

Energy Harvesting for Wireless Electric power Transmission Based on Analysing Inductive coupling

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Keywords: wireless electric power transmission, Inductive coupling, nonresonant induction.

Abstract. With parameter values chosen to obtain good calculate, the experimental results show that the load will receive the maximum voltage and maximum electric power at resonant frequent 22kHz when Tesla coils are 4mm away. The maximum electric power transfered by two Tesla coils of diameter 30mm with 13 loops per Tesla coil is at 1.4W when the distance separating the Tesla coils is 4mm. Under the resonance frequency, about 42% of the electric power is delivered to the load that is supplied by a sinusoidal AC source (electric power function generator).

Introduction

The ability to provide electric power for these and other electric devices wirelessly would greatly increase their portability and accessibility for the public. The past decade has witnessed a surge in the use of wireless electric power transmission. As a consequence, profit in transmission via Inductive coupling has reemerged. Radiative Transmission, although perfectly suitable for transfer information, poses a number of difficulties for electric power Transmission applications: The efficiency of electric power Transmission is still low^[1].

Inductive coupling is an old and well-understood method of wireless electric power Transmission. The source drives a primary Tesla coil, creating a sinusoidally varying magnetic field, which induces a voltage across the terminals of a secondary Tesla coil, and thus Transmission electric power to a load^[2, 3, 4].

Research has been done which indicated that electric power Transmission can be achieved efficiently using two or more resonant objects of the same resonance frequency. As shown in figure 1, a schematic electric circuit of electromagnetic induction which consist of a source Tesla coil pair and a single receiving Tesla coil pair. Single receiving Tesla coil pair consists of L_2 , L_1 . Below is an analysis of how magnetic induction generates electric power.

Resonance Frequency

The energy is transferred in form of electromagnetic wave, where^[4,5,6]:

$$H = \frac{B}{m_0} = xI, \text{ where } x = \frac{r^2}{2(r^2 + D^2)} \quad (1)$$

$$U = \frac{EB}{m_0} = cm_0H^2, \text{ where } E = cB \quad (2)$$

H —Magnetic field intensity; B —Magnetic flux; U —Energy; E —Electric field; r : radius of the loop; D —distance between the Tesla coils; k —coupling ratio. The magnetic field from a loop is given by

$$H = K \cdot I \left(\frac{r^2}{2(r^2 + D^2)} \right)^{3/2} \cdot e^{-\gamma D} \quad (3)$$

$$I(z) = 2r \cdot H(z) \quad (4)$$

and γ is the loss in the medium, where:

$$\gamma = \sqrt{-1.1126 \times 10^{-17} w^2 + 3.33 \times 10^{-9} jw} \quad (5)$$

The new and effective technique for increasing the energy received by the Tesla coil is to add a parallel or serial capacitor to the secondary side to form a resonant electric circuit under the different frequency^[7, 8]. Figure 2 show a schematic electric circuit drawing of Inductive coupling. An inductive electric power Transmission model is built to show correlation theory. An AC source drives a primary Tesla coil pair and a secondary receiving Tesla coil pair is close to primary Tesla coil. The secondary receiving Tesla coil pair consists of L_2 , R_2 , C_2 , R_L . In the system of figure 2, the AC source drives multiturn Tesla coil L_1 that is inductively coupled to another multiturn Tesla coil L_2 of the same diameter. The resistances R_1 and R_2 are the resistances of the Tesla coils, while R_s is the internal resistance of the source, and R_L is the load resistance. The R_L in Figure 2 and other figure are linear elements, used to demonstrate wireless electric power Transmission's effect. This electric circuit representation described here and in subsequent sections use a bulb as resistive load^[9].

Schematic Electric Circuit Drawing of Inductive Coupling

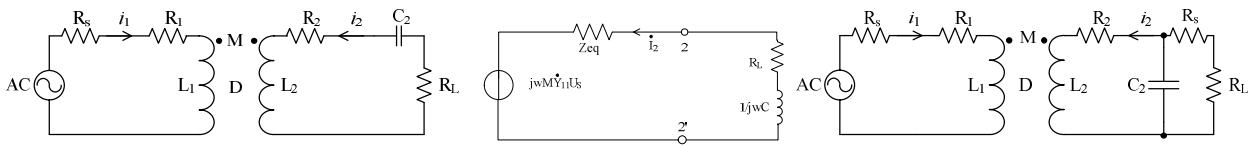


Figure 1. A schematic electric circuit drawing of Inductive coupling

Figure 2. Equivalent electric circuit (primary side convert to secondary side)

Figure 3. A schematic electric circuit of a source Tesla coil pair and a receiving one.

Under the above conditions, parallel resonant can occur, at last reach wireless electric power transmission based on resonance. Figure 2 shows electric circuit model, after an electrical inductance L_2 and a capacitance C_2 are resonant, the resonant between L_2 C_2 and source will occur. The resonant frequency is given by:

$$f_0 = 1 / 2\pi \sqrt{LC} \quad (6)$$

The impedance of this electric circuit is:

$$Z = R_L + j(\omega L - 1 / \omega C) \quad (7)$$

At resonant frequency, $\omega L = 1 / \omega C$, $\omega^2 = 1 / LC$, $f_s = 1 / 2\pi (LC)^{1/2}$. This formula is used to solve frequency matching problem. As a result, the electric power consumed in the parasitic impedances is very little and can be negligible. In this electric circuit, a serial electric circuit is designed and parallel electric circuit will be studied in the later. To find the value of the capacitor, let $L_1 = 30.9 \mu H$. The Figure 1 can be modeled at $f = 1 \text{ kHz} \sim 30 \text{ kHz}$. The figure above gives $L_2 = 31.2 \mu H$. L_1 and L_2 are the values of primary Tesla coil and secondary Tesla coil. The two Tesla coils are made of electrically conducting wire and they are approximately same. The distance between L_1 and L_2 is labeled D ^[10].

In the system of figure 3, the following linear equations are obtained^[3, 6].

$$X_L = X_C \quad (8) \quad r = \omega_0 L = \frac{1}{\omega_0 C} = \sqrt{\frac{L}{C}} \quad (9)$$

$$Q = \frac{r}{Z_0} = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 C R} = \frac{\sqrt{L/C}}{R} \quad (10) \quad U_L = I_0 X_L = U_C = I_0 X_C \gg U = I_0 R \quad (11)$$

$$|Z| = |R + j(X_L - X_C)| = \sqrt{R^2 + (X_L - X_C)^2} \quad (12) \quad Z = R + j(\omega L - \frac{1}{\omega C}) \quad (13)$$

$$k = \frac{M}{\sqrt{L_1 L_2}} \quad (14) \quad k^{\text{def}} = \frac{M}{\sqrt{L_1 L_2}} \leq 1 \quad (15)$$

$$L_{eq} = \frac{(L_1 L_2 - M^2)}{L_1 + L_2 + 2M} \geq 0 \quad (16) \quad Z_{eq} = R_2 + j\omega L_2 + (\omega M)^2 Y_{11} \quad (17)$$

$$R_r = 20(2\pi / \lambda)^4 (pa^2 n)^2 \quad (18)$$

Where, R_r —radiation resistance; n —Tesla coil turn; R —radius of Tesla coil (m); λ —wave length, $\lambda = c/f$, $c = 3.00 \times 10^8$; a —radius of conductor section (m).

Tesla coil 2, then has the largest radiation resistance, which is far small in comparison with the resistance R_L . So R_r is to be neglected. It is easy to show that the key to efficient of energy Transmission is $Z_{eq} = jX_c$.

Paper [1] and [9] present a coupled electric circuit mode which works depend on two resonant Tesla coils mainly. A LC resonant electric circuit under the resonant frequency is designed by the method of Inductive coupling. The value of L_1 and L_2 can be measured by a digital electric bridge. The key challenge for such system is how to achieve maximum electric power of receiver terminal once frequency varies. As shown in figure 3, it is the curves that matlab code written to calculate and plot the picture of receiving voltage vs. frequency and voltage vs. distance describe voltage vs. frequency distance.

The resonance frequency of LC electric circuit is f_s . In theory, when f is close to or equals to f_s , the oscillation of source resonance electric circuit is strongest, the value of resonance current is highest, and the magnetic field intensity H is also strongest. Inductor L and capacitor C is designed a receiving terminal resonance electric circuit to produce resonance depending on the magnetic field which generated by source terminal resonance electric circuit. The resonance frequency of receiving terminal electric circuit is f_s , the parameters of L and C need not be in full accord with the source resonance electric circuit. What the receiving terminal resonance electric circuit must need is to ensure $f_t = f_s$. That is the necessary condition for energy Transmission.

In the work described here, there are two conclusions: This experiment demonstrates wireless electric power transmission with a LC resonant electric circuit; This experiment result shows that the resonant frequency is 18 kHz with $C=100\mu F$ at distance $D=3mm$; another resonant frequency is 22 kHz with $C=470\mu F$ at distance $D=4mm$. When the system works at the resonant frequency, R_L will receive the maximum electric power and $P_1 = U^2_{max}/R_L = 3.1^2/6.9 = 1.4W$, $\eta = P_1/P_2 = 1.4W/3.3W = 42\%$.

This electric circuit provides a simple method to achieve resonant coupling between source Tesla coil and receiving Tesla coil.

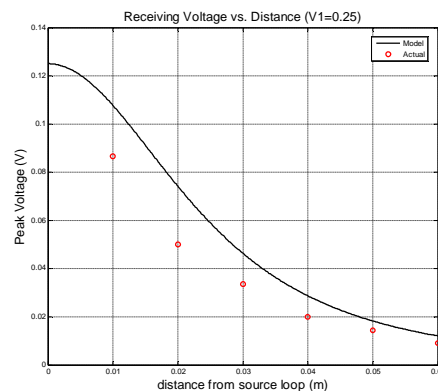


Figure 4. Receiving Voltage(v) vs. Distance(m)

For the experimental setup with a load, the receiving terminal maximum voltage across a resistive bulb placed in the receiving terminal is 3.1V, corresponding to wireless electric power Transmission delivered electric power of 1.4W. When the receiver is displaced 10mm away from the axis of the transmitting Tesla coil, the voltage drops from 3.1V to 0.44V. In this electric circuit model, electric power disappears by means of electric power dissipation in the resistances. For these parameter values showed in the Figure4, much of the electric power leaves in the terminal of the source (electric power dissipation in the resistance R_s). 42% of the electric power is delivered to the load resistance R_L .

Efficiency of Electric Power Transmission

The source, operating at frequency of 22kHz, is connected directly across the terminals of the left Tesla coil with diameters of 30mm, spaced 3mm apart. The right Tesla coil is inductively coupled to the left Tesla coil, and is terminated by a capacitor. In the center of the desk is a electric power

function generator which connected a Tesla coil inductively coupled to another Tesla coil that is connected to a serial capacitor, with the same parameter that is connected to a bulb.

That a small rectification electric circuit connected to LC oscillating electric circuit does deserve to be mentioned. The charging current is about 380mA. The mobile charger can work well, whose maximum charging voltage is about 4V.

Summary

In conclusion, the transferred electric power in the experiment is lower than the total electric power. This is caused by resistance in the Tesla coil and capacitor, because that electrical inductance and capacitor may be a complex electric circuit under high frequency. The maximum electric power transferred by two inductors is at 1.4W if the distance separating the inductors is 4mm. The inductors is diameter 30mm with 13loops per inductor. Based on the experimental result and analysis, it is proved that energy Transmission is completely feasible using this method of magnetic coupling resonance. Nevertheless, there are still a lot of research and experimental work to do to prove the transmission efficiency and Transmission distance. about 42% of the electric power is delivered to the load that is supplied by a sinusoidal AC source

Acknowledgements

This work was financially supported by fund project of Civil Aviation Flight University of China (Q2018-170) and (J2015-63). Helicopter multi mission flight training device development, civil aviation innovation and guidance fund projects major projects (MHRD20130108).

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