論 文 の 内 容 の 要 旨

論文題目　Development of secondary-side-only simultaneous power and efficiency control in wireless power transfer system
（ワイヤレス電力伝送システムにおける二次側のみの制御による電力と効率の同時制御法の開発研究）

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This dissertation is entitled「Development of Secondary-side-only Simultaneous Power and Efficiency Control in Wireless Power Transfer System（ワイヤレス電力伝送システムにおける二次側のみの制御による電力と効率の同時制御法の開発研究）」and discusses the control methods as well as the circuit architecture suitable for secondary-side-only power and efficiency control of wireless power transfer (WPT) systems when many constraints such as lack of communication are included. This dissertation explores the following two main themes: secondary-side-only power and efficiency control with two converters in static scenario and secondary-side-only power and efficiency control with two converters in dynamic scenario. Thus, a part is devoted to the explanation about the necessity of field programmable gate array for use in converter control for WPT systems, as well as the guidelines for creating from scratch a digital controller for power converter at a machine logic level. Finally, by virtue of FPGA's superior characteristics, the concepts of secondary-side-only power control with one converter in case of constant power load and constant voltage load are explained and evaluated. By the aforementioned points of investigation, the work of this thesis aims at providing the design process of robust controllers able to satisfy the requirements of power and efficiency by only the secondary side. The controllers do not need communication and offer great versatility at a slight trade-off, making them very application-oriented.

Wireless power transfer via magnetic resonance coupling is a technology allowing the transmission of electric energy without the need of cables and with a high efficiency over several tens of centimeters. In particular, current electric vehicle problems and issues such as potential dangers to the users during battery charging process, low cruising range, long battery charging time can be solved by wireless power transfer. In fact, wireless power transfer can be performed not only when the transmitting side and the receiving side are not moving (a static scenario), but also during their relative motion (a dynamic scenario) .

Previous research rarely considered power and efficiency control on secondary side only. Including all the control only in the secondary side of the system is a desirable feature since it allows real time adaptation to the primary side of the whole system. Until now, control for both sides with communication has been the only method to regulate power and efficiency at the same time. However, communication availability and speed is important in practical applications and it is an issue in dynamic scenarios, where the control objective has to maintain high efficiency and desired power while the system parameters are varying.

In this research, a technology called WPT to send electromagnetic energy wirelessly is used. The transmitting efficiency and load power is controlled at the same time only by the secondary side, therefore a system without need of communication able to maintain controllability is proposed. The theory as well as the controller design are explained; experimental results verify the validity of the proposed system.

The chapter 1 is entitled「Introduction」. In here, the research background regarding control methods for power converters in wireless power transfer systems by magnetic resonant coupling is introduced in order to establish the motivation and the position of the research described in this dissertation. In previous research, the regulation of the transmission efficiency and power has been designed without considering the circuit composition, such as the number of power converters or the type of load. The need of control only on the secondary side without communication in case of practical system is established.

The chapter 2 is entitled「Power and efficiency control theory in WPT systems for EVs」and here the power control and efficiency control concepts presented in past research are reviewed. In particular, efficiency is regulated via load impedance matching, while power is often regulated by frequency or duty control. Then, static WPT and dynamic WPT scenarios are explained. Finally, since wireless power transfer by magnetic resonance coupling encompasses different compensation methods, it is briefly discussed the suitability of series-series (SS) compensation for automotive application.

The chapter 3 is entitled 「Secondary-side-only power and efficiency control for constant voltage load」, where a novel control designed for a WPT system with constant voltage load (CVL) and two power converters in the secondary side is proposed. No communication between sides is used and only secondary side is manipulated. In order to have two degree of freedom of control, both converters contain active devices. The regulated parameters are the average power and the transmitting efficiency. After defining the conditions for correct operation, the controller design is described. Experiments show the feasibility of the proposed control method both in static WPT and dynamic WPT scenario.

The chapter 4 is entitled「FPGA-based implementation of digital current limiter and secondary DC current controller」and describes the method of performing converter control through a FPGA. After underlining the superiority and suitability of FPGA in high frequency environments, an example of logic project creation for implementing a digital current limiter for the primary side of the WPT system is described. After analyzing the reference circuit of the case of study, the chosen control concept is symmetric phase shift. A simple PI current controller is then applied to the secondary side to regulate the power flow. Experimental results show the correct operation of both the primary side current limiter and secondary side current controller.

The chapter 5 is entitled「Secondary-side-only voltage stabilization control for constant power load」and proposes a control is designed for a WPT system with constant power load (CPL). The constant power load is unstable in open loop, thus the controller objective is to stabilize with a closed loop function. In order to perform control, the converter must be a full bridge active rectifier. The voltage is stabilized by use of combined synchronous rectification and symmetric phase shift. By modifying the conversion ratio, the secondary side coil voltage is controlled and stabilizes the CPL smoothly. Past research never achieved smooth transient and simple control method by only secondary side at the same time. The controller design is described and the conditions for stability are described. Experiments show the feasibility of the proposed control method both in static WPT and dynamic WPT scenario.

The chapter 6 is entitled 「Vision of future WPT society」and introduces the probable future scenario in case of widespread use of WPT. Because of the increased flexibility and safety provided by WPT in many fields, such as automotive, medical and industrial, the quality of life of the whole society will benefit greatly.

The chapter 7 summarizes the main points of the previous chapters and states the future works necessary for advancing the technology of WPT.