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Wireless Power Transfer for Electric Vehicle Applications

Amal Jose George¹, Athira K S², Gishnu Mohanan³, Renas K Nasser⁴, Eldhose K A⁵

U.G. Student, Department of Electrical and Electronics Engineering, MACE, Kothamangalam, Kerala, India^{1,2,3,4}

Assistant Professor, Department of Electrical and Electronics Engineering, MACE, Kothamangalam, Kerala, India⁵

ABSTRACT: 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 30 years with the term inductive power transfer. WPT technology is developing rapidly in recent years. At kilowatt power level, the transfer distance increases from several millimetres to several hundred millimetres with a grid to load efficiency above 90 percentage. The advances make the WPT very attractive to the electric vehicle (EV) charging applications in both stationary and dynamic charging scenarios. This project reviewed the technologies in the WPT area applicable to EV wireless charging. By introducing WPT in EVs, the obstacles of charging time, range, and cost can be easily mitigated. Battery technology is no longer 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.

KEYWORDS: Dynamic charging, electric vehicle (EV), inductive power transfer (IPT), safety guidelines, stationary charging, wireless power transfer (WPT).

I. INTRODUCTION

Until now, the EVs are not so attractive to consumers even with many government incentive programs. Government subsidy and tax incentives are one key to increase the market share of EV today. 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. Besides the cost issue, the long charging time of EV batteries also makes the EV not acceptable to many drivers. For a single charge, it takes about half an hour to several hours depending on the power level of the attached charger, which is many times longer than the gasoline refuelling process. The EVs cannot get ready immediately if they have run out of battery energy. To overcome this, what the owners would most likely do is to find any possible opportunity to plug-in and charge the battery. It really brings some trouble as people may forget to plug-in and find themselves out of battery energy later on. The charging cables on the floor may bring tripping hazards. Leakage from cracked old cable, in particular in cold zones, can bring additional hazardous conditions to the owner. Also, people may have to brave the wind, rain, ice, or snow to plug in with the risk of an electric shock[1].

The wireless power transfer (WPT) technology, which can eliminate all the charging troubles, is desirable by the EV owners. By wirelessly transferring energy to the EV, the charging becomes the easiest task. 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 percentage or less compared to EVs with conductive charging. From the functional aspects, it could be seen that the WPT for EV is ready in both stationary and dynamic applications. However, to make it available for large scale commercialization, there is still abundant work to be done on the performance optimization, setup of the industrial standards, making it more cost effective, and so on. Although the market demand is huge, people

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were just wondering whether the WPT could be realized efficiently at a reasonable cost. The research team from MIT published a paper in Science, in which 60 W powers is transferred at a 2-m distance with the so called strongly coupled magnetic resonance theory. The result surprised the academia and the WPT quickly became a hot research area. A lot of interesting works were accomplished with different kinds of innovative circuit, as well as the system analysis and control. The power transfer path can even be guided using the domino-form repeaters. In order to transfer power more efficiently and further, the resonant frequency is usually selected at MHz level, and air-core coils are adopted.

II. LITERATURE REVIEW

[1] S. J. Gerssen-Gondelach and A. P. C. Faaij, "Performance of batteries for electric vehicles on short and longer term"-Wireless power transfer has been a popular topic of recent research. Most research has been done to address the limitations of coil-to-coil efficiency. However, little has been done to address the problem associated with the low input power factor with which the systems operate. Wireless power transfer (WPT) is possible because of resonant circuits. When a transmitter circuit is tuned to resonate at the same frequency as a receiver circuit, power is transmitted wirelessly through the magnetic coupling of the inductive coils found in the circuits. Because the power is transferred by magnetic coils, there is little electric contact danger to any biological entity. Electronics within the charging area are also unaffected unless they are resonant at the same frequency. Near-field WPT systems are of two types: inductive, which use magnetic field coupling between conducting coils, and capacitive, which use electric field coupling between conducting plates to transfer energy. For medium range applications (in which the distance between the transmitter and the receiver couplers is comparable to the size of the couplers, as in EV charging), inductive WPT systems have traditionally been preferred. After market stationary chargers are already available, and some EV manufacturers have announced plans to introduce built-in stationary inductive WPT systems as early as 2018. However, for magnetic ux guidance and shielding, inductive WPT systems require ferrite cores, making them expensive and bulky. Also, to limit losses in the ferrite, the operating frequencies of these systems are kept under 100 kHz, resulting in large coils and low power transfer densities. The high cost and low power transfer density are particularly problematic for dynamic WPT, as these systems need to have very high power capability to deliver sufficient energy to the vehicle during its very brief time passing over a charging coil.

[2] B. L. Cannon, J. F. Hoburg, D. D. Stancil, and S. C. Goldstein, "Magnetic resonant coupling as a potential means for wireless power transfer to multiple small receivers"-There are four basic topologies of compensation circuits, namely series-series (SS), series-parallel (SP), parallel-series (PS) and parallel-parallel (PP) [1]. Each topology has its inherent advantages and disadvantages. The SS topology needs load-independent capacitors while other topologies require variable compensating capacitors to operate at a given frequency. However, the load current of the SS topology varies with the variation of load, which is not suitable for battery charging. Other types of compensation circuits have been introduced to overcome limitations of these basic topologies. A systematic comparison between the SP and LCL-LC topologies was done in, which showed that the LCL-LC topology had outstanding properties compared to the basic SP topology thanks to its stable load current, low source current and simple control.

[3] O. H. Stielau, "Design of loosely coupled inductive power transfer systems"-Closely coupled IPT systems are systems where the magnetic coupling between the primary and the secondary is very good. These would be systems where the leakage inductances are small relative to the magnetising inductance in the system. Such systems are very common in the power systems arena where transformers of all shapes and sizes are used to transform power from one form to another. Loosely coupled systems, on the other hand, are systems where the magnetic coupling between the primary and the secondary is poor. In these systems the leakage inductances are usually much larger than the magnetising inductance. Such systems usually result due to mechanical constraints of the application, in many cases there would be a requirement that the secondary must be able to move relative to the primary with no physical contact between the two. Examples of such systems are non-contact vehicle battery charging, roadway powered electric vehicles, sliding transformers, robotic applications, contact less energy transfer in wet or hazardous environments, and underwater power transfer. Few such systems exist in practice due to the difficulty in transmitting power effectively, but with the

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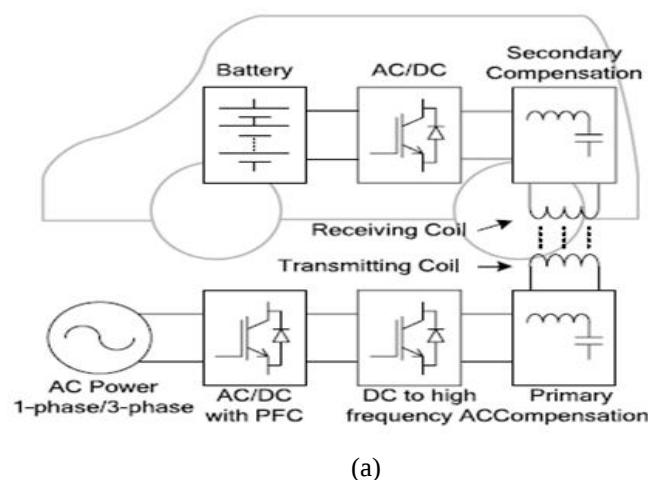
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recent improvements in power electronic technologies this is about to change. Designing closely coupled systems is a well-known procedure. Designing loosely coupled IPT systems, however, can be a daunting task. Many design examples have been described in the literature, but no generalised design procedure explaining how to go about designing a complete system has been found. In this paper a design methodology is proposed to deal with the additional complexities of loosely coupled systems.

[4] A. P. Sample, D. A. Meyer, and J. R. Smith, "Analysis, experimental results, and range adaptation of magnetically coupled resonators for wireless power transfer"-Concept of wireless power transfer has been discovered widely since Nikola Tesla carried out his first experiment about pursuing his idea on wireless lighting and electrical distribution after successfully invent an alternating current. Thereafter a great interest and investigation on that area began. According to working principles, wireless power transfer technology can be classified into few methods of principle such as microwave, laser, photoelectric, radio waves (RF), magnetic resonance and inductive coupling method. Based on the power transfer distance wireless energy transfer methods can be categorized into two types; near field and far field. Laser, photoelectric, RF and microwave can be considered as far field energy transfer methods while inductive coupling and magnetic resonance coupling are based as near field approaches. This typical inductive power transfer (IPT) schemes are limited to a few centimetres. Current technology of electrical vehicles charging allows EV battery charges by plug-in cable source into receptacle on the vehicle. However, this conventional method will expose EV owner to physical and safety hazard such as electrocution due to poor aesthetics system and inconvenient charging situation. Therefore a convenient, affordable and safety station to charge EV are required. Wireless power transfer for electric vehicle charging system would be a convenient feature of solution for this matter. The process is fully automated, whereby no human handling works are required to perform the charging process. There are two concepts enabled in EV charging system; stationary and dynamic. Stationary WPT can replace the charging cable for PEVs whereby activated when vehicle reaches to the charging area. While the concept of dynamic WPT charged while vehicle is moving in a road. This particular concept will increase the effective driving range while reducing the volume of battery storage however required large area and costly.

III. WIRELESS POWER TRANSFER

Wireless charging consists in transferring energy from the source to the load without physical contact. This technology can be applied to EV battery charging for which daily recharge is mandatory. The tedious and inconvenient aspects of connecting the power cable hinder some users and may hinder the development of the EVs. A user friendly solution consists in using a system of power transmission without contact. This solution provides ease of use and a good robustness to vandalism [3]. A general block diagram for the contactless charger for EV battery is shown in Fig. (a)



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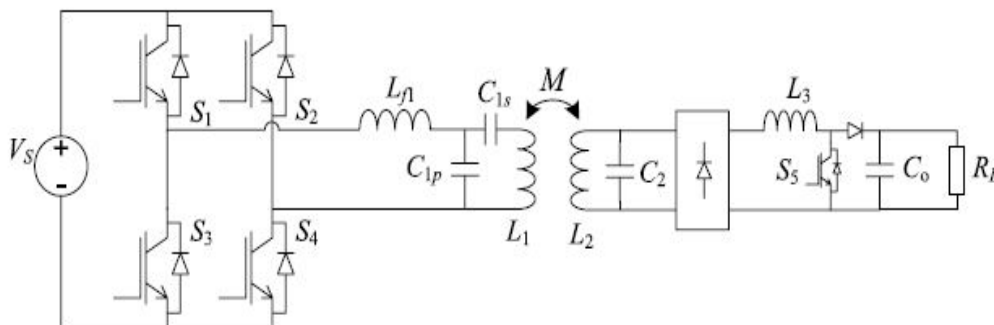
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It includes several stages to charge an EV wirelessly. First, the utility ac power is converted to a dc power source by an ac to dc converter with power factor correction. Then, the dc power is converted to a high-frequency ac to drive the transmitting 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

Power electronic device and power control

In a WPT system, the function of the primary side power electronics converter is to generate a high-frequency current in the sending coil. To increase the switching frequency and efficiency, usually a resonant topology is adopted. At the secondary side, a rectifier is adopted to convert the high-frequency ac current to dc current. Depending on whether a secondary side control is needed, an additional converter may be employed. The primary side converter may be a voltage or a current source converter. As a bulky inductor is needed for the current source converter, the most common choice at the primary side is a full bridge voltage source resonant converter. A typical wireless power circuit schematic is shown in the figure (b).



(b)

IV. EXPERIMENTAL RESULTS

The transmitter section of WPT model. It consists of MOSFET which acts as the inverter, compensation network and various IC to drive the MOSFET. The transmitting coil is connected to the transmitter section.

The receiver section of the WPT model. It consists of a diode bridge which acts as a bridge rectifier, secondary compensation network, and a filter capacitor used to remove the ripples from the output waveform.

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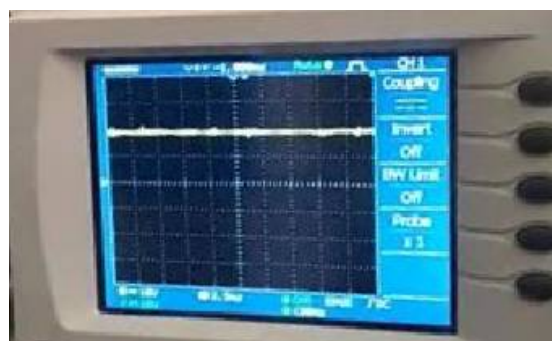
Transmitter



Receiver

Output waveform in CRO

Figure shows the output voltage waveform obtained in the CRO. It is clear that a ripple free output waveform is obtained.



V. CONCLUSION

Stationary wireless charging systems have comparable system performance to conductive charging systems. Progress in technology has led to improved system performance. In this project a prototype of WPT system is designed and implemented. From the technical perspective, major challenges are: (1) how to improve the system efficiency of charging systems and maximize the amount of energy received by vehicles; and (2) how to balance the size of the

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charging system and its misalignment tolerance and efficiency. It is clear that electric vehicles are 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. In future efficiency can be further increased by introducing suitable core between the transmitter and receiver so that maximum flux link with receiver. Problems due to varying distance between coils can be mitigated if a movable core can be introduced. Further studies in topology, control, inverter design, and human safety are still needed in the near term.

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