전기자동차 충전을 위한 고효율 무선전력전송 시스템

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Extremely high efficiency wireless power transfer system for EV charger

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ABSTRACT

This paper proposes a high efficiency wireless power transfer system with an asymmetric 4-coil resonator. It presents a theoretical analysis, an optimal design method, and experimental results. In the proposed asymmetric 4-coil system, the primary side consists of a source coil and two transmitter coils which are called intermediate coils, and in the secondary side, a load coil serves as a receiver coil. In the primary side, two intermediate coils boost the apparent coupling coefficient at around the operating frequency. Because of this double boosting effect, the system with an asymmetric 4-coil resonator has a higher efficiency than the conventional symmetric 4-coil system. The prototype operates at 90 kHz of switching frequency and has 200 mm of the power transmission distance between the primary side and the secondary side. An AC-DC overall system efficiency of 96.56% has been achieved at 3 3 kW of output power.

1. Introduction

Nowadays, global warming caused by greenhouse gas has become a significant problem in the world. So, the United States (US), the European Union (EU), China, Japan, South Korea, and other countries have proposed and established new fuel economy and car CO_2 emission standard which are very challenging when compared with the former regulations. Therefore, the automobile industries have been working on a lot of projects for the development of HEV, PHEV, and BEV, and they expect EV sales increases to 5.9 million units by 2020. As EV sales increases, the electric vehicle supply equipment (EVSE) market will also increase.

In the EVSE market, a battery charging method can be classified into wired charging and wireless charging. Wireless charging uses induction coils to create an alternating electromagnetic field in the primary side on the floor of the charging station while a second induction coil in the car receives power from the electromagnetic field and charges the battery. The convenience of wireless charging can make EVs more acceptable to drivers because they do not need to handle the power plug which may shock the human body due to its very high voltage. Wireless charging stations also require less hardware and can be installed underground. Therefore, the wireless power transfer (WPT) technology for EV chargers has been studied and developed for the last few years. However, the power transfer efficiency, which is lower than the wired AC charging, is a major concern. Recently, to increase the efficiency in wireless charging systems, a multi-coil resonator which has more than three coils has been studied. Generally, in a multi-coil resonator, since the magnetic field is expanded by intermediate coils or relay coils, the coupling between the primary and the secondary side is strengthened.

The conventional 4-coil resonator with a symmetric coil configuration is shown in Fig. 1. In the primary side, there are source and transmitter coils, and the secondary side contains receiver and load coils. However, in most WPT systems, the main power losses occur in the primary side because there are many resistive components including inverter switches. Therefore, a reduction of the rms current in the primary side is an easy way to increase the system efficiency. To achieve a low rms current in the primary side and a high system efficiency, this paper proposes a WPT system with an asymmetric 4-coil resonator.

2. Analysis of the proposed asymmetric 4-coil resonator WPT system

The proposed asymmetric 4-coil resonator for WPT systems consists of a source coil and two intermediate coils in the primary side and a load coil in the secondary side as shown in Fig. 2. The source coil and the intermediate coils are placed on a same plane to maximize the boosting effect.

Fig. 3 shows effective inductance graphs which have the single boosting effect of the conventional system and the double boosting effect of the proposed system, respectively. In the case of the single boosting system, $Z_{L1.single}$ increases very rapidly.

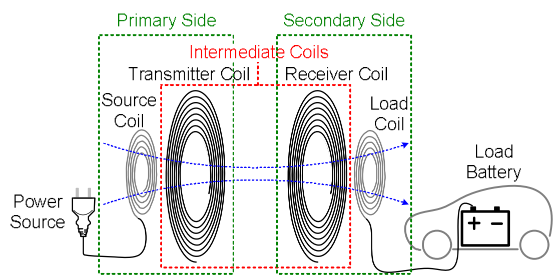

Fig. 1 The conventional symmetric 4-coil resonator

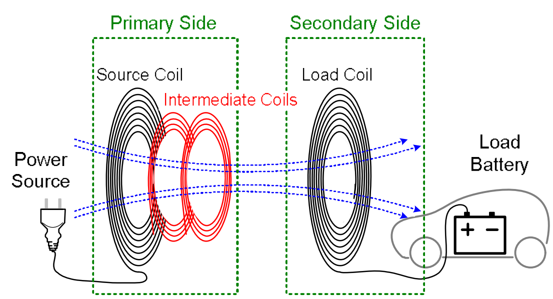

Fig. 2 The proposed asymmetric 4-coil resonator

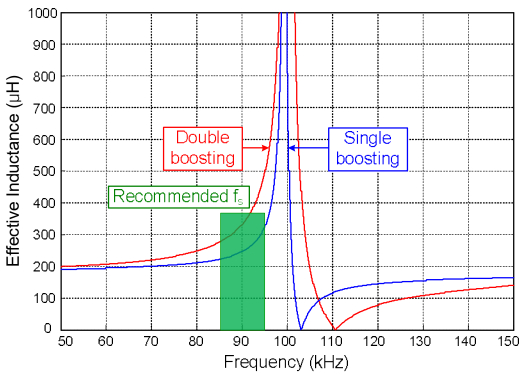

Fig. 3 Z_{L1} graphs in cases of single and double boosting systems

On the other hand, in the double boosting system, Z_{L1} is increased slowly and is higher than that of the single boosting system because Z_{L1} is boosted two times by each of the intermediate coils at around their L-C resonance frequencies. Therefore, the proposed system has a higher apparent coupling coefficient k_a than that of the conventional single boosting system so that the power transfer efficiency is increased.

3. Experimental results

A prototype of a 3.3 kW WPT system which has a distance between the primary and the secondary side of 200 mm is implemented with the proposed asymmetric 4-coil resonator and the specifications shown in Table I.

TABLE I. SPECIFICATIONS OF PROTOTYPE

3Φ line voltage V_{line} (line-line)	337.5 Vac
Rated output voltage V_o	283 Vdc
Rated output load current I_o	11.66 A
Rated load resistance R_o	24 24 Ω
Rated output power P_o	3 3 kW
Switching frequency f_s	90 kHz

Fig. 4 shows a block diagram of the proposed asymmetric 4-coil system. From the three-phase AC source, the power is transferred through the full bridge inverter, the resonator, the output rectifier, and the load. To verify the efficiency of the proposed system only, three phase power factor correction circuit is not applied. In the resonator, the ratio of transmission distance and the radius of the source coil is about 1/2 so that this system can be considered near-field transmission system.

Fig. 5 shows the input and output powers at the rated load. The input power is measured by a PM3000A precise power analyzer. The prototype with the proposed asymmetric 4-coil system shows an overall system efficiency of 96.56% from the three phase AC source to the output load. The power consumptions of the gate drivers and the control ICs are also considered in the efficiency calculation.

Fig. 6 shows the AC-DC overall system efficiency with load variations for the proposed asymmetric 4-coil system, the single boosting system which has an intermediate coil, and the conventional 2-coil system. Since the proposed system has a higher apparent coupling coefficient caused by double boosting, the proposed system shows about 1.2%p higher than the single boosting system which has a k_a of 0.408 in a wide load range. In the conventional 2-coil system, since there is no boosting effect, the system has very low k of 0.191 so that the efficiency is about 5%p lower than it of the proposed system.

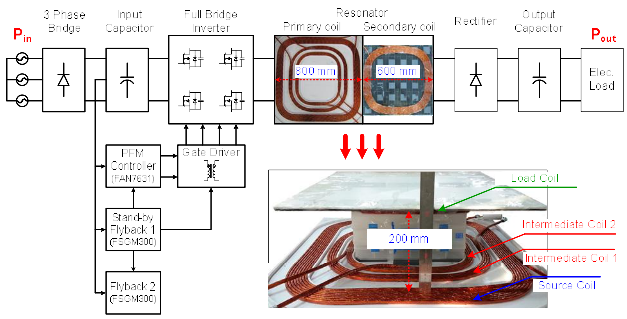

Fig. 4 Block diagram of the proposed asymmetric 4-coil system

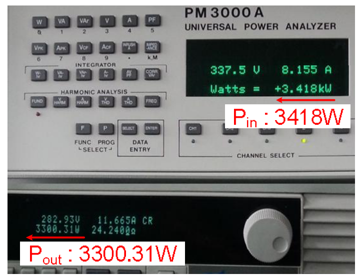

Fig. 5 Input and output Power of the proposed asymmetric 4-coil system

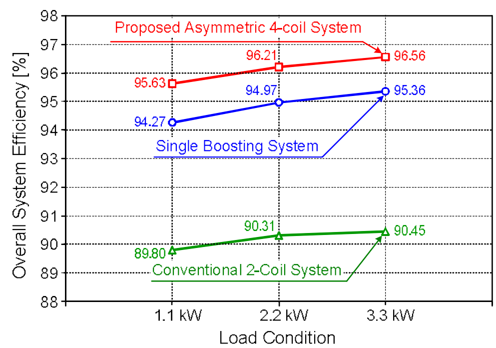

Fig. 6 Overall System Efficiency with load variation

4. Conclusion

In this paper, a wireless power transfer system with an asymmetric 4-coil resonator for electric vehicle battery chargers has been proposed. In the proposed system, two intermediate coils in the primary side boost two-times the effective inductance of the source coil at around their L-C resonance frequencies. Thus, the proposed system has a higher power transfer efficiency with a relatively long distance. To verify the proposed asymmetric 4-coil resonator WPT system, a 3.3 kW prototype was implemented and experimented on. The results showed that the proposed WPT system has an very high AC-DC overall efficiency of 96.56% with a 200 mm of power transmission distance under a 3.3 kW output load condition. Therefore, the proposed system can be a good candidate for the electric vehicle wireless charger.

References

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