Capacitive Power Transfer with Adjacent Parallel-plate Capacitors

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Abstract

A capacitive power transfer system is designed by placing two parallel-plate capacitors adjacently side to side or partially overlapped. The secondary capacitor is connected with a large capacitor in parallel to increase the capacitivity of the secondary circuit. The mutual inductions between the two capacitors are not equal. The consumed power on load is not equal to the feeding power from the primary circuit.

Description

In this work, a capacitive power transfer system is designed by placing two parallel-plate capacitors adjacently side to side or partially overlapped. As shown in Fig.1, the primary circuit is composed of source Vs, resistor R_1, inductor L_1, and the parallel-plate capacitor C_1. The parallel-plate capacitor C_1 is composed by two metal plates separated by a distance d_1. The secondary circuit is composed of the secondary parallel-plate capacitor C_2, variable capacitor Cv, inductor L_2, and load resistor R_2. The secondary parallel-plate capacitor is composed by two metal plates separated by a distance d_2. The capacitor C_2 is placed adjacently to C_1 side to side. The capacitivity between the edges of C_1 and C_2 is negligible. The electric field at the edge of C_1 supplies the electromotive force (emf) to the secondary circuit. The electric field at the edge of C_2 supplies the reaction emf to the primary circuit. The variable capacitor Cv is used to tune the resonant frequency and also increase the capacitivity of the secondary circuit. The sum of C_2 and Cv is designed much larger than C_1. The mutual induction from the primary current I_1 to the secondary circuit is

$$M_{21} = -j\frac{1}{wC_1} \cdot \rho_{21} \tag{1}$$

where ρ21 is the emf pickup efficiency to the secondary circuit. The mutual induction from the secondary circuit I2 to the primary circuit is

$$M_{12} = -j \frac{1}{w(C_2 + C_v)} \cdot \rho_{12} \tag{2}$$

where ρ12 is the emf pickup efficiency to the primary circuit. When C1 and C2 are setup adjacently side to side, the efficiencies ρ21 and ρ12 are approximately equal assuming d1and d2 are equal. The mutual induction M21 is much larger than M12 because $C_2 + C_v \gg C_1$.

The coupling equations are listed in following:

$$U_1 + W_{12} = I_1 \left(R_1 + jwL_1 - j \frac{1}{wC_1} \right) \tag{3}$$

$$I_2 = \frac{M_{21} I_1}{R_2 + jwL_2 - j \frac{1}{w(C_2 + C_v)}} \tag{4}$$

$$W_{12} = M_{12} I_2 \tag{5}$$

Where W12 is the reflect emf from the secondary circuit to the primary circuit. In the case of resonance, $L_1 C_1 = L_2 (C_2 + C_v)$, we get

$$I_1 = \frac{U_1 R_2}{R_1 R_2 + \frac{\rho_{12} \rho_{21}}{\omega^2 C_1 (C_2 + C_v)}} \tag{6}$$

The feeding power through the primary circuit is

$$P_1 = U_1 \cdot I_1 = \frac{U_1^2 R_2}{R_1 R_2 + \frac{\rho_{12} \rho_{21}}{\omega^2 C_1 (C_2 + C_v)}} \tag{7}$$

The consumed power on R2 is

$$P_2 = I_2^2 \cdot R_2 = \frac{\rho_{21}^2 U_1^2}{R_2 \omega^2 C_1^2 (R_1 + \frac{\rho_{12}\rho_{21}}{R_2 \omega^2 C_1 (C_2 + C_v)})^2} \tag{8}$$

The power transfer efficiency is

$$\frac{P_2}{P_1} = \frac{\rho_{21}^2 (C_2 + C_v)}{R_1 R_2 \omega^2 C_1^2 (C_2 + C_v) + \rho_{12}\rho_{21} C_1} \tag{9}$$

The capacitors C1 and C2 can also be setup partially overlapped at the edge.

As a comparison, Fig. 2 shows the schematic of conventional capacitive power transfer system which is widely used in industry designing. In this configuration, the metal plates of the secondary capacitor are connected to the primary capacitor face to face respectively. The secondary circuit is integrated into the primary circuit so that M21 is always equal to M12. In this scenario, the consumed power on R2 is equal to the feeding power from the primary circuit.

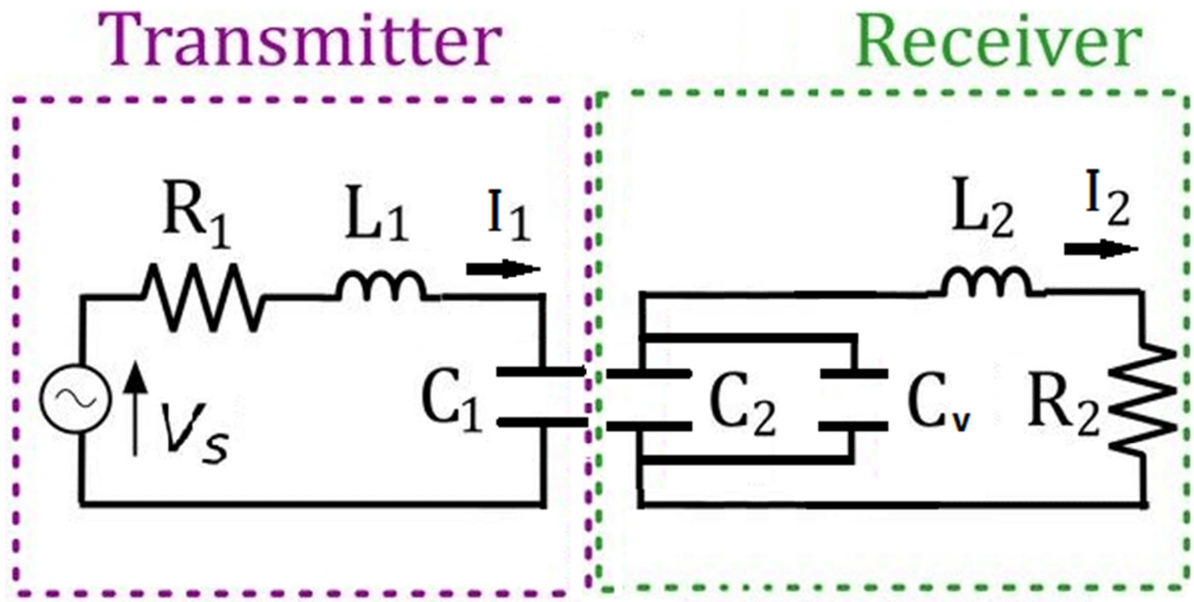

Figure 1: Schematic of invented capacitive power transfer system.

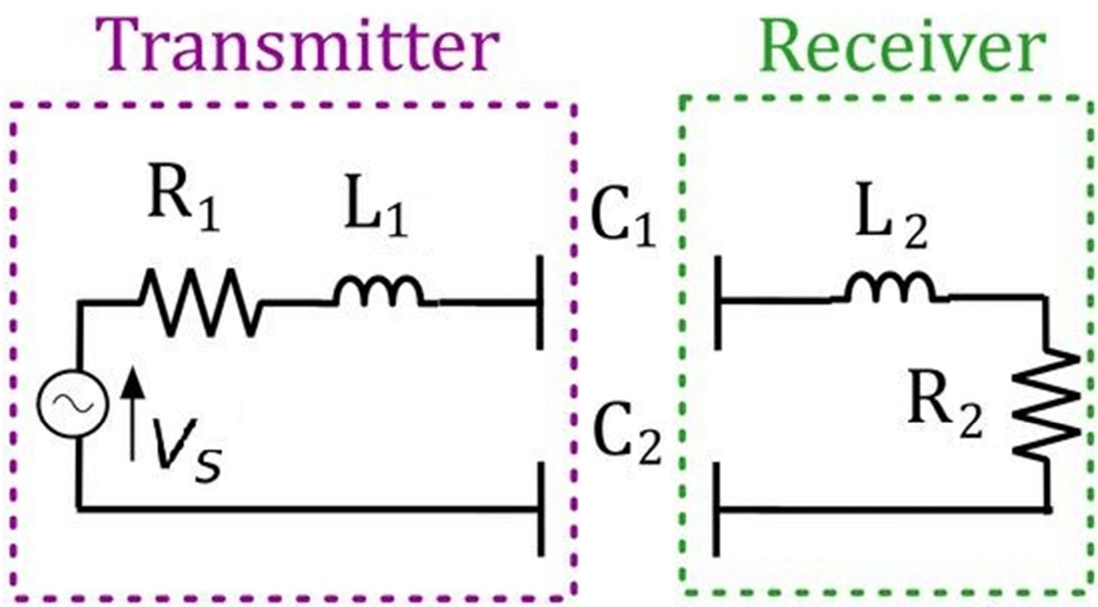

Figure 2: Schematic of conventional capacitive power transfer system.