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Wireless Power Transmission using LC Cancellation

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Abstract

Wireless power transmission technology enables flexible comfortable supplying energy needs to electric devices. However, the wireless power transmission technologies that use the magnetic field resonance method have various problems. Much of the research is often focused on the efficiency between resonators. The relationship between the internal resistance and efficiency is not clear. The efficiency at high output power is not well understood. Practically adding an internal resistance as an equivalent of both of rectifier and inverter losses is important for efficiency calculation. Even if the wireless power transmission has high efficiency it is not suitable for practical use if the output power rating is very small. We can increase transmission power in accordance to the principles of the LC cancellation by using the resonance phenomenon even at a small coupling coefficient.

Keyword- Wireless Power Supplies, LC Cancellation, Magnetic Resonance, Total Efficiency

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I. INTRODUCTION

Nowadays, with the current increase demand for electrical energy due to the rapid population growth and industrialization, wireless power transfer (WPT) is receiving more and more attention. WPT is a transmission technology that consists of transferring electric power over distances without the need for a wired connection. This technology has been proven to be very useful in situations where interconnecting wires or cable become inadequate or hazardous when power transfer is required.

The first interest in WPT dates back to the early 20th century when Nikola Tesla devoted much effort toward schemes to transport power wirelessly. Until very recently, this technology consisted of using magnetic inductive coupling, wherein two conductive coils have inductive action upon each other. While purely inductive coupling has several applications such as biomedical devices, automotive systems, industrial manufacturing and in some consumer electronics, it is only suitable for very short range since it requires high coupling coefficient between the coils which becomes difficult with long distance power transmission. Indeed, coupling coefficient of the coil becomes smaller with longer transmission distance which causes the efficiency of power transfer to drop by orders of magnitude when the distance between the coils becomes larger than their sizes. It was therefore proposed that, by using the reactive fields present near open resonators, electrical power can be transmitted to significantly larger distances. The idea is to use two resonant objects coupled by the same resonant frequency to exchange energy efficiently, while dissipating relatively little energy in extraneous off resonant objects. This is commonly known as resonant WPT. Electromagnetic induction system requires high coupling coefficient that is difficult with long distance power transmission. But this method is highly efficient for power transmission between 1 to 2m distances. Coupling coefficient of the coil becomes smaller with longer transmission distance. However the use of the suitable capacitor generates a resonance phenomenon. In this study the drawbacks of the electromagnetic induction system are studied in details. The transmission power capability has been increased using LC cancellation principle with the resonance phenomenon even if the coupling coefficient is small. The characteristics of efficiency are theoretically and experimentally studied. Then the results are compared.

II. DRAWBACKS OF ELECTROMAGNETIC INDUCTION

Electromagnetic induction is a process where a conductor placed in a changing magnetic field causes the production of a voltage across the conductor. This process of electromagnetic induction in turn causes an electrical current. It is said to induce the current. The process of electromagnetic induction works in reverse as well so that a moving electrical charge generates a magnetic field. A traditional magnet is the result of the individual motion of the electrons within the individual atoms of the magnet aligned so that the generated magnetic field is in a uniform direction.

Fig 1 shows the equivalent circuit diagram of an electromagnetic induction method. The electromagnetic induction system uses the electromotive force generated by the change in the magnetic flux that passes through the coil. As interlinkage flux increases if the two coils are very close, coupling coefficient increase. However the interlinkage flux decreases when the distance between the coils increases hence leakage inductance increases and coupling coefficient decreases. By using this method we cannot transmit power for long distance without using wires because coupling coefficient of the coil becomes smaller with longer transmission distance.

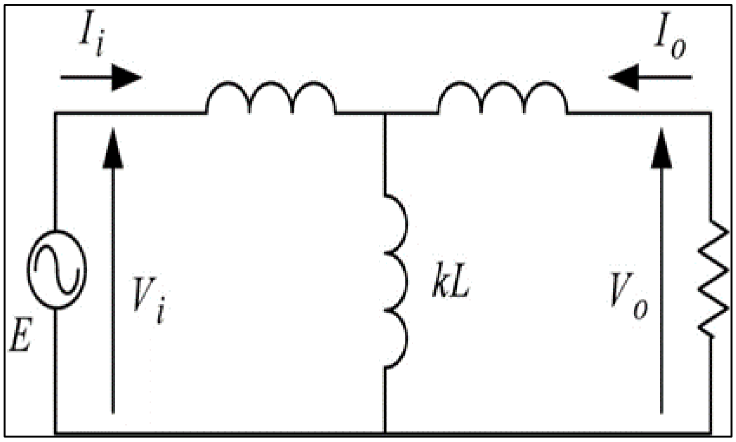

Fig. 1: Equivalent circuit diagram of an electromagnetic induction method

$$P = \frac{Rk^2V^2}{(1-k^2)^2\omega^2L^2 + R^2}$$

$$P_{\max} = \frac{k^2V^2}{2(1-k^2)\omega L}$$

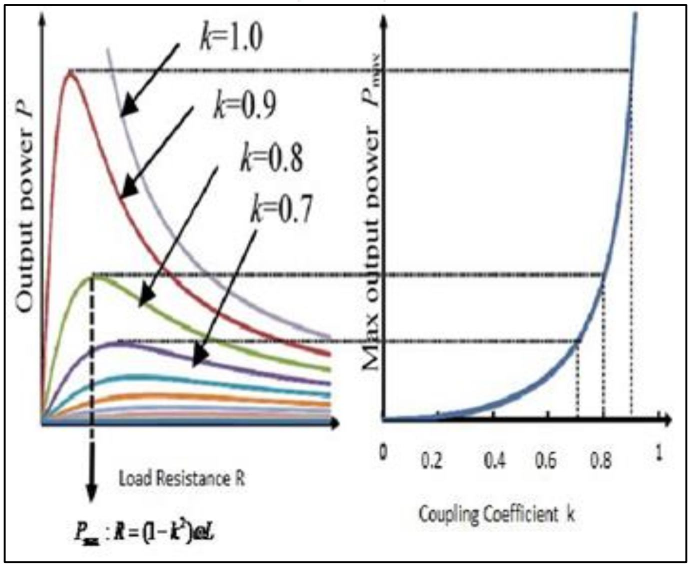

Fig. 2: Output power characteristics

Fig 2 shows the output power characteristics. If the coupling coefficient is small the output power is significantly reduced. Therefore, the electromagnetic induction method can transmit enough power only at small distance range. As presented in graph of the coupling coefficient of Fig 2 maximum output power is apparently reduced if coupling coefficient is small. This is the drawbacks of electromagnetic induction method. Thus if we need to transmit enough power even if coupling coefficient is small, it is necessary to apply a technique to compensate the leakage inductance so we are using LC cancellation principle with resonance phenomenon.

III. PRINCIPLE OF LC CANCELLATION

When the inductance and capacitance are connected in series as shown in fig 3, at series resonance, the voltage difference across the LC series circuit is considered zero as shown in Fig 4. However, an internal resistance exists in each component; which causes power loss. The generated voltages in both of L and C should not increase higher than their break down voltages.

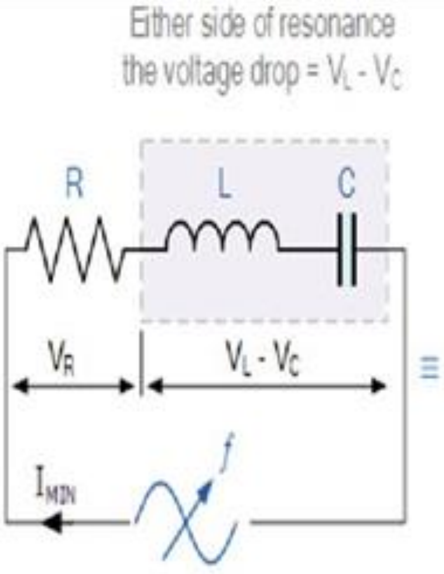

Fig. 3: LC Series connection without Resonance

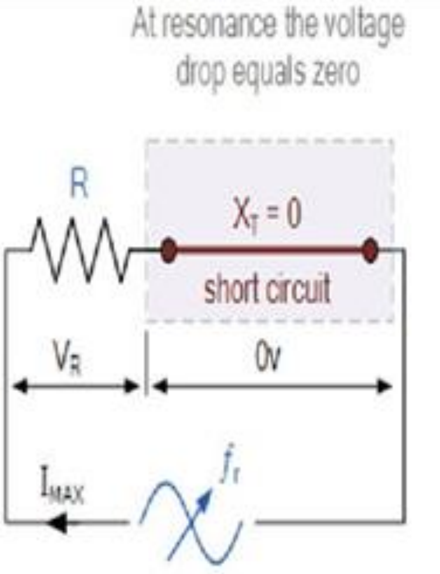

Fig. 4: LC Series with resonance

IV. ANALYSIS OF MAGNETIC COUPLING RESONANT METHOD

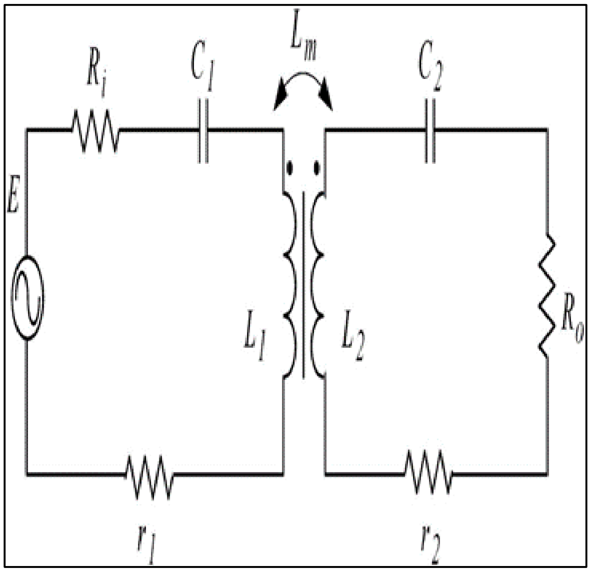

Fig. 5: Equivalent circuit of the resonant magnetic coupling system

A. *Equivalent Circuit of the Resonant Magnetic Coupling System*

Fig 5 shows the equivalent circuit of the resonant magnetic coupling system. R_I is the equivalent resistance of the total losses due to the rectifier and inverter. Here the input power is defined P and the output
Power is defined P_O .
The efficiency of this circuit is;

$$\eta = \frac{Outputpowe \quad r}{Inputpower} \times 100$$

$$\eta = \frac{V_o I_o}{V_I I_I} \times 100$$

$$\therefore \eta = \frac{P_o}{P_I} \times 100 \ [\%]$$

B. *Equivalent Circuit Analysis*

Mutual inductance,

V.

$$L_m = k\sqrt{L_1 L_2} = kL$$

$$L_1 = L_2 = L$$

$$C_1 = C_2 = C$$

$$r_1 = r_2 = r$$

$$f_r = \frac{1}{2\pi\sqrt{(1-k)LC}}$$

f_r is the resonance frequency. The frequency of the power source f has the same value of the resonance frequency of the resonator. k is the coupling coefficient between inductances.

Characteristic impedance, $Z_C = \sqrt{\frac{L}{C}}$

C. Relationship between Internal Resistance Output Power, Input Power and Efficiency

Fig 6 shows the output power characteristics due to the change in the internal resistance to kZc, Input supply voltage is 100V, the frequency of input supply voltage is always kept to match the resonant frequency, the load resistance is 10Ω the coupling coefficient is 0. 01, and the conductor resistance is 0Ω. The internal resistance is set to 0.1Ω , 1Ω, and 10Ω. From Fig 6, the output power decreases when the internal resistance increases. In addition, it can be continues to increase the value of kZc'.

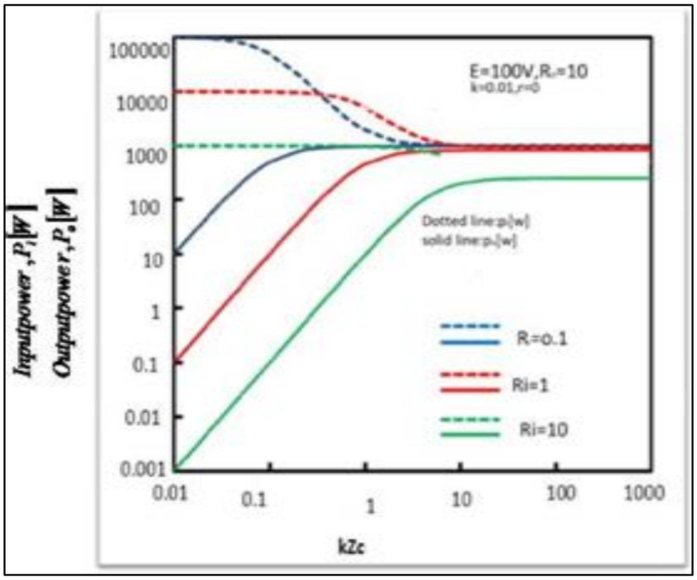

Fig. 6: Output power characteristics

V. EXPERIMENTAL SETUP

A. Experimental Circuit

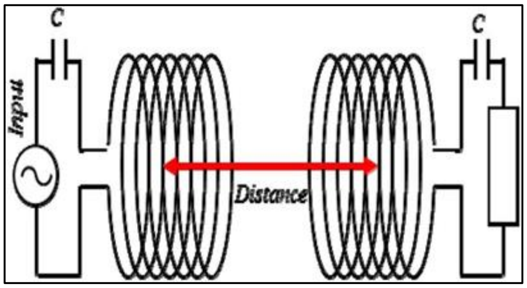

Fig. 7: schematic diagram of the experimental setup

Fig 7.shows the circuit diagram of experimental setup for electromagnetic resonance method. A helical coil is used as an inductance of the resonator. Experiment is performed under the condition that the resonance capacitor is connected in series with the helical coil, and the frequency of power supply matches the resonant frequency of the resonator.

B. Coupling Coefficient and the Transmission Distance

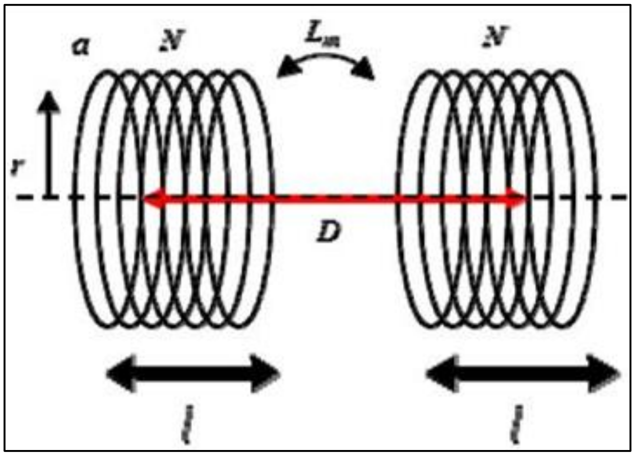

Fig. 8: helical coil

It is necessary to understand the relationship between the coupling coefficient and the transmission distance. The mutual inductance for the helical coil placed as shown in Fig 8.

$$L_m = \frac{\mu_0 \pi N_1 N_2 (r_1 r_2)^2}{2(r_1^2 + D^2)^{\frac{3}{2}}}$$

Therefore the coupling coefficient k can be expressed in terms of the transmission distance D as follows;

$$k = \frac{\mu_o \pi N^2 r^4}{2(r^2 + D^2)^{\frac{3}{2}} L}$$

VI. EXPERIMENTAL RESULT

Power transmission experiment at k=0.2

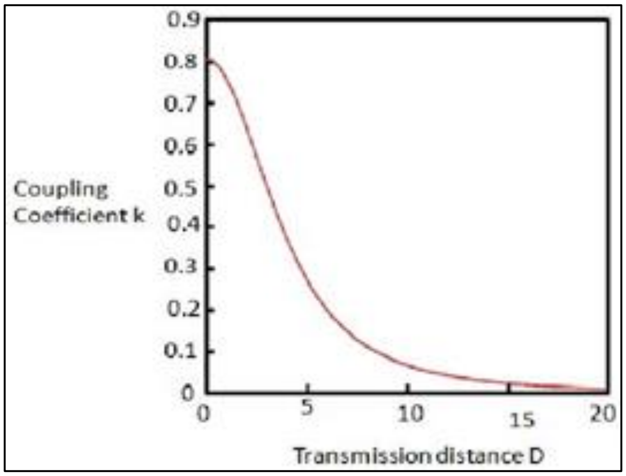

Fig. 9: Relationship between the coupling

Coefficient and the transmission distance

Fig 9 shows the relationship between the coupling coefficient k and the transmission distance D, (at k= 0.2, D = 6cm). Experiment requires that the driving frequency matches the resonant frequency. For realizing the resonant frequency, two identical helical coils should be used with inserting resonant capacitors in series. Measurement is performed by matching the driving frequency to the resonant frequency. Internal resistance Ri = I n is connected in series to the power supply. Furthermore, conductor resistance will vary depending on the driving frequency. Therefore a resistance r = 0.8n is adopted at 100 kHz. This result is measured by an impedance analyser. It is clear that the experimental results are in agreement with the theoretical results. A small error exists due to that the conductor resistance value changes by the effect of the changes in the driving frequency.

VII. ADVANTAGES

1) Reliable
2) Efficient
3) Fast
4) Low maintenance cost
5) It is used for short – range or long-range

VIII. DISADVANTAGES

1) High initial cost
2) High frequency signal must be supply
3) Electromagnetic waves in excess can cause cancer

IX. CONCLUSION

In this paper, wireless power transmission technology using electromagnetic resonance method, considering circuit losses, is discussed in terms of efficiency and output power. The equivalent circuit of the electromagnetic is analyzed. Input power, output power, and efficiency characteristic are analysed in terms of coupling coefficient and characteristic impedance. The input power, output power and efficiency are constant in range of large characteristic impedance. As a result, the trends of the measured and theoretical results are in good agreement with each other. Moreover, the presence of internal and conductor resistances affects the overall efficiency. Currently, the achieved relation in this paper is used to develop a design strategy for electromagnetic resonance based wireless power transmission systems.

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