Design Guidelines and Loss Analysis for Compensation Networks In Capacitive Power Transfer System

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Introduction

Wireless power transfer is moving from research to application, with potential uses in electric and autonomous underwater vehicles. Low-power applications, such as automatic guided vehicles and electric scooters, mainly use inductive power transfer in the kHz band, but challenges remain, including foreign matter tolerance and the cost of litz wires and cores. Capacitive power transfer (CPT) has been proposed as an alternative; although historically inefficient at kHz, recent GaN and SiC devices enable MHz operation with reduced losses and higher power.

For MHz CPT systems, inductors in the compensation network dominate losses and size. Core-type inductors are compact but suffer from core loss and saturation, while air-core inductors avoid these issues but radiate strongly and are bulky. Several compensation topologies, including multi-stage LC filters and voltage-limiting networks, have been investigated to address these trade-offs. However, a unified criterion for determining the optimal topology has not yet been established. This study focuses on this gap and proposes a comprehensive evaluation method for compensation networks. The proposed approach enables fair comparison of different topologies and supports the design of low-loss, compact CPT systems.

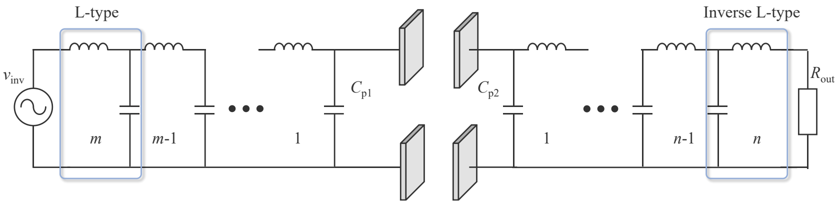

Figure 1 Circuit configuration of proposed capacitive power transfer

Relation Between Efficiency and Compensation Network

There is a relation between the efficiency of the compensation network and the distance on the Smith chart (Poincaré length), as given in (1). Here, η represents the compensation efficiency, Q is the quality factor of the component, and Λ is the hyperbolic length of the path on the Smith chart, which is defined in (2)[1].

$$-\log_e \eta = \frac{1}{\sqrt{1+Q^2}}\Lambda \qquad (1) \qquad \Lambda = \int_z \frac{1}{\mathrm{Re}(Z)}|dZ| \qquad (2)$$

Figure 1 shows the circuit configuration of the CPT system, where multiple stages of L-type compensation networks are implemented on both the transmitting and receiving sides[2]. Figure 2 illustrates the trajectory on the Smith chart when varying the number of L-type networks on the receiving side. Employing multiple stages of L-type networks improves efficiency by approximately 8 percentage points, assuming an inductor quality factor of 100. Figure 3 illustrates the relationship between the inductor quality factor and the efficiency characteristics of each topology. These results indicate that the improvement effect decreases as the number of stages increases. The most significant improvement is observed when using a 2-stage configuration.

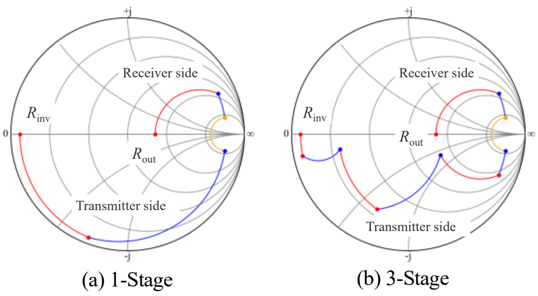

Figure 2 Impedance transformation trajectories of proposed compensation networks on the smith chart.

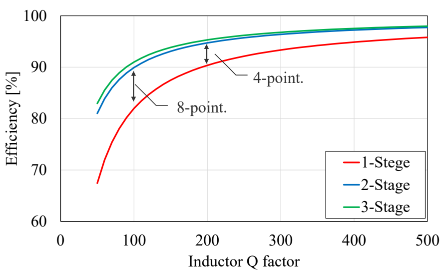

Figure 3 Inductor Q value and efficiency characteristics of each topology

References

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