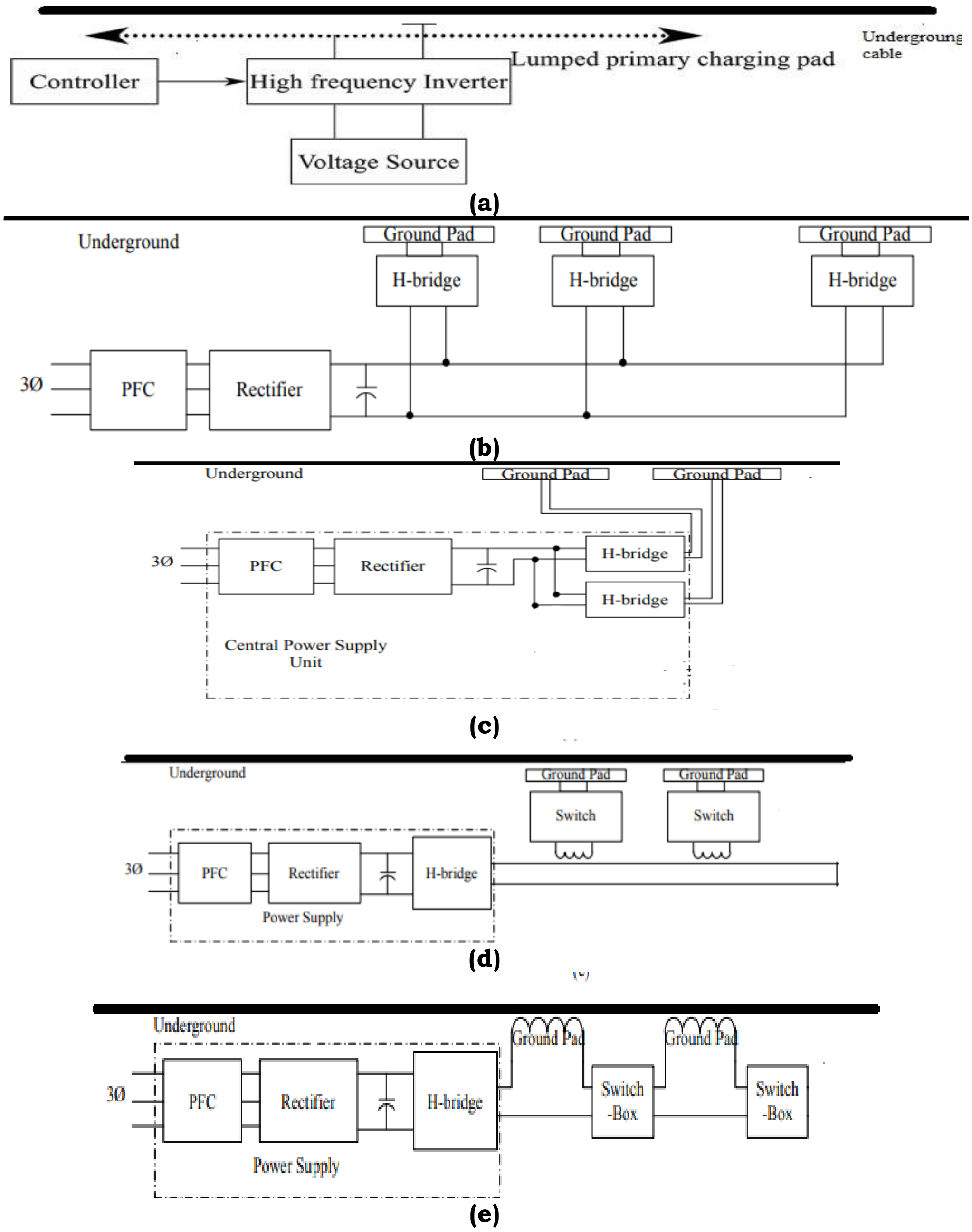

Fig. 6 (a) Singletrack coil system (b) Segmented coil system (c) Segmented coil with parallel H-bridge (d) Segmented coil with parallel switches (e) Segmented coil with series switches [25]

According to Faraday's law when the metal object material is placed in a varying magnetic field circulating currents is induced on the surface of the conductor. The metal object, gets heated up due to this circulating current, which may lead to damage of the equipment hence reduce efficiency [8] By making use of radar, thermal imaging, and camera, metal and other living objects can be detected. This system is relatively of high costs hence needs extra space. This detection system has a non-overlapping sensing coil having two copper wires that induces a voltage difference between two wires when a metal object is detected. If the voltage difference is zero then there is no detection of foreign object. Thus, the metal object detection ensures the safety of wireless electric vehicle charging system.

VII CONCLUSION

In this paper provides a brief review in charging an EV on the move as the vehicles are charged continuously in moving conditions where the mileage anxiety is eliminated, highly reliable, and efficient. As a result, green transportation will drastically increase. Various coil topologies were discussed and analyzed. Besides various controllers, EMI issues and the need of Metal object detection were reviewed. Future works may lead to improvements in integration and development of aluminum shielding, such as shielding which has a great impact on parameters, like self-inductance or the coupling factor.

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