무선충전 Pad와 공진 인덕터가 결합된 DS-LCC 토폴로지 연구

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Study of DS-LCC Topology Integrated with Compensation Inductor and Wireless Charging Pad

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ABSTRACT

This paper proposes a fully integrated DS-LCC compensated wireless power transfer (WPT) system to improve misalignment performance. In the design, the main coils are unipolar coils, and the compensation inductors are designed as extended double D (EDD) coils. When the system is misalignment, the coupling between the compensation inductors, the cross-coupling between the compensation inductors and main coils on the opposite side can increase the system output power. The proposed magnetic coupling structure was optimized and verified using simulation tools.

1. Introduction

Wireless Power Transfer (WPT) technology is a convenient, safe, and reliable charging method for electric vehicles (EVs), which has attracted widespread attention from the society. However, misalignment parking of EVs is unavoidable, which will reduce the efficiency of system output power. [1] designed a new coil structure with uniform magnetic induction density called extended DD (EDD) coil, which can improve the misalignment performance. Furthermore, in order to improve the misalignment capability and reduce the WPT system volume, [2] proposed a dual-coupled DS-LCC compensated WPT system with a compact magnetic coupler. However, this design requires the compensation inductances to be located above and below the main coils, which undoubtedly increases the thickness and volume of the package.

In this study, a fully integrated DS-LCC compensated WPT system is proposed to reduce volume and focus on solving the misalignment problem. The main coils are unipolar coils, and the compensation inductances are EDD coils integrated in the main coils. Using the FEM simulation tool to optimize the design of the EDD coil, to maximize the coupling between the two compensation inductors, the cross couplings between the compensation inductor and main coil, thereby increasing the output power. In addition, the

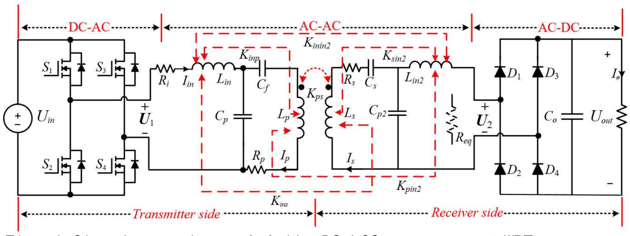


Fig. 1 Circuit topology of fully DS-LCC compensated WPT system.

misalignment performance of the proposed magnetic coupling structure is analyzed and verified using the PSIM simulation tool.

2. Analysis of the Fully DS-LCC Topology

The proposed topology of the fully integrated DS-LCC compensation WPT system is shown in Fig. 1. L_p and L_s are main coils, L_{in} and L_{in2} are compensation inductances. Since only the different-side coupling coefficients can contribute to power transfer. Therefore, there are four important couplings in this magnetic coupling structure, which are K_{ps}, K_{inin2}, K_{ins}, and K_{pin2}, can be defined as:

$$K_{ps}=\frac{M_{ps}}{\sqrt{L_pL_s}}\ K_{inin2}=\frac{M_{inin2}}{\sqrt{L_{in}L_{in2}}}$$
$$K_{pin2}=\frac{M_{pin2}}{\sqrt{L_pL_{in2}}}\ K_{ins}=\frac{M_{ins}}{\sqrt{L_{in}L_s}}. \quad (1)$$

According to the Kirchhoff's current law can draw the relational expression of I_s. Since the system output power $P_{out}=U_2I_s$, so P_{out} can be expressed as:

$$P_{out}=\frac{|U_1|^2M_{ps}\sqrt{(M_{ins}M_{pin2}+L_{in}L_{in2}-M_{ins}M_{pin2})^2-(2M_{ins}L_{in})^2}}{\omega|(M_{ins}M_{pin2}+L_{in}L_{in2}-M_{ps}M_{inin2})^2-(2M_{ins}L_{in})(2M_{pin2}L_{in2})|}. \quad (2)$$

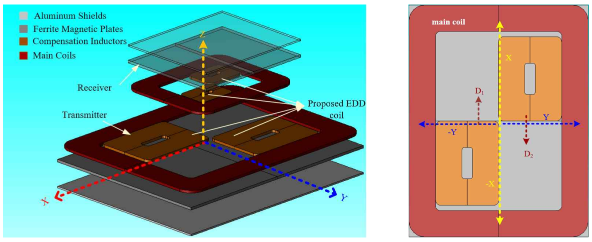
When the system is alignment, the designed magnetic coupling structure only has K_{ps}, the other coupling coefficients are almost 0, so P_{out} can be simplified as:

$$P_{out}=\frac{\sqrt{L_sL_p}}{\omega\sqrt{L_{in}L_{in2}}}K_{ps}|U_1|^2. \quad (3)$$

According to (1), (2), can be seen when misalignment, the output power increases with the increase of K_{inin2}, K_{ins}, and K_{sin2}, and thus improves the misalignment performance.

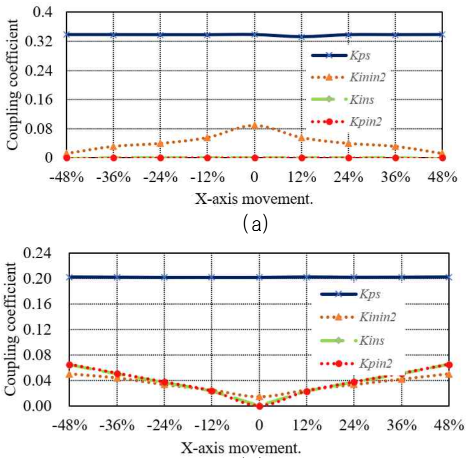
3. Design and Verification of Magnetically Coupled Structures

3.1 Design Optimization of EDD Coil



(a) (b)

Fig. 2 (a) 3-D geometric structure of the designed magnetically coupled structure, (b) main coil and EDD coil.



(a)

(b)

Fig. 3 Variations of the four couplings at different distances between D_1 and D_2 of the EDD coil, (a) system is alignment, (b) system is X-axis misalignment 150mm.

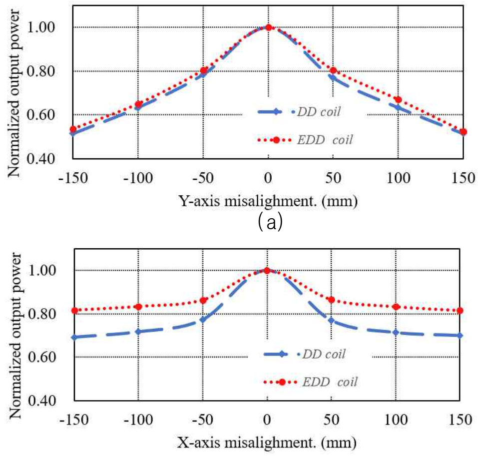
Fig. 2 shows the proposed magnetic coupling structure. The EDD coil consists of two oppositely connected unipolar coils (D_1 and D_2). The distance between them is used as variable for the optimized design. In Fig 3, when the system is alignment state, the distance between D_1 and D_2 moves along the ±X-axis to increase, K_{inin2} is reduced to almost 0 which can simplify design and analysis of the system. When the system is misalignment state, K_{inin2}, K_{ins}, and K_{pin2} increase as the distance between D_1 and D_2 increases, according to (2), the output power will also increase. So, the optimal moved distance between D_1 and D_2 is designed to be 48% of the main coils's inner diameter length, as shown in Fig 2 (b).

3.2 System Simulation Verification

When the system is misalignment state, the output power is compared, when the compensation inductances are DD coils (distance between D_1 and D_2 is 0mm) or proposed EDD coils. As can be seen in Fig. 4, the system is X-axis

Tab.1 System specifications and circuit parameters.

Symbols	Value	Symbols	Value
U_{in}	380V	f_o	85kHz
P_{out}	3.3kW	K_{ps}	0.32
L_p	77.91μH	L_s	50.92μH
L_{in}	23.12μH	L_{in2}	12.19μH
C_{p1}	287.42nF	C_{f1}	53.35nF
C_{p2}	151.13nF	C_{f2}	101.02nF



(a)

(b)

Fig. 4 Comparison of the normalized output power of two types of compensation inductors in (a) X-axis, (b) Y-axis misalignment.

misalignment state, using EDD coil as compensation inductor can improve the misalignment performance. When the Y-axis misalignment state, since two types compensation inductors K_{inin2}, K_{ins}, and K_{pin2} are similar, so the output power is almost the similar.

4. Conclusions

This paper proposes a fully integrated DS-LCC WPT system to improve misalignment performance. The EDD coils as compensation inductors are integrated in the unipolar main coils. The design of the EDD coil is optimized by using the FEM simulation tool, and the output power is calculated by the PSIM simulation tool. The results show that the misalignment performance is improved, and the reliability of the proposed idea is verified.

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참 고 문 헌

[1] Mohamed. A.A.S, Shaier. A.A, Metwally. H, Selem. S.I, "An Overview of Dynamic Inductive Charging for Electric Vehicles," Energies., 2022, 15, 5613.

[2] F. Lu, H. Zhang, H. Hofmann, W. Su, and C. C. Mi,, "A Dual-Coupled LCC-Compensated IPT System With a Compact Magnetic Coupler," IEEE Trans. Power Electron., vol. 33, no. 7, pp. 6391-6402, Jul. 2018.