論 文 の 内 容 の 要 旨

論文題目　　**Wireless Power Transfer for Moving Electric Vehicles**

（走行中電気自動車への給電をめざしたワイヤレス電力伝送）

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This thesis focuses on designing and evaluating various wireless power transfer design for charging while moving of electric vehicles. Vehicle electrification has become a recognized solution to oil shortage and pollution problems from engine-driven vehicle. Electric vehicles are also cleaner, quiet and more energy efficient. Renewable energy sources can be used especially with the recent development of distributed energy system. However, energy storage is a bottleneck for rapid development and wide adoption of electric vehicles. Batteries for supporting the same or close to the driving range of drivers used to enjoy are costly, heavy and with long charging time.

Wireless power transfer alleviates above mentioned problems by providing a safer and more convenient charging method compared to plug-in charging. For charging while parking, the wireless charging facility is more durable, space saving and does not pollute the city view with overhead electricity grid. Current development of wireless power transfer technology enables the possibility of dynamic charging on highways and roads. The wireless power transfer system is constructed to support certain distance and vehicles pick up power while moving along the road. The challenges of constructing the system include complexity of the wireless powering network underneath the ground, cost, transfer gap, efficiency and power levels.

In this work, wireless power transfer configurations which consist of combination of multi-receiver and repeaters are proposed for dynamic charging. Power division method between receivers with different amount of coupling to the transmitters is proposed. On the other hand, repeaters are also used in a system to extend the effective range. New methods for power division and impedance matching are derived and then

generalized for arbitrary number of receivers and repeaters including cross coupling consideration. Impedance inverter representation is used to simplify the analysis and calculation. Additionally, a special case where the existence of repeaters causes dead zone is analyzed. The simplicity of using impedance inverter representation compared to only solving conventional equivalent circuit equations is further demonstrated in the analysis of this special case. All the methods proposed are validated using simulations and experiments.

Above mentioned work generalized the analysis of wireless power transfer using impedance inverter representations of coupling for arbitrary combinations of receiver and repeaters. Using this theory as basis, a dynamic charging system using two transmitters simultaneously powering a receiver to achieve even magnetic field and therefore constant power level during running is proposed. Mutual inductance is calculated using Neumann formula. Maximum efficiency depends on the ratio of mutual inductance to the coil resistance if the frequency is fixed. When using long transmitters, the mutual inductance is similar to using short transmitters but the coil resistance is larger. Therefore multiple short transmitters are connected in parallel to the power source via impedance inverter circuit is proposed. The coupling design which depends on the size and turns of the transmitters, and receiver size determines the power level. Spacing between transmitters is also designed to achieve even magnetic field. Additionally, cross coupling between the transmitters does not affect the power level due to the impedance inverter circuit. The hardware setup for this even magnetic field system including the transmitter module, the receiver module and the magnetic sensors for sensing the position of the receiver is shown in the last chapter.

In the next chapter, the steady state and transient analysis of one-to-one wireless power transfer are discussed. In series-series compensated wireless power transfer, the maximum efficiency depends on both the receiver and the transmitter. However the maximum power depends dominantly on the transmitter. This characteristic is exploited to achieve a flatter efficiency curve across different power levels as different power is required when the vehicle is at different moving speeds. A design flow is then proposed using efficiency vs. power level curve. The design method is discussed using round spiral coils and the AC resistance is approximated using extended Dowell formula. However the method can be applied to other coils once the AC resistance calculation method is developed. The transient of the wireless power transfer is then studied using general state space averaging (GSSA).

The outline of this dissertation is illustrated in the figure of next page. The research is divided into theory portion and practical implementation portion. The details of this dissertation are summarized as follows:

1) Research background

In Chapter 1, the history of wireless power transfer and application for electric vehicles are reviewed. Then the motivation and structure of this dissertation are also explained.

2) Theory of wireless power transfer

In Chapter 2, impedance inverter representation of coupling is proposed. Then the generalized theory for arbitrary number of receivers and repeaters are explained.

In Chapter 3, a special phenomenon when using repeaters in wireless power transfer for dynamic charging is explained. Using derived method from Chapter 2, the dead zone case is generalized into two different cases which are the even repeater and odd repeater.

3) Practical dynamic configuration

In Chapter 4, a practical wireless power transfer method is proposed using multiple transmitters to one receiver to achieve even magnetic field. Neumann formula, maximum efficiency and AC resistance calculation method are also explained in this chapter.

In Chapter 5, the effect of impedance inverting characteristic to power level and efficiency is studied. Design method is proposed to achieve flat efficiency across different power level. GSSA modeling method to study wireless power transfer small signal transient is also presented in this chapter.

In Chapter 6, the hardware built for even magnetic field experiment is described.

4) Conclusion

Chapter 7 lists the conclusion and future works of this dissertation.