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Wireless Power Transmission in Electric Vehicle Applications

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Abstract

For energy, environment, and many other reasons, the electrification for transportation has been carrying out for many years. In railway systems, the electric locomotives have already been well developed for many years. A train runs on a fixed track. It is easy to get electric power from a conductor rail using pantograph sliders. However, for electric vehicles (EVs), the high flexibility makes it not easy to get power in a similar way. The problem for an electric vehicle is nothing else but the electricity storage technology, which requires a battery which is the bottleneck today due to its unsatisfactory energy density, limited life time and high cost. Wireless power transfer (WPT) using magnetic resonance is the technology which could set human free from the annoying wires. In fact, the WPT adopts the same basic theory which has already been developed for at least 30years with the term inductive power transfer. WPT technology is developing rapidly in recent years. The advances make the WPT very attractive to the electric vehicle (EV) charging applications in both stationary and dynamic charging scenarios. Here uses reviews of the technologies in the WPT area applicable to EV wireless charging. By introducing WPT in EVs, the obstacles like charging time, range, and cost can be easily mitigated thus battery technology will no longer be relevant in the mass market penetration of EVs. It is hoped that researchers could be encouraged by the state-of-the-art achievements, and push forward the further development of WPT as well as the expansion of EV.

Keyword- Electric Vehicles, Wireless Power Transfer, Inductive Power Transfer, Static and Dynamic WPT

I. INTRODUCTION

In an EV, the battery is not so easy to design because of the following requirements: high energy density, high power density, affordable cost, long cycle life time, good safety, and reliability, should be met simultaneously. To challenge the 300-mile range of an internal combustion engine power vehicle, a pure EV needs a large amount of batteries which are too heavy and too expensive. Advances in wireless communication and semiconductor technology have enabled a wide variety of portable consumer electronic, medical, and industrial devices. However, users are still required to manually plug in these mobile devices, limiting ultimate mobility and disrupting use when charge is depleted. Wireless power offers the possibility of connector-free electronic devices, which could improve both size and reliability. With wireless charging technique the battery capacity of EVs could be reduced to 20% or less compared to EVs with conductive charging. This seminar mainly discusses on two types of charging stationary and dynamic charging. For a stationary WPT system, the drivers just need to park their car and leave. For a dynamic WPT system, which means the EV could be powered while driving; the EV is possible to run forever without a stop. Also, the battery capacity of EVs with wireless charging could be reduced to 20% or less compared to EVs with conductive charging. Stationary WPT for EV charging has better market acceptance and lower implementation cost compared to dynamic WPT.

There are two basic coupling methods used to complete the connection between the utility power grid, the battery charger, and the vehicle connector. The first is the traditional plug (called conductive coupling). With this connection, the EV operator plugs his vehicle into the appropriate outlet (i.e. 110 or 220 volts) to begin charging. This type of coupling can be used with the charger in the car (onboard) or out of the car (offboard).

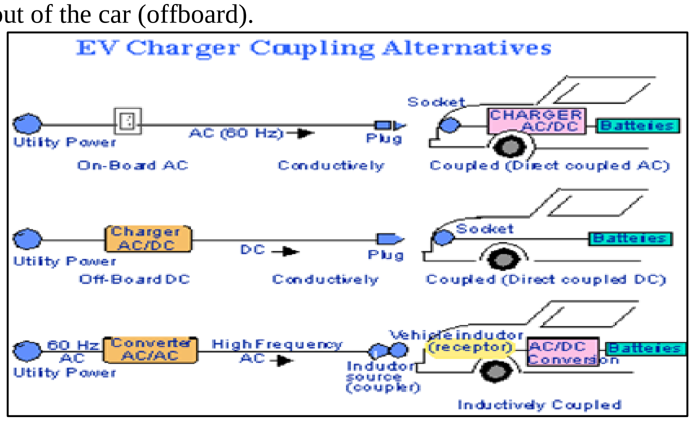

Fig. 1: EV charger coupling alternatives

The second type of coupling is called inductive coupling. This type of coupling uses a paddle which fits into a socket on the car. Rather than transferring the power by a direct wire connection, power is transferred by induction, which is a magnetic coupling between the windings of two separate coils, one in the paddle, the other mounted in the vehicle.

II. WIRELESS POWER TRANSFER

Based on the power transfer distance wireless energy transfer methods can be categorized into two types; near field and far field. If transfer distance is longer than the wavelength of electromagnetic wave, it is categorized in to far field technique. Laser, photoelectric, RF, microwave can be considered as far field energy transfer methods. Inductive coupling and magnetic resonance coupling based methods are regarded as near field approaches. Even though far field techniques have transmission range up to several kilometres, they suffer from the trade-off between directionality and efficiency. Frequency range of far field approaches are typically very high (GHz range) compared to near field (kHz–MHz).

A. Inductive Coupling versus Magnetic Resonant Coupling

Traditional inductive power transfer (IPT) systems based on inductive coupling resulting from the Faraday's law of induction and Ampere's circuital law. The integrated magnetic field due to current carrying loop (transmitting coil) is defined by the Ampere's circuital law. According to Faraday's law of induction, time-varying magnetic field induces electric field in receiving coil. Initial configurations of IPT systems used inductor in series with the coil. This is analogues to loosely coupled transformer. Later, IPT based topologies are adopted with capacitor compensation. Conversely, magnetic resonance technology originally used with self-resonance coils which resonates with its self-inductance and parasitic capacitance .An external lumped capacitor is added to build the resonance coils when parasitic capacitance of coils are inadequate to make resonance at frequency of interest in later studies .Frequency selection for IPT based designs are limited to several kilohertz while magnetic resonance based systems can operate infrequencies up to a few Megahertz. Typical IPT schemes are limited to a few centimetres whereas magnetic resonance WPT can be used with larger range.
The figure below shows IPT:

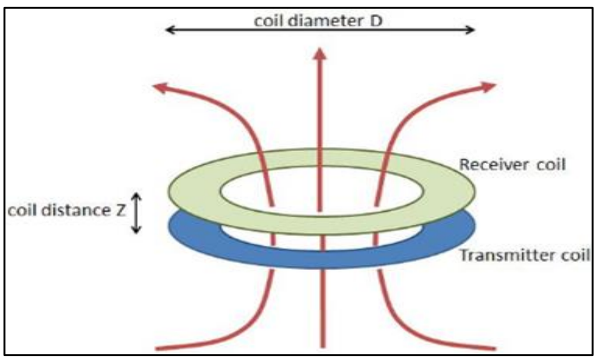

Fig. 2: Inductive Power Transfer

III. WIRELESS POWER TRANSFER TECHNOLOGY IN EV

A typical wireless EV charging system is shown in Fig. 3. It includes several stages to charge an EV wirelessly. First, the utility ac power is converted to a dc power source by an ac to dc converter with power factor correction. Then, the dc power is converted to a high-frequency ac to drive the transmitting coil through a compensation network. Considering the insulation failure of the primary side coil, a high-frequency isolated transformer may be inserted between the dc-ac inverter and primary side coil for extra safety and protection. The high-frequency current in the transmitting coil generates an alternating magnetic field, which induces an ac voltage on the receiving coil. By resonating with the secondary compensation network, the transferred power and efficiency are significantly improved. At last, the ac power is rectified to charge the battery.

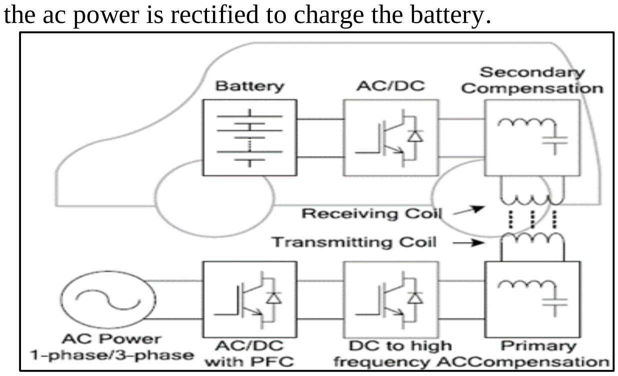

Fig. 3: Typical wireless EV charging system

Fig. 3 shows that a wireless EV charger consists of the following main parts:

1) The detached (or separated, loosely coupled) transmitting and receiving coils. Usually, the coils are built with ferrite and shielding structure, in the later sections, the term magnetic coupler is used to represent the entirety, including coil, ferrite, and shielding;
2) The compensation network;
3) The power electronics converters.

The main difference between a wireless charger and a conventional conductive or wired charger is that a transformer is replaced by a set of loosely couple coils.

To give a quick Idea of the WPT principle, the coil and the compensation network are pulled out separately, as shown in Fig.4.

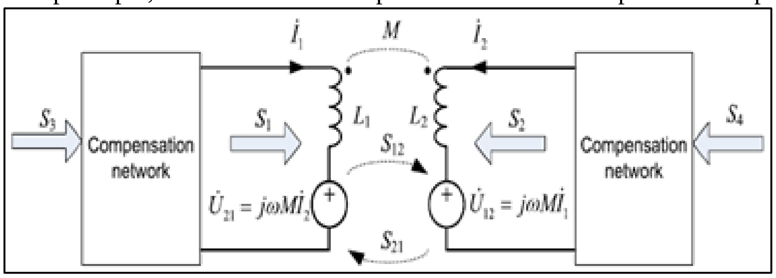

Fig. 4: General two-coil WPT system

L1 :- self-inductance of the primary side transmitting coil
L2 :- self-inductance of the receiving coil; ˙
I1 and ˙ I2 :- current in the two coils;
U12 :- voltage in the secondary coil that is induced by the current in the Primary side coil.
U21 :- mutual inductance between the primary and secondary coils.
S1 and S2 :- Apparent power that goes intoL1 and L2, respectively.
S3 and S4 :- Apparent power provided by the power converter.
S12 and S21:- Apparent power exchange between the two coils

The system shown in above figure can transfer active power in both directions. For a traditional transformer, the reactive power represents the magnetizing power. Higher magnetizing power brings higher copper and core loss. To increase the transformer efficiency, the ratio between the active power and reactive power should be maximized. When k is close to 1, it is a traditional transformer. While for WPT, k is close to 0. The degree of coupling affects the design of the compensation network. Taking the series–series topology as an example, there are two ways to design the resonant capacitor. One way is design the capacitor to resonate with the leakage inductance which could achieve a higher transformer efficiency another way is to resonate with the coil self-inductance which could maximum the transferred power at a certain coil current.

When the coupling is loose, like k <0.5, which is the case for the EV wireless charging, usually the capacitor is tuned with the self-inductance to make the system working at a resonate mode to achieve maximum transferred power at a certain coil current. In this case, most of the magnetic field energy is stored in the large air gap between the two coils. The hysteresis loss in the ferrite is not so relative to the magnetizing power. However, the loss in the copper wire is proportional to the square of the conducting current. To efficiently transfer more power at a certain coil current, the Induced current I2 should lag I1 by 90°. Since the induced voltage U12 on the receiving coil lags I1 by 90°, U12 and I2should be in phase. The secondary side should have a pure resistive characteristic seen from U12 at the frequency of I1.At the meanwhile, the primary side input apparent power S3should be minimized. For a certain transferred power, it is necessary to make the Secondary side resonant to reduce the coil volt-ampere (VA) rating, which reduces the loss in the coils; and to make the primary side resonant to reduce the power electronics converter VA rating, which reduces the loss in the power converter. Therefore, we transfer power at the magnetic resonance. And estimate the highest possible power transfer efficiency.

In EV wireless charging applications, the battery is usually connected to the coil through a diode-bridge rectifier. Most of the time, there is some reactive power required. The reactive power can be provide by either the coil or the compensation network like a unit-power-factor pickup. Thus, a battery load could be converted to a resistive load. For stationary EV wireless charging, the coupling between the two coils is usually around 0.2. If both the sending and receiving coils have a quality factor of 300, the theoretical maximum power transfer efficiency is about 96.7%.

IV. DYNAMIC WPT FOR EV CHARGING

From the vehicle viewpoint, dynamic WPT enabled infrastructure where EVs can be charged continuously while in motion, theoretically solve the EV battery problem with unlimited driving range. However, employment of such system is reliant on the infrastructure development, which in turn limited by its cost. In addition, amount of the energy gained through WPT depends on the power level of the system, vehicle speed and duration that vehicle travel within the WPT enabled zone.

Dynamic EV charging approaches can be mainly categorized into two types based on transmitter array design; single transmitter track and segmented transmitter coil array. First type consists of a substantially long transmitter track connected to a power source. The receiver is noticeably smaller than the length of the track. Segmented coil array-based designs have multiple coils connected to high frequency power sources as shown in Fig.5 Transmitter track based systems are easier to control as the track is powered from a single source. Coupling coefficient along the track is nearly constant when the vehicle moves along the track. The transmitter track can be few meters to several tens of meters long. Usually ferromagnetic materials have been used to guide the magnetic flux and increase the efficiency. Relative range of track-based systems are much smaller than unity.

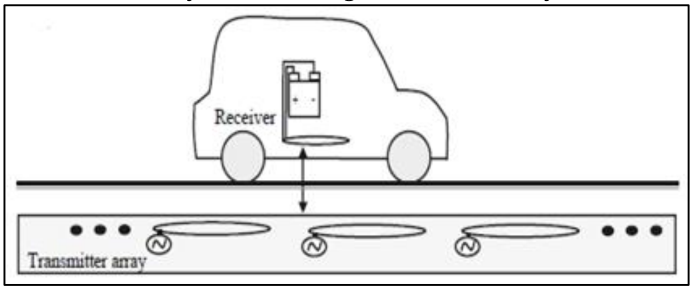

Fig. 5: Dynamic WPT for EV

A. Disadvantage of Dynamic Charging

- The electromagnetic field emitted within the uncoupled region has to be suppressed to eliminate harmful exposure.
- The compensation capacitor has to be distributed along the track to compensate large inductance. This brings additional constrain in Construction.
- Coupling coefficient is fairly low because of the smaller transmitter region covered by the receiver resulting lower efficiency.

V. STATIONARY WPT FOR EV CHARGING

Stationary WPT can replace the charging cable for PEVs. WPT system is activated when vehicle reaches to the charging area. Fig.6 illustrates typical stationary WPT platform for EV charging. High frequency power inverter converts low frequency utility power to high frequency AC power. Resonance electromagnetic field generated in the transmitting resonator transfers power to the receiving resonator. Received power at the secondary resonator is rectified to charge the battery pack. Power converters used for the WPT can mainly categorized in to two types, namely indirect power converters and direct power converters. Utility power is first converted to DC and then invert to high frequency AC power in indirect conversion method. Energy conversion undergoes two conversion stages AC-DCAC in indirect method. Alternatively, direct conversion method converts energy directly from low frequency mains to high frequency in a single stage.

The charging system can be implemented in urban areas such as parking lots and bus stops. Some of the commercial pilot projects have been successfully demonstrated recently. Automotive manufacturers such as Delphi, Magna, Maxwell and Panasonic have been working on developing WPT systems. Stationary WPT solutions for EV charging has to be designed shifting the system complexity more towards the transmitting side infrastructure and keeping the vehicle component as simple as possible. Although mechanical and electrical hazards with plugged-in charger can be eliminated using stationary WPT for EV charging, driving range and slower charging time will still be a dominant issue.

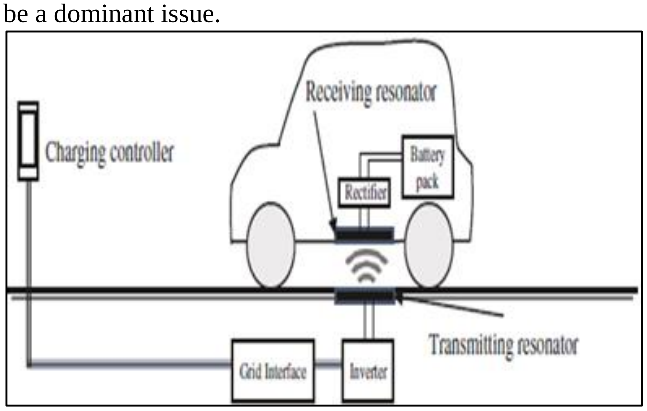

Fig. 6: Stationary WPT for EV

Stationary WPT for EV charging has better market acceptance and lower implementation cost compared to dynamic WPT.

VI. ADVANTAGES AND DISADVANTAGES OF WPT

A. Advantages

- Completely eliminates the existing high-tension power transmission cables, towers and sub stations.

- The power failure due to short circuit and fault on cables never exist in this transmission
- The cost of transmission and distribution become less and the cost of electrical energy for the consumer also would reduced.
- Zero environmental pollution.
- Loss of transmission is negligible level in the Wireless Power Transmission; therefore, the efficiency of this method is very much higher than the wired transmission.

B. Disadvantages

- The Capital Cost for practical implementation of WPT seems to be very high.
- Radiation.

VII. CONCLUSION

This study gives a review of wireless charging of electric vehicles. It is clear that vehicle electrification is unavoidable because of environment and energy related issues. Wireless charging will provide many benefits as compared with wired charging. In particular, when the roads are electrified with wireless charging capability, it will provide the foundation for mass market penetration for EV regardless of battery technology. With technology development, wireless charging of EV can be brought to fruition. Further studies in topology, control, inverter design, and human safety are still needed in the near term.

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