AN EFFICIENT CLASS-D DC-DC CONVERTER FOR WIRELESS POWER TRANSFER TECHNOLOGY

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Abstract
The research progress in the field of Wireless Power Transmission (WPT) using Magnetic Resonance coupling with DC-DC converter. The transfer of energy from a source to a receiver has traditionally necessitated the use of a physical connection, but wireless power transfer (WPT) is essentially the transmission of an electrical current from a power source to a receiving device without the need for a physical connection. Wireless power transfer is based on the principle of magnetic resonance. The process whereby electricity is transfer between two objects through coils. The important feature of WPT is high efficiency at large transmission distance. To make the technique of WPT feasible for industrial and commercial applications. WPT is an extremely useful technology that has numerous applications and benefits such as cell phones, laptops and other mobile devices could function without ever having to be plugged in. The simulation results are carried out using MATLAB Simulink environment.
Keywords: Wireless power transfer (WPT), magnetic resonant coupling, class-D converter.

INTRODUCTION

Wireless power transfer (WPT) can mitigate complicated charging operations by eliminating the use of wiring. Wireless power transfer using the non-radiative energy generated by two strongly coupled objects[1]. This method is based on the fact that two objects which have the same resonant frequency can exchange energy efficiently in the medium-range distances. It was reported in [2] that 60W power was transferred over a 1 and 2 meters distances with 40% and 90% efficiencies, respectively. This highly-efficient method can be used in many applications to power devices ranging from small devices rated at a few watts up to high power applications such as charging the batteries of Electric Vehicles, cell phones and Laptop without the need to connect wires. However, in general, the rated power of these applications was a few milliWatts and the distance between two coils was a few centimeters [3][4].

In 2009, Waffenschmidt and Staring [5] discussed about the limitations of the inductive power link system in consumer electronics. They derived optimal system parameters for efficient power transfer and investigated the effects of distance and size of coil on power transfer efficiency. However, their analysis only used a resonant circuit on the receiver coil, not on the transmitter, and as a result, they concluded that inductive power transfer is only effective over short distances. In 2007 discussed about inductor modeling in wireless links for implantable devices design [6].

To overcome these problems various improvements have been suggested in literature. Design and optimization methodologies for increasing the efficiency or the maximum transferable power of a WPT link have been proposed in [7]–
[10], assuming that the system parameters are freely selectable. However, these optimization strategies are not applicable to commercial charging applications, where the system parameters are defined by a standard.

This paper studies the wireless power transfer system via magnetic resonance coupling at a fixed resonance frequency (80 KHz). A system to improve the efficiency of the power transfer based on impedance matching (IM) is proposed.

However, for applications that require a constant DC voltage, this high frequency voltage must be converted into a DC voltage by means of a rectifier.

In this paper, the method for controlling DC-DC converter for WPT via magnetic resonant coupling is proposed. In this paper, a model for a 2 to 3m air-gap, 200W, high efficiency wireless power transfer system is introduced. Based on electric and magnetic field analysis, the two coils of the system are modeled as two inductors having low coupling coefficients. With the equivalent circuit model, the efficiency of wireless power transfer system using two tuned LC resonant tanks is analyzed.

The main objective of this paper is to design a wireless power transfer for large distance, minimum loss , maximum efficiency, implement class D DC-DC converter and also achieve ZVS condition in main switches to reduce switching losses.

The paper is structured as follows. The basic operating principle of the proposed method is explained in section II. Section III given the mathematical models of different parameters. The simulation results respectively to verify the basic operating principle and the mathematical models are given in section IV. Final work is concluded in section V.

A. Electromagnetic Resonance Coupling

A WPT system is divided into two parts: the transmitter side and the receiver side. The transmitter consists of a function generator which generates a high frequency AC voltage. This voltage is fed into a transmitting coil [11]. The receiving coil has a similar structure as the transmitting one. Figure. 1 shows the block diagram of the wireless power transfer system. The impedance matching system is used to match the load impedance to the characteristic impedance so that the reflected power is reduced. Unlike electromagnetic induction method which utilizes frequencies in the 80KHz range and can be used in the range of 2 to 3 meters, in the resonance enhanced electromagnetic coupling, although the coupling coefficient k(l) between the coil is drops drastically with the increase of distance between the coil, but the quality factor Q of each coil is increased by the resonance between the inductance and distributed capacitance of the windings which allows high efficient energy transfer with less interaction with nearby, off-resonant objects[12].

$$k=\frac{L_m}{L_1 L_2}$$

Where, Lm: magnetizing (mutual) inductance
L_1,L_2: inductances of transmitter and receiver coils.

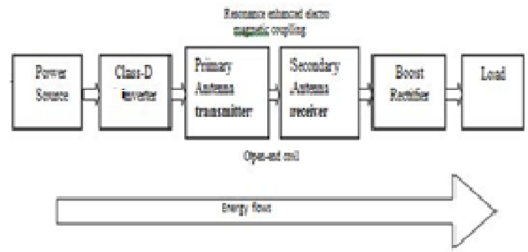

Figure 1. Block diagram of the WPT system

II. THE PROPOSED METHOD

A. Circuit Construction

The basics of wireless power involve the transmission of energy from a transmitter to a receiver via an oscillating magnetic field. To achieve this, DC supplied by a power source is converted into high frequency AC by specially designed electronics built into the transmitter.

The AC energies a copper wire coil in the transmits, which generate a magnetic field. The magnetic field generates a current which flows through the coil of the receiving device. The process whereby energy is transmitted between the transmitter and receiver coils is also referred to as magnetic or resonant coupling and is achieved by both coils resonating at the same frequency. The current flowing within the receiver coil is converted into DC by the boost rectifier circuit, which can then be used to power the device.

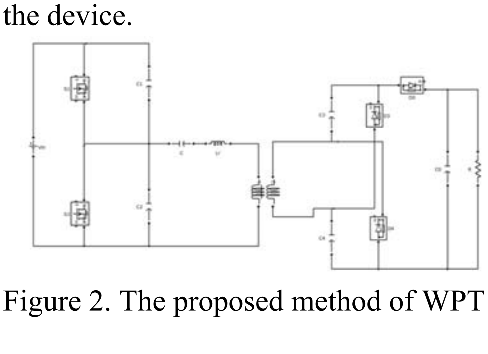

Figure 2. The proposed method of WPT

The circuit is composed of class-D converter coupled magnetic inductor and boost rectifier. The switching losses can be reduced with the soft switching. This converter to achieve high step-up gain.

The circuit includes dc input voltage *V*in, two active switches S_1 and S_2, transformer *Tr*, two boosting capacitors C_3 and C_4, two boosting diodes D_3 and D_4, output diode *Do*, output capacitor *Co*, and output load *R*. Switches S_1 and S_2 are controlled simultaneously by one control signal.

B. *Class-D Inverter*

A class-D inverter will be generally used to energize the induction coil to generate high-frequency magnetic induction between the coil and the cooking vessel, consequently, high-frequency eddy current, and, finally, heat in the vessel bottom area. The class-D inverter takes the energy from the input source. The dc voltage is converted again into a high frequency ac voltage by the class-D inverter. Then, the inverter supplies a high-frequency current to the induction coil. Figure 3 shows the class-D inverter system of IH jar. The class-D inverter consists of two switches *S*1 and *S*2 with antiparallel diodes *D*1 and *D*2, two resonant capacitors *Cr/*2, and an induction coil that consists of a series combination of equivalent resistance *R*eq and inductance *L*eq. The dc input voltage is directly supplied into an inverter. Then, (S1, D1), and (S2, D2) are alternately used to administer a high-frequency current to the induction coil. In particular, two switches are operated at square wave with suitable dead time between the two driving commands. The class-D inverter is operated above the resonant frequency, which means that the switches are turned on with ZVS.

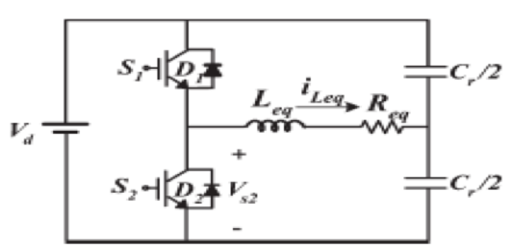

Figure 3. Class-D inverter system

C. *Magnetic Resonance Coupling*

WPT via magnetic resonant coupling applies series or parallel resonance to a transmitter and a receiver. This paper uses a series-series (SS) circuit topology and its equivalent circuit. The magnetic couple resonance can be explained by equivalent circuit. The equivalent circuit is illustrated in Figure 4 [13]. The transmitter and the receiver consist of the inductance L_1, L_2. C_1, C_2 are primary and secondary capacitance of coil. R_1, R_2 are coil resistance. These parameters are decided by coil figure and does not have relation condition of WPT system as transmitting distance and load condition. Term Lm is mutual inductance which is related to transmission distance. Inductance and capacitance of transmitting coil and receiving coil satisfy because WPT via magnetic couple resonance send the power by electrical resonance.

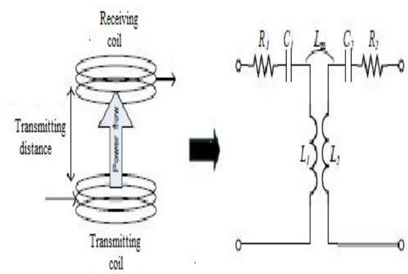

Figure 4. Equivalent circuit of magnetic resonant coupling

Figure 5 shows equivalent circuit of WPT system which connected power and load. Where V_1 is the primary side voltage, V_2 is the secondary side voltage, and R_L is load resistance. Term Zin2 is secondary side input impedance and equal to R_L in this figure.

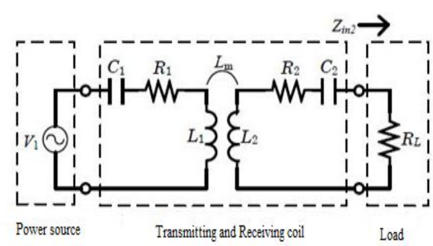

Figure 5. Equivalent circuit of magnetic resonant coupling with power source and load

III. ANALYSIS AND DESIGN

The detailed design of the circuit is discussed. Because the non-radiative wireless power transfer (WPT) scheme presented in [1] utilizes the near-field of a current carrying coil as a power transfer medium, the characteristics of an

electric and magnetic field in the near-field of a coil can be formulated to circuit model.
For the design purpose the calculations are as from the following equations.

$$L = \frac{Vin * (Vo - Vin)}{\Delta IL * FS * Vo}$$

Where, $\Delta IL + (0.2 \text{ to } 0.4) * Ioutmax * \frac{Vout}{Vin}$

where; L = Inductance
Fs = Switching frequency
Ioutmax = Maximum output current
ΔIL = Ripple current through inductor

$$\text{Resistance } R = \frac{Vo}{Io}$$

Where, R= Resistance, Io = Output current

$$\text{Duty ratio } D = \frac{Ton}{Ttot}$$

Where, D = Duty ratio
Ton = on time period
T = Total time

The determined voltage stress on power switch is

$$Vs1, max = Vs2, max = \frac{Vo}{2}$$

Where, Vs1max = Vs2 max = Voltage stress across power switches S_1 and S_2

The inductor values for series resonant tank is calculated from the following

$$Lr = \frac{Ton^2 * Vin.Fs}{2 * ILr(\text{max})}$$

The parameter of designed is given in Table.1.

TABLE I. Parameters and their numerical values

Parameters	Value
Inductor	$868e^{-6}$H
Resistance	250Ω
Duty ratio	0.304
Voltage stress on switch	100V
Resonant inductor	5.7e-6Henry
Output current	0.78A

IV. SIMULATION RESULTS

In figure 6 the simulation circuit diagram of class-D DC-DC converter for wireless power transfer with magnetic resonance circuit.

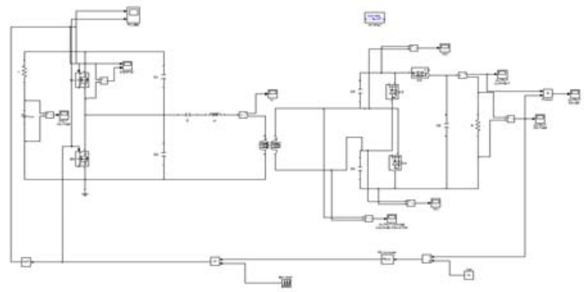

Figure 6. Simulation Circuit Diagram of WPT

The input voltage waveform of class-D DC-DC converter shown in figure 7. The input voltage is 100V.

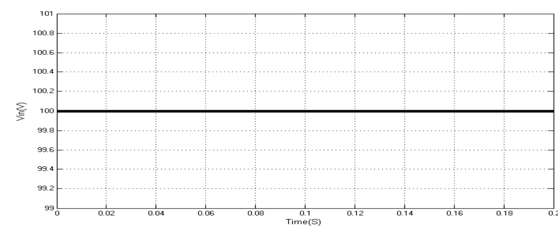

Figure 7. Waveform of Input Voltage

The figure 8 shows input pulses to switch S_1 and S_2, both of them are controlled by the same PWM signals with a duty cycle of 0.304.

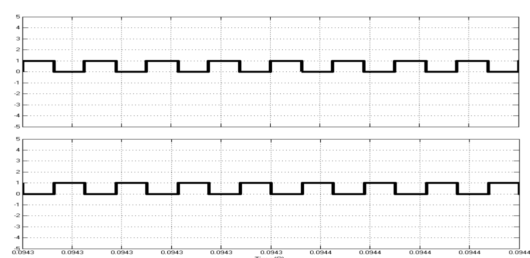

Figure 8. waveform of gate pulse

The figure 9 shows the simulation result of the current through the inductor. The resonant inductor current is similar to the sine wave.

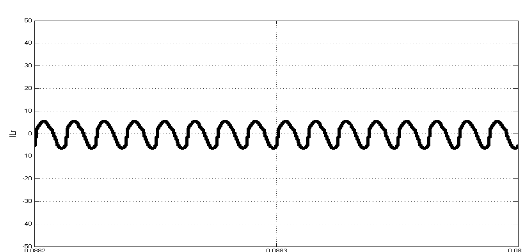

Figure 9. Waveform of Resonant Inductor Current Output

In figure 10 waveform of ZVS across the switch S_1.

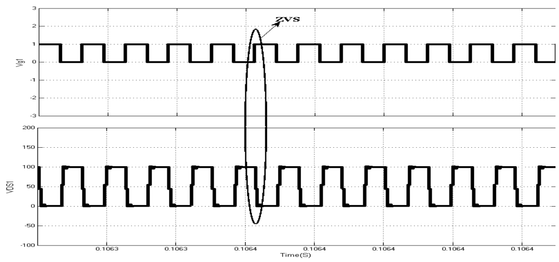

Figure 10. Waveform of ZVS across the switch S_1

The figure 11 shows the simulation result of across the magnetic resonant coupling inductor.

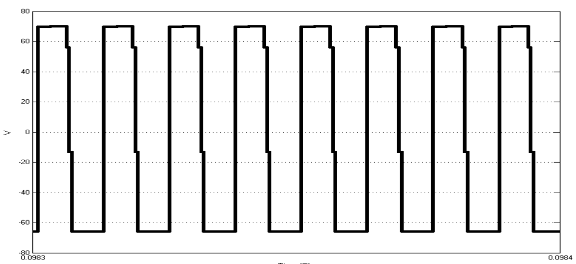

Figure 11. Waveform of output across the Magnetic Resonant Coupling Inductor

The figure 12 shows the simulation result of output voltage of class-D DC-DC converter. The output voltage is 200V.

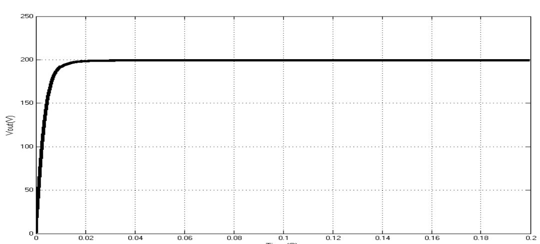

Figure 12. Waveform of Output Voltage

The figure 13 shows the simulation result of the output current of class-D DC-DC converter. The output current is 0.8A.

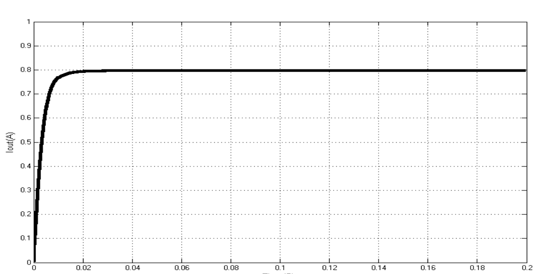

Figure 13. Waveform of Output Current

V. CONCLUSION

This paper proposed a Class-D DC-DC converter for wireless power transfer technology, whose smooth switching transitions make them suited to high frequency DC-DC conversion. The circuit configuration of the proposed converter is simple. DC-DC converters operating in the megahertz frequency range. These should offer high efficiency, good electromagnetic compatibility. ZVS condition is achieved. The voltage stresses across the switch are also reduced. The proposed method is applicable in Electric vehicle applications Electronic portable devices like Cell phones, laptops, tablets, smart watches; Aerial hicles and Solar Power Satellites. The simulation results are given as waveforms.

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