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The Study on the Wireless Power Transfer System for Mobile Robots

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Abstract**—**A wireless power transfer system can attribute to the fields in robot, aviation and space in which lightening the weight of device and improving the movement play an important role. A wireless power transfer system was investigated to overcome the inconvenience of using power cable. Especially a wireless power transfer technology is important element for mobile robots. We proposed the wireless power transfer system of the half-bridge resonant converter with the frequency tracking and optimized power transfer control unit. And the possibility of the application and development system was verified through the experiment with LED loads.

Abstract**—**Wireless Power Transmission (WPT), resonance frequency, protection circuit. LED.

I. Introduction

A wireless power transfer system is the new concept for power transmission. It is the method of transmitting the energy which is converted to microwave in favor of wireless power transmission [1] [2] [3]. That electrical energy is transmitted rather than the signal of the radio in that system. Nowadays, the interest in the power transmission using the wireless power transfer system has sharply risen due to the improvement of the mobile devices the last few years. That's why the research of the wireless power transfer system is required [4] [5] [6] [7].

A wireless power transfer system is very essential for the charging system of mobile robot due to increasing usage of the robot. This system can supply stable power without another charging stations. In addition, that system doesn't need to change the batteries.

In this paper, the system is designed to charge 30W robot. This system is operated in the resonant frequency area in order to maximize the efficiency of the wireless power transfer system. The circuit is designed to minimize the loss of the power due to operating as well as tracking the frequency using typical IC.

II. Wireless power transfer system

Fig. 1 shows the proposed wireless power transfer system.

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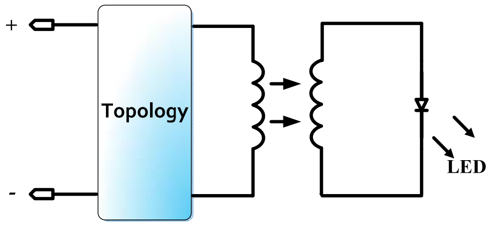

Fig. 1 Typical wireless power transfer system

Basic devices for wireless power transfer system consist of transmitter and receiver. The transmitter consists of dc-dc converter and transmitting coil. The receiver consists of receiving coil, rectifier circuit and load. The transmitter and the receiver are optimized when designing, and the entire system considering characteristics of each device is designed [8] [9] [10] .

In this paper, a half-bridge resonant converter is designed for the transmitter.

III. Half-bridge resonant converter

Fig. 2 shows the half-bridge resonant converter and rectifier circuits. An operating sine-wave considers the power, and B which is part of rectifier considers load. In this paper, this circuit is minimized to obtain the equivalent circuit of the half-bridge resonant converter.

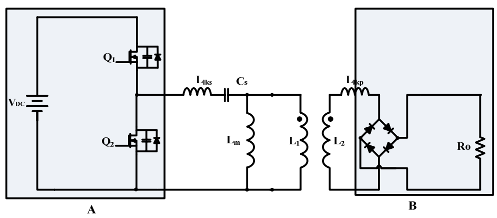

Fig. 2 Half-bridge resonant converter and rectifier circuits

I_{ac} is the current of the equivalent power in above figure 2. I_o can express the average equation of I_{ac} like next equation (1).

$$I_{ac} = \frac{\pi I_o}{2}\sin(\omega t) \quad (1)$$

V_i shows the next equation (2). V_o is the output voltage.

$$V_i = \frac{4V_o}{\pi}\sin(\omega t) \quad (2)$$

The equivalent equation of Rectifier B shows the next equation (3). R_o is the resistance value of LED.

$$R_{load} = \frac{8V_o}{n^2\pi^2 I_o} = \frac{8}{n^2\pi^2}R_o \quad (3)$$

Fig. 3 shows the Half-bridge equivalent circuit. V_i is just sine-wave which is made through two MOSFET because it is delivered through the resonant circuit. The total circuit which is part of output rectifier replaces the equivalent resistance. The L_{lkp} is the leakage inductance of the first and second coil.

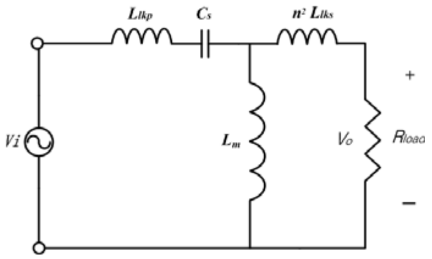

Fig. 3 Half-bridge equivalent circuit

The next equation (4) shows the voltage gain through the above figure 3.

$$M=\frac{\frac{4V_o\sin(\omega t)}{n\pi}}{\frac{4}{\pi}\frac{V_i}{2}\sin(\omega t)}=\frac{2V_o}{nV_i}$$

$$=\frac{\omega^2 L_m C_r R_{load}}{j\omega\cdot\left(1-\frac{\omega^2}{\omega_o^2}\right)\cdot(L_m+n^2L_{lks})+R_{load}\left(1-\frac{\omega^2}{\omega_p^2}\right)} \quad (4)$$

$$\omega_0=\frac{1}{\sqrt{L_rC_r}} \qquad \omega_p=\frac{1}{\sqrt{L_pC_r}}$$

$$L_p=L_m+L_{lkp} \qquad L_r=L_{lkp}+L_m//(n^2L_{lks}) \quad (5)$$

This circuit has the two resonant frequency as the above equation (5). ω_o is decided through the L_r and C_r. ω_p is decided through L_p and C_r.

If $L_{lkp}=n^2L_{lks}$, the above equation (4), (5) are expressed as the next equation (6), (7).

$$M=\frac{2V_o}{nV_i}=\frac{\left(\frac{\omega^2}{\omega_p^2}\right)\frac{k}{k+1}}{j\frac{\omega}{\omega_0})\cdot\left(1-\frac{\omega^2}{\omega_p^2}\right)Q\frac{(k+1)^2}{2k+1}+\left(1-\frac{\omega^2}{\omega_p^2}\right)} \quad (6)$$

$$k=\frac{L_m}{L_{lkp}} \qquad Q=\frac{\sqrt{L_r/C_r}}{R_{load}} \quad (7)$$

The leakage inductance (L_{lks}) effects the voltage gain (M) through the above equations. In addition, if law value of Q is selected, the equivalent leakage inductance (L_r) is decreased and then magnetizing inductance (L_m) is also decreased. Lower L_m makes the high current which makes low efficiency. Therefore, higher Q in rated load makes higher L_r and L_m but the value of resonant capacitor (C_s) is decreased. If value of Cs is too high, voltage stress and rating is decreased but resonant tank impedance is too law. It affects the circuit characteristics about the switching frequency control. That's why optimal C_s is very important to get the stable gain.

IV. Proposed Circuit

Fig. 4 shows the proposed wireless power transfer system.

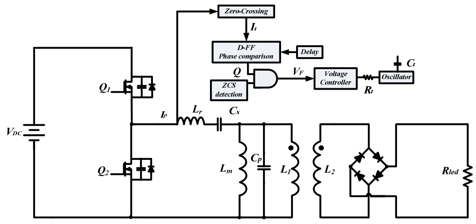

Fig. 4 Proposed wireless power transfer system

That is half-bridge LLC series resonant converter. Half-bridge circuit is used that L_m doesn't effected resonant frequency.

That circuit has two resonant frequencies. The next equations show the equations of two resonant frequencies.

$$F_{r1}=\frac{1}{2\pi\sqrt{L_rC_s}} \quad (8)$$

$$F_{r2}=\frac{1}{2\pi\sqrt{L_rC_s}} \quad (9)$$

The resonant tank designed correctly operates in ZVS area despite the V_i and variable R_{lamp}. In this circuit, the 50% duty ratio is made through VF-1020A 20Mhz DDS Function Generator, and the frequency is made of R_t and C_t. Accordingly, the variable frequency control is possible through I_{rt} control flowing R_t. I_{rt} can express the V_{osc} and V_{rt}.

$$I_{Rt}=\frac{(V_{osc}-V_{Rt})}{R_t} \quad (10)$$

If R_t is high, operating frequency is decreased. In the opposite circumstance, operating frequency is increased. The value of R_t control is not easy so the value of I_{rt} will be controlled by changing the value of the V_{rt}. The detection circuit for ZCS detects the failure of operating ZCS. If ZCS is not happened, D-flip flop (Q) output signal will be changed to high and the detection circuit for ZCS will be failed. At that time, ZCS can be operated through decreasing V_{rt} and increasing operating frequency.

A wireless power transfer system was designed and operating of the system was confirmed. The next figure 5, 6 shows the waveforms which are before and after applying circuit designed.

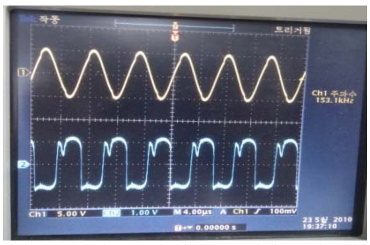
Fig. 5. (a) The waveforms before applying circuit designed

(b) The waveforms after applying circuit designed

The output waves are the waveforms applying 10 LED. The waves before applying circuit designed are a little bent and lower value than ideal value. This situation causes significant efficiency degradation. The waves after applying circuit designed are stable waveforms. A energy of the primary side transfers to secondary side with the law loss because of the clean waveforms.

V. Conclusion

In this paper, frequency tracking compensation circuit is designed for frequency compensation which improves the efficiency according to decreasing resonant frequency, and the size of the passive components become smaller by using high frequency. The smoothing capacitor having small capacity is used through high speed switching. 3.7W, 67% efficiency was gotten by operating ZVS. This research showed the higher efficiency than existing efficiency. However, the distance limit between coils and low output are still problems so many researches are needed to apply to the actual fields.

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