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Review of Wireless Charging Technologies

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Abstract: The slow development of energy storage technology combined with a limited number of plug-in charging stations negatively affects people's desire to purchase pure battery electric vehicles. A new wireless vehicle-to-vehicle charging technology structure is proposed, which can function with plug-in electric vehicles or operate independently. With a limited number of charging stations this technology can be used to increase charging opportunities through vehicle-to-vehicle (V2V) charging. In electric vehicle charging of battery through charger and wire is inconvenient, hazardous and expensive. The existing gasoline and petrol engine technology vehicles are responsible for air, noise pollution as well as for greenhouse gases. This paper aims to review current wireless power transfer (WPT) technologies on electric vehicle charging. Basic principles of the technologies, including capacitive, electromagnetic field and magnetic gear are elaborated. Advantages and limitations of each technology for EV charging are discussed. The latest development, key technical issues, challenges and state-of-art researches are introduced.

Keywords: Capacitive, Electric vehicles, Inductive power transfer, Offset, Wireless power transfer.

INTRODUCTION

In order to develop the market for pure battery electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) demands more recharging facilities. Wireless Power Transfer[1] (WPT) technologies for both EVs and PHEVs are new, secure, easy, versatile, and autonomous charging methods. WPT technologies use electromagnetic field or electrical filed or mechanical force to transfer energy from the grid to battery chargers nearby. The EV is inherently isolated from the grid of the utility but via the air gap between the transmitting pad and the receiving coil mounted on the EV. WPT charging is also easy and versatile because there is no need for cables and adapters, and wireless charging is fully autonomous. Automotive manufacturers and major global suppliers of vehicles have started R&D work on various WPT technologies[2]. Nissan and Chevrolet developed wireless charging systems for their EVs, such as Nissan LEAF and Chevrolet Volt, in partnership with Evatran. In 2011, Qualcomm acquired the former Auckland University-owned HaloIPT company and announced the largest pre-commercialwireless EV charging trial in Europe.This paper aims to review various WPT technologies namely capacitive, electromagnetic field and magnetic gear. Their operating principles will be explained with summary of their potential and constraints in EV charging.

CAPACITIVE WPT

By using capacitiveWPT[3] technology, a.c.Power transfer electric field. It has a comparatively smaller EMI than that of conventional electromagnetic field-based equivalents, as the electrostatic field is contained inside conductive plates, whereas the magnetic flux fringes through the coils in all directions to form a closed flux loop.Another benefit was their ability to transfer energy through metal barrier. In an electric field, the upper and lower surfaces of the metal barrier can serve as conductive plates. This effect splits the original electric field but would not interrupt the transfer of power. Given its benefits, due to the small coupling power, the capacitive WPT technology[4] faces a major practical challenge. The other benefit was their ability to pass energy through metal barrier. In an electric field, the upper and lower surfaces of the metal barrier can serve as conductive plates. This effect splits the original electric field but would not interrupt the transfer of power. Air permittivity is quite small, special and costly dielectric materials with high dielectric constant, such as $BaTiO_3$ are typically used to increase capacity. Yet any current air gap or coupling plate displacement would dramatically decrease power. It makes it impractical for wireless EV charging applications where the air gap and wide displacement must be at least 150~200 mm (Fig. 1).

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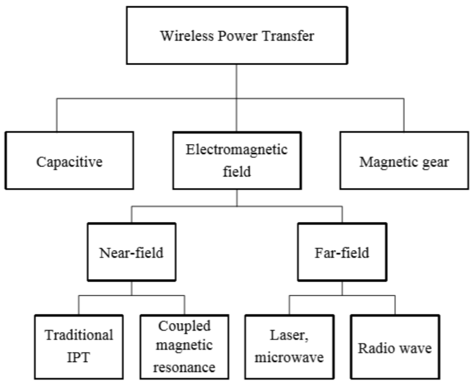

Fig. 1: Classification of WPT technologies

ELECTROMAGNETIC FIELD WPT

There are two main types of time-varying electromagnetic field WPT technologies, the near-field and the far-field.

Near-field:

The near-field is non-radiative and can transfer energy over less than a wavelength gap. Transfer of inductive power (IPT) is a common near-field technology which is commonly used in induction engines. This was also used for wireless charging of electronic devices, such as electric toothbrushes and mobile phones.However, as the distance increases ($1/r^3$), the transferred power rapidly decays. The efficient range of operation is therefore always limited to several centimeters. The near-filed[5] RFID device has a longer operating span, since only a small fraction of the power is needed to operate. Coupled magnetic resonance is proposed to achieve an increased operating range and greater efficiency. It also belongs to near-field technology, but is improved by resonance, thereby expanding the power transfer range.

Far-field:

Far-field technologies are capable of transferring energy through propagation of electromagnetic waves from two wavelengths to infinity. High-directivity antennas[6] and laser beams can transfer power at high efficiency in space applications; however, a direct line-of-sight transmission path and complicated tracking strategies are required to maintain perfect alignment. While in Omni-directional application, when the distance increases ($1/r^2$), the power density decreases. So it is typically used in signal transmission where the necessary power is at the level of the microwatts. In fact, the antennas should be wide enough to meet the safety standards on EMI for charging applications, which makes them unsuitable for EV applications. While in Omni-directional operation, when the gap increases ($1/r^2$), the power density decreases. So it is typically used in signal transmission where the necessary power is at the level of the microwatts. In addition, the antennas should be large enough for charging applications to meet EMI safety standards, which makes them unsuitable.

TRADITIONAL IPT VS. COUPLED MAGNETIC RESONANCE

Intensive research on the analysis and comparison of those prototypes has been carried out. The primary side is usually compensated to lower the reactive power and hence the power supply's VA value. The secondary side is also compensated so that almost all of the transferred power is acquired by the load, thus enhancing the power transfer capability.Various near-field WPT technologies are shown in Fig. 2. Coupled magnetic resonance is a near-field WPT[7] with some improvements from traditional IPT. As shown in Fig. 2(b), two or more pairs of RLC resonators are used to enhance power transfer efficiency with extended transfer range. Two capacitors connected in series as in Fig. 2(b).However it is possible to connect both primary and secondary side compensation capacitors in series or parallel, resulting in four separate prototypes. Application-oriented topology is the choice.

- Series compensation on secondary side is suitable for constant voltage application.
- Parallel topology on secondary is capable to support a constant current.
- Series-compensated primary can reduce the power supply voltage which is very attractive in long track application
- Parallel-compensated primary is capable to support a large supply current.

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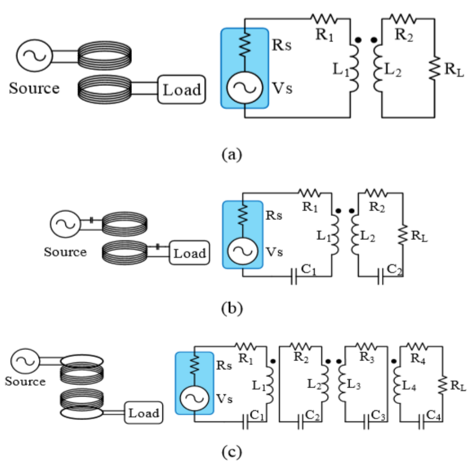

Fig. 2: Near-field wireless power transfer technologies: (a) traditional IPT; (b) coupled magnetic resonance and (c) strongly coupled magnetic resonance

MAGNETIC GEAR WPT

In the process of energy conversion, magnetic gear (MG) technology[8] uses mechanical force. To replace the conventional contact gear, it was first introduced. Uses include wind power turbines and EV motors. It was also extended when charging medical implants such as cardiac pacemakers with low power. Higher power systems have also been researched for the electronics and automobiles. In 2009, two prototypes were reported capable of transmitting 1.6kW at an efficiency of 81 percent through a 150 mm air gap and 60W through a 100 mm air gap. The transmitter winding is input from a current source, which induces an electro-mechanical torque on the transmitter PM, and the PM rotates. The PM of the receiving side catches up with the magnetic field from the transmitting side and rotates in synchronous manner with the transmitter PM. The receiver operates at generating mode and delivers power to charge the battery via a rectifier circuit (Fig. 3).

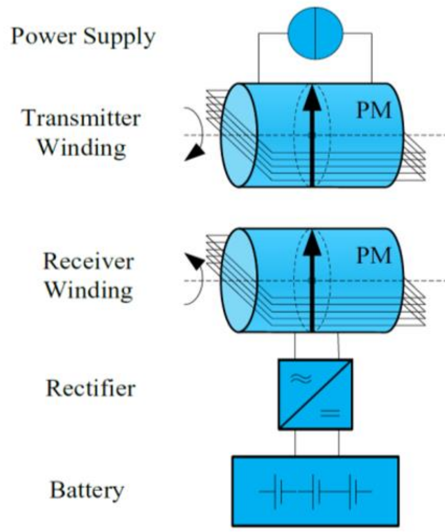

Fig. 3: Magnetic gear WPT charging system

In WPT, this MG technique[9] was first used in powering medical implants. However, the power level and air gap are both small. In, the maximum transferred power is 6.6W and the maximum power at 1.0 cm is 1W. This is due to the limited space in human body application. By applying the same technique, researcher has scaled up the power level to 1.6kW with an air gap of 15cm, which deemed suitable for vehicle charging application.

COMPARISON

Table 1 shows the comparison between the WPT Technologies on EV Charging

Table 1: Comparison of WPT technologies on EV charging

WPT technology	Medium of power transfer			Power level	Range	Efficiency	Capability
Capacitive	Electric field			Low	Low	High	Both power and range are too small for EV charging.
Electro-magnetic	Electro-magnetic field	Near-field	Traditional IPT	High	Low	High	Range is too small for EV charging.
			Coupled Magnetic Resonance	High	Medium	High	Capable for EV charging
		Far-field	Laser, Microwave	High	High	High	Need direct line-of-sight transmission path, large antennas, and complex tracking mechanisms.
			Radio wave	High	High	Low	Efficiency is too low for EV charging.
Magnetic gear	Electro-mechanical force			High	Medium	High	Capable for EV charging

CONCLUSION

In this paper, capacitive, electromagnetic field and magnetic gear WPT technologies for EV charging are reviewed. The coupled magnetic resonance and magnetic gear technologies are potential technologies for EV charging and the basic principle of each technology is explained. The latest development and research are also summarized. Technical challenge and future development trends are also introduced. It can effectively solve the problem of a limited number of plug-in stations and can realize mutual power supply between vehicles. One issue with the wireless V2V charging[10] technology is the angular offset due to the change in the location of the device. Therefore, this paper presents the fundamental theory of multi-turn coil design with angular offset. Results show that if the transmitter coil and receiver coil are of same size and closely wound, the system can achieve high mutual inductance. If the size of transmitter coil and the receiver coil are different, the coil will require an optimal design. In the future, the attention should be given to the hardware implementation.

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