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Resonant Converter Based Wireless Power Transmission

Ishani Engineer[1], Shruti Jadhav[2], Vijetha Jogu[3], Pooja Sawant [4]Pragya Jain[5]
[1]*(Department of Electrical Engineering, Atbara College of Engineering/ Mumbai University, India)*
[2]*(Department of Electrical Engineering, Atbara College of Engineering/ Mumbai University, India)*
[3]*(Department of Electrical Engineering, Atbara College of Engineering/ Mumbai University, India)*
[4]*(Department of Electrical Engineering, Atbara College of Engineering/ Mumbai University, India)*
[5]*(Department of Electrical Engineering, Atbara College of Engineering/ Mumbai University, India)*

Abstract : *This paper presents a wireless transmission system aimed to provide electrical utility power to electrical appliances wirelessly. The proposed operation involves, converting utility power into high-frequency power signal using resonant converters. This power is transmitted to receiving side using an antenna, the load being DC load.*

Keywords – *Antenna, gate driver, high switching frequency, Inverter, RF Power MOSFET*

I. Introduction

With the advent of portable devices, wireless power transfer is gaining increased importance due to ease of use and flexibility. Technological innovations demand power that is available everywhere and this is possible wirelessly. An important consideration for any power transfer system is its overall efficiency. To achieve maximum conversion efficiency we propose a class Φ_2 inverter which converts utility power into 30MHz RF power signal. Class Φ_2 inverter topology is a tuned switched-mode converter which incorporates a resonant network for obtaining increased efficiency at higher frequency. The wave-shaping section of the converter circuit is designed in such a manner that parasitic capacitance of the MOSFET is included in the natural operation of the wave-shaping section. Also passive component like inductors are of small value so as to reduce the energy storage requirement as well as to achieve fast dynamic response. The components of the resonant circuit are tuned to obtain low peak voltage across the switching device and hence reduce the voltage stress on the switching device. The proposed topology also enables zero *dv/dt* across the switch with proper tuning so as to protect the MOSFET from high rate of rise of voltage which is important for high frequency operation.

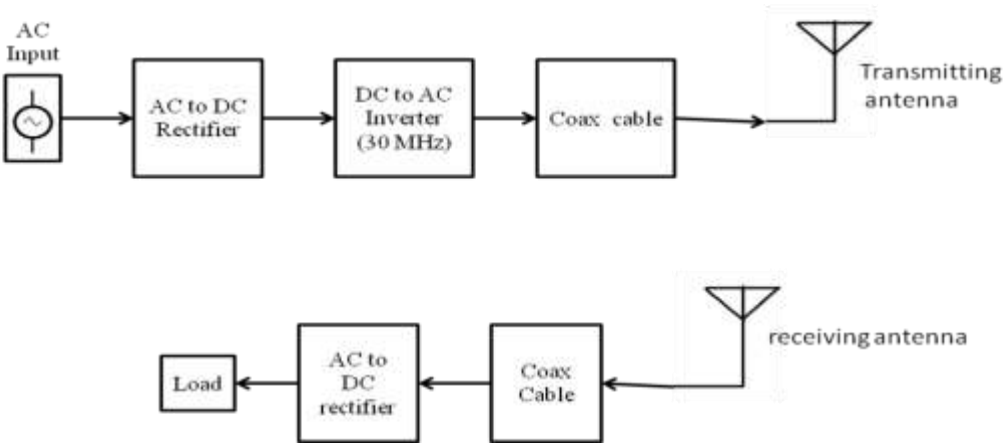

Fig 1 Block Diagram of wireless power transmission

II. Rectifier

A rectifier of transmitting section converts utility power into DC. The rectifier used is a fully uncontrolled rectifier. Rectifier circuit produces an output voltage or current which is pulsating DC. To obtain the continuous DC wave, in this paper, the bridge rectifier is designed. Four individual rectifying diodes are used which are connected in a closed loop "bridge" configuration. The average DC output of the rectifier can be improved by using capacitors to filter the output waveform. Smoothing capacitors are connected across the output or load. So this capacitor will charge and discharge between two peaks of the pulsating DC.

A bridge rectifier is selected depending on the load requirement. While selecting a rectifier power supply for an appropriate circuit's application components' rating and specification, transient current, temperature ranges, mounting requirements, forward current rating and other factors are also considered. The diodes are chosen based on the maximum voltage applied, the maximum current and also the frequency of sine wave of supply. The diode selected for the transmitting side is 1n5404.

For receiving section, as the input is 30MHz sine wave which is received by an antenna is fed to the full controlled bridge rectifier. So we cannot use the same diode as on transmitting side's rectifier. That's why, in the receiving section, an ultrafast diode is used for bridge rectifier circuit. Due to very low forward voltage and ultrafast reverse recovery, these diodes are very efficient, in high frequency switched mode power supplies, for rectification. They can directly reduce switching loss and thus, overall power efficiency is improved due to a good combination of reverse recovery time and forward voltage. Also, ultrafast rectifiers have high reverse voltage surge capability, high thermal cycling performance, low thermal resistance and very low on-state loss. Also, the soft recovery characteristic of ultrafast diodes minimizes power consuming oscillations. The ultrafast diode used is UF4004.

III. Inverter

High-frequency operations can be done by using suitable resonant inverters. This inverter utilizes specially tuned the resonant network to achieve zero voltage switching and low voltage device stress. The resonant network has been used in order to get the efficient operation at high frequencies and to achieve other desire requirements. There are different types of high-frequency inverters. Each having advantages and disadvantages in its own way. This inverter circuit generates power of 200W with a frequency of 30MHz at its output it utilizes high switching frequency MOSFET for its operation. The input voltage given to the inverter is from 160-200Volts. Various types of components have been used in an inverter circuit. These components work at high frequency. The components required to design an inverter are high switch frequency MOSFET, inductors each having same or different value, capacitors having same or different values, gate driver circuit, for the triggering purpose of the MOSFET.

3.1 MOSFET Selection

Power MOSFET being the switching device for proposed converter reducing the switching losses for efficient operation is major design concern. Conventional power MOSFET packages are not suited for high power, high switching frequency operation. MOSFET selection plays a major role while designing an efficient converter. MOSFET has finite switching time during which it suffers from switching losses due to dynamic current and voltages. Gate driver losses also contribute to switching losses since are required to turn ON and turn OFF the MOSFET. High switching frequency and high input voltage require lower gate charge and gate capacitance to cut down switching losses. Moreover, this can be achieved by reducing the energy required to charge the MOSFET gate capacitance;

$$P_{SW} = V_{IN} \times I_{OUT} \times F_{SW} \times [(Q_{GS2}+Q_{GD})/I_G] \quad (1)$$

Where $V_{IN} = V_{DS}$, $I_{OUT} = I_D$, F_{SW} is switching frequency and I_G is gate current.

The inductor current i.e. the current flowing through MOSFET's parasitic lead inductance contributes to the increased conduction losses. This current can be reduced by reducing the lead inductance of MOSFET. Also, the conduction losses of MOSFET can be reduced by reducing the on state drain-source resistance $R_{DS(ON)}$. MOSFETs with low $R_{DS(ON)}$ provide lower conduction losses with the increase in gate capacitance which increases the switching losses. Hence we can either reduce conduction losses at the cost of an increase in switching losses or vice versa. There is a figure of merit number relating gate capacitance and drain-source resistance which will be used to decide the lowest value of power loss which can be achieved for a particular MOSFET;

$$P_{CON} = R_{DS(ON)} \times I^2_{QSW\ (RMS)} \quad (2)$$

Apart from improving the electrical properties of MOSFET, it is important to optimize the thermal and mechanical performance of MOSFET. The packaging type of the MOSFET majorly contributes to the behavior of the MOSFET and hence the performance. The device selected in this paper is DE-SERIES fast power MOSFET.

MOSFET circuit model represents various parasitic components. These parasitic components inhibit the high-speed operation during turn ON, parasitic elements LG, Rg and LS isolate the capacitance of internal gate structure of power MOSFET which limits the rate of voltage rise across gate thus increasing the charging time and slowing the turn ON of the device. Further, LG, Ls, Rg, Ciss, Crss forms a resonant tank circuit which can oscillate and limit the maximum frequency of the device. Also when the device turns ON additional parasitic elements limit the high-speed operation. The rise of drain current causes the voltage drop across Ls which provides negative feedback and this further limit the turn ON speed of the device. From the above discussion, we can conclude that a new packaging system needs to be devised to address and eliminate these stray inductances. We know that stray inductances are formed in the connecting leads of MOSFET due the energy stored in its magnetic field. If the packaging type of the device is designed in such a manner that two equal magnitudes, out of phase magnetic field vector yield a zero resultant then it will be possible to eliminate the stray inductance. In order to achieve this, DE-SERIES devices have four source tracks. SG1 & SG2 are ground tracks for gate signal and SD1 & SD2 are ground tracks for drain signal such that their magnetic field vectors give zero resultant and hence reduce the stray inductances compared to conventional designs. Further, Coss, Ciss and Crss are also reduced up to certain extent thereby reducing the required charging time, enabling faster charging of device.

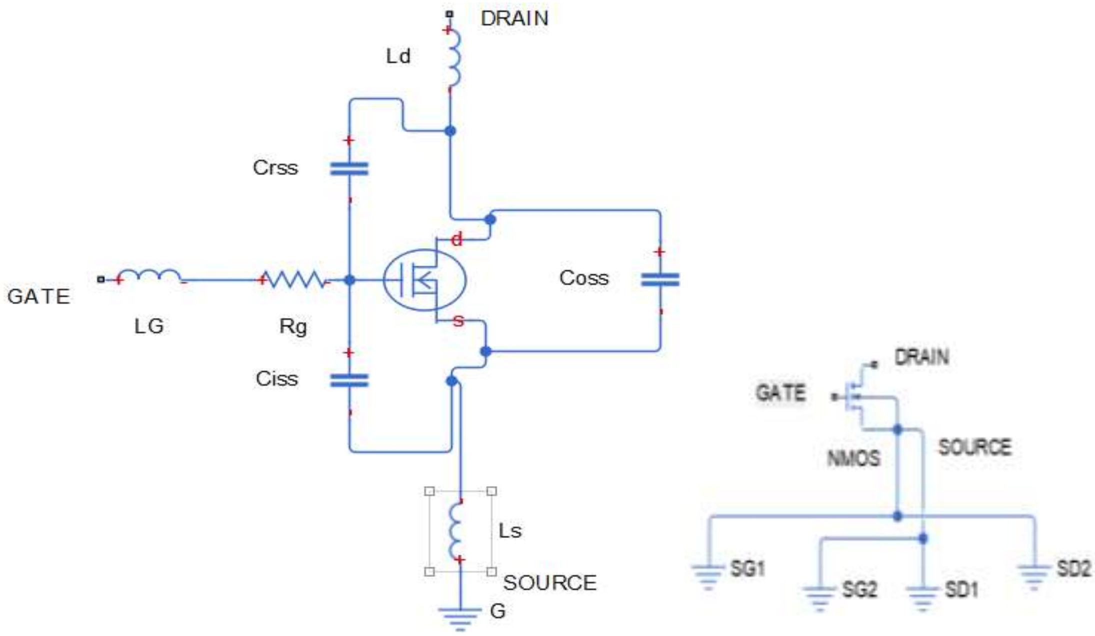

Fig. 2 Mosfet pspice model and DE-SERIES Mosfet Terminals.

3.2 Inverter Topology

When the power converters are designed, reduction of the price and physical size i.e. increasing the power density is the aim. The development of Switch Mode Power Supplies (SMPS) has made it possible to increase the power density significantly, but the limitation is the size of the passive energy storing components which are inductors and capacitors. The value and size of these components vary with the switching frequency. If the switching frequency is very large then the size of the SMPS is reduced. Also, to avoid or to reduce the switching losses and to increase the frequency while keeping the efficiency high, new topologies have to be used. There are different topologies of inverter like class E, class D, class DE, Class ϕ_2 and class F . The topology must have zero current switching (ZCS) and /or zero voltage switching (ZVS). MOSFET is turned on when the voltage and/or current across/through it is zero. The switching frequency affects passive components. Thus, the size is reduced of passive components, at the high switching frequency. This leads to capacitors with lower values. Another advantage of the increase in the switching frequency is that it will become easier to comply EMI requirements, as small and cheap filters can be used to filter out switching harmonics. The resonant inverters are load dependent, which means it will be difficult to achieve good performance at varying load.

$$V_{IN}^2 \times \frac{f_s}{P_{OUT}} \propto \frac{1}{n} \quad (3)$$

Equation 3 concludes that it is very difficult to have high input voltage and switching frequency with low output power and still keeping the efficiency high. The input voltage sets, together with C_{OSS}, the energy stored in the output capacitance of the MOSFET each switching period and f_s sets how many times this has to be done each second. As the load is known, the first step should be to design the rectifier and then design the inverter for the given input and load. It is also possible to design the inverter first and then using different resistance compression networks to match the impedance of the rectifier.

While selecting the inverter topology, flexibility of design, ease of operation, range of frequency, efficiency and output power these points are considered. Based on this we can select the inverter design. Class

E, class DE and class ϕ_2 are compared and the pros and cons are as follows. Class E has advantages of having slow side switching and Easy tuning whereas this circuit has large stress and require large value inductors. Class E On the other side class $\phi 2$ has reduced stress, low side switching, fast dynamic response, high output power and can be operated at high switching frequency but has the complex circuit. Class DE contain only one inductor, has low losses and low stress, the disadvantage is high side switching. For low operating or switching frequency Class DE can be used.

Design of Class Φ_2 Inverter**: -** This involves selecting different components and their requirement as per their function. The selecting of components is the much difficult task as it affects the overall performance of the inverter. It includes:-

1. Selecting the proper size of the inductance and RLOAD at the load side to get the desired power at the output.
   $X_s=R_{LOAD}\,(V_{ds1,RMS}/(P_{out}\times R_{LOAD})-1)^{1/2}$
2. Selecting the proper value of capacitance as it attenuates the value of impedance connected next to load at third harmonics.
3. Components selected should be done by the complete study of the circuit as it will affect the performance of the inverter etc.

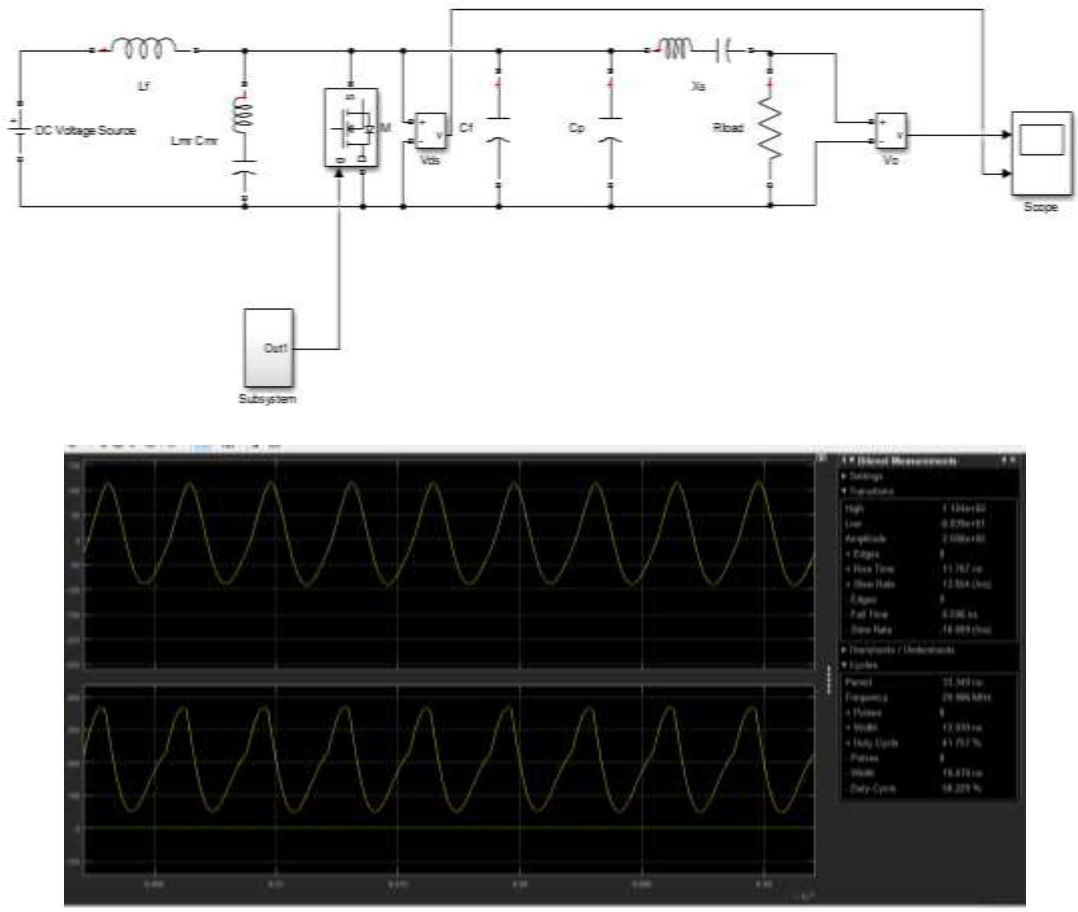

Fig. 3 Class ϕ_2 inverter

Lf	270nH
Cmr	18.8pF
Lmr	414nH
Cp	11nF
Cs	2nF
Ls	190nH
Cf	20pF
Rload	30 ohm
MOSFET	DE275-501N16A

Table No. 1 Component list of Class ϕ_2 inverter

3.3 Gate Driver Circuit

The gate driver circuit is implemented using RF frequency generator along with dc offset on the gate voltage. This circuit is used to trigger MOSFET gate sinusoidally. The RF frequency will be generated by frequency generator circuit AD9851 and DC offset is provided by DC supply $V_{G,DC}$. DC supply can also be used to vary the duty cycle of the triggering signal. $R_{G,DC}$ and $L_{G,DC}$ are used to prevent RF signal from reaching DC supply $V_{G,DC}$. $C_{G,RF}$ provides low impedance path to the RF signal generated by the signal generator.

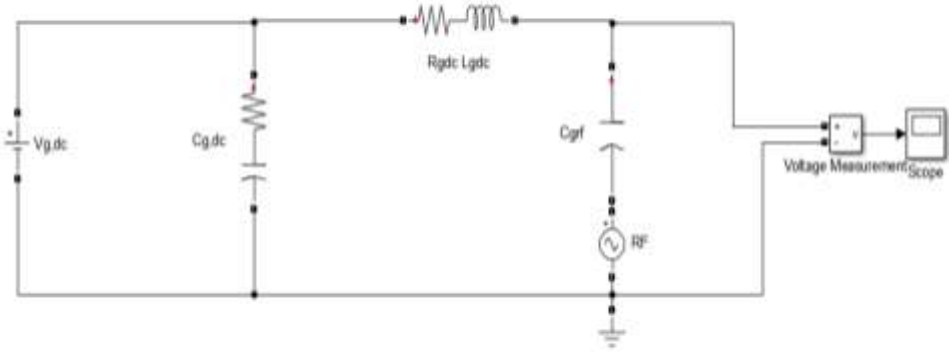

Fig. 4 Gate Driver Circuit

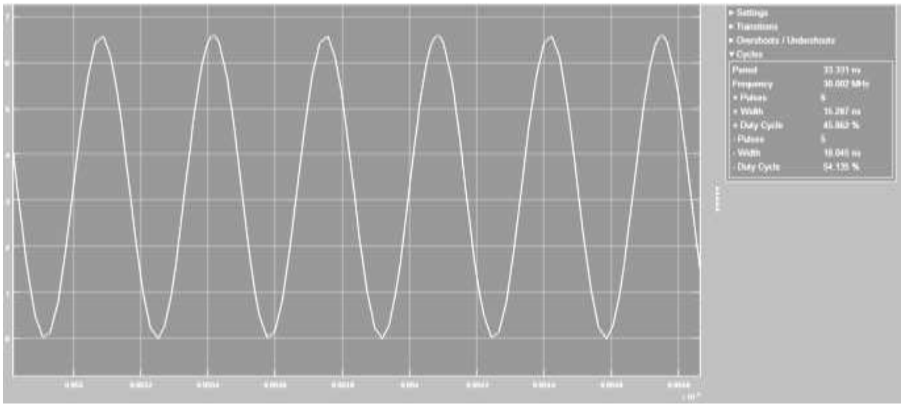

Fig 5 Simulation of gate driver circuit shown in fig 4

Cg,dc	5nF
Cgrf	5nF
Lgdc	568nH
Rgdc	10K Ohm

Table No. 2 Component list of gate driver circuit

IV. Antenna

4.1 Transmitting Antenna

The wireless concept in our project is implemented using antenna; they are used for wirelessly transmitting the power. It is a loop of metal aluminum conductors that carry our high-frequency power from the inverter circuit into free space. The two antennas transmitting and receiving are square loop antennas they are fabricated in a way to provide minimum losses in terms of Joule heating in the feed-line and maximum efficiency.

$$\lambda = \frac{c}{f} \quad (4)$$

$$R=31200(NA/ \lambda^2)^2 \quad (5)$$

The operating frequency of inverter circuit is 30 MHz, the wavelength associated with our power signal is calculated by equation 4 given. The wavelength thus obtained is 10. The radiation resistance offered by Antenna is calculated by equation 5 given. Radiation resistance calculated using that equation is 121.875 Ω of transmitting antenna. The selection of coax cable that is to be connected to transmitting antenna depends on this radiation resistance. Coax cable available in the market is 50Ω, 75Ω, 100Ω the value closest to radiation resistance is chosen. As the calculated value of radiation resistance is 121.875 Ω which is closest to 100Ω coax cable of is selected.

4.2 Receiving Antenna

Receiving antenna as our transmitting antenna is a square loop antenna. It is fabricated in a way to receive 150W Power transmitted at a frequency of 30MHz. It is associated with another 100 Ω coax cable to carry the received power signal to a Rectifier circuit. Here the received 30MHz AC power signal is carried to a rectifier circuit with converts AC into DC and feeds the DC load.

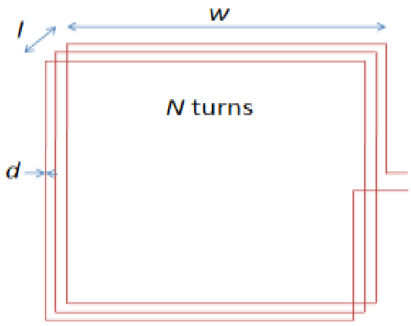

Fig. 6 Square loop Transmitting and Receiving Antenna

V. Conclusion

Emerging technology focuses on achieving greater level of flexibility as well as greater efficiency for better performance. This goal can be achieved through improved design. This paper presents, design of resonant converter i.e. Class ϕ_2 inverter operating at 30MHz switching frequency, which attempts to achieve reduced switching losses, lower voltage stress on power MOSFET and flexibility in design for high frequency operation. The switching device selected for this purpose has lower parasitic components which contribute to improved performance of the inverter. The proposed design enables higher frequency operation of the converter compared to other conventional designs, which limits the maximum achievable frequency of operation. Also smaller valued passive components like inductors and capacitors used in inverter circuit reduce the energy storage requirement and enables faster dynamic response, since lower valued inductors decreases the stored energy and hence reduces the time required by the converter to adjust its operating time. Moreover this topology includes the parasitic capacitance of the MOSFET for the design of wave-shaping section of the converter circuit due to which parasitic capacitance is included in the natural operation to inverter. This inverter topology when connected to an antenna will form the transmitting side which will be able to transmit 30MHz frequency power signal. This power signal will be received at the receiving end using a receiving antenna.

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