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Modelling of Wireless Power Transmission

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Abstract- In this paper wireless power transmission (WPT) technique has been projected for transmitting the power in the electrical system.Transmission of electrical energy from source to load for a distance without any conducting wires or cables is called as wireless power transmission. In this paper renewable energy (electrical power is generated from solar panel) has been used as a source for the proposed technique. Then the generated electrical power is fed to DC-DC converter, hence the voltage is increased. After that the increased voltage has been fed to class E power amplifier. The output of class E amplifier i.e., 90V, 13.56 MHz is transmitted through transmitter to the receiver. One of the Near-field wireless power transfer techniques is opted i.e., (Magnetic resonance coupling). Magnetic Resonance coupling technique has been utilised for the transmission of power between transmitter and receiver. Then the Power from receiver has been fed to the rectifier circuit & converted into DC voltage around 75.6 V from that it has been given to DC load.

Keywords- Wireless power transmission, Magnetic Resonant coupling, Class-E power amplifier.

I. INTRODUCTION

Transfer of electric energy from a source to load without any physical connection between them, is known as Wireless Power Transfer Technology (WPTT). Nikola Tesla in the 1890's demonstrated a wireless power transfer (WPT) system. There are two types of wireless power transfer systems: 1. Radiative Power Transfer 2. Non Radiative power transfer; in radiative power transfer high frequency radio /microwave beams are used to transfer the energy. Magnetic resonance and/or radio frequency (RF) based far field power transfer are used in extended range of wireless power transfer (WPT). In 1887, Heinrich Hertz demonstrated a model of magnetic resonance based WPT [1]. Harrell V. Noble at the Westinghouse Laboratory demonstrated the first successful RF based power transfer in general public at the Chicago World's fair of 1933–1934 [2]. Later on, RF based far-field WPT technology further developed and applied in areas such as aeronautics and aerospace. Around 2008, simultaneous wireless transmission of power and data in communication systems was achieved [3],[4]; however efficiency of the system is not very excellent and still research is going on in this field to perk up the efficiency of the system. In Non Radiative System two objects are resonating at the same-frequency and Transfer occurs through strongly coupled electrical / magnetic fields [5]. In this paper renewable energy (solar power) used as the source for wireless power transmission. A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switchingmode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple. Power can also come from DC sources such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage [6], [7]. The main purpose of a power amplifier in this paper is to generate the alternating signals in the transmitter [8], [9]. But the power loss of these amplifiers is very high. The oscillating signals are then fed into the transmitter setup [10], [11], and [12]. By achieving proper resonance coupling between the transmitter and the receiver setup power gets transferred wirelessly [13], [14]. The output of receiver coil is AC. It is converted to DC using an AC to DC bridge rectifier. Capacitive filter is used to remove the ripples after rectification [15], [16]. In this work power transmission has been done by WPT through magnetic resonant coupling.

This paper presents the modelling of wireless power transfer. Section I contains introduction of evolution and techniques in WPT, Section II contains description of the block diagram of the proposed system, Section III contains design calculations of proposed system, Section IV contains simulation of the proposed wireless power transmission model using MATLAB/SIMULINK. And in section V the output of the Simulink model is concluded.

II. DESCRIPTION OF THE PROPOSED SYSTEM

In this proposed WPT system solar panel, step up converter, amplifier, rectifier step has been utilized.

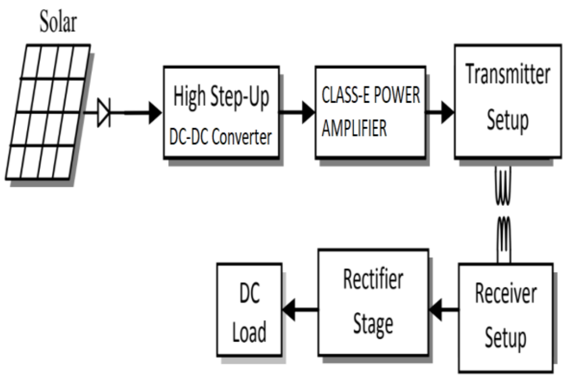

Fig 1. Block diagram of proposed WPT system

Solar Panel: A Polycrystalline solar panel is taken which suits the design specifications of this proposed model as shown in fig 1. Moreover a polycrystalline solar panel has an efficiency of 18% which can drive the power that is obtained from the source to the load. Polycrystalline are the most common because they are often the least expensive. Besides this it has durability and longevity, and being able to produce energy from sun it helps in reducing greenhouse gases. The process of electron transition where the electrons by gaining energy jumps from valence band to conduction band and emit or release heat or light is faster in case of Polycrystalline solar panels.

High Step-Up DC-DC Converter: A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. In this proposed methodology the converter is a class of switching mode power supply (SMPS). It contains at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. The power can also be received from DC batteries, rectifiers and DC generators. In this proposed technique the power is received from solar panel. The step-up converter has following advantages:
a. The converter has a high step-up conversion ratio because of the connection of the coupled inductors, diodes and the capacitors.

b. It has very high efficiency and lower stress on the switches as the leakage inductor energy can be recycled.

Class E Power Amplifier: The class E concept was introduced in 1975 by sokal et al and offered a new means of highly efficient power amplification. Later in 1977, Raab expanded Sokal's work by providing an analytical basis for Class E operation. It was also shown that at low frequencies Class E amplifiers provide a higher efficiency and a better overall linearity than Class B, Class C and Class F amplifiers. Up to this point, Class E amplifier required an RF choke between the DC power supply and switching transistor. A major improvement in class E design was reported in 1987 as Zulinski showed that Class E design may be maintained with the RF choke replaced by a smaller reactance, increasing the power output capability by a factor of about 2.5. Previously work on Class E amplifier was limited to frequencies below 10MHz. But, now a day the Class E amplifiers can be used at much higher frequencies and particularly in wireless communication. In a practical Class E amplifier, a transistor (either bipolar or FET) acts as the switch. FETs are better switches than bipolar because they offer much lower saturation voltages. The on-resistance of the FET can be reduced by increasing the size of the device, and unlike the bipolar transistor, the FET is a bidirectional switch which does not require input drive current. It is assumed that a FET is used as the switch in Class E amplifier implementation. The on-resistance, nonzero switching time and voltage dependent parasitic capacitances of the FET degrade the performance of the Class E amplifier and reduce its efficiency. In a Class E power amplifier, the RF output amplitude is a linear function of the DC supply voltage, since the wave shapes andconduction angle are not changed by the DC supply voltage**.** Therefore, the RF output canbe amplitude modulated by varyingthe supply voltage with the modulating signal. Deviations from perfect linearity can be caused by
a) Feed through of the drivingsignal, which has constant amplitude, via gate draincapacitance to the output.
b) Envelope distortion of the AM output voltage caused by the load network.
c) Voltage variable parasitic capacitances of the transistor.

The feed through of the driving signal does not allow the output voltage to drop to zero when the supply voltage is reduced to zero. Inorder to avoid this problem, both the driver andthe power amplifier must be amplitude modulated. In this way, when the supply voltage decreases, sodoes the input driving signal and the feed through is eliminated. The main purpose of a power amplifier is to generate the alternating signals in the transmitter.

To generate the alternating signals and to have greater efficiency we use class E power Amplifier for producing the AC signal for transmission. In general, the choice of power amplifier's operating class is based on requirements regarding linearity and power efficiency. Typically, Class-E amplifiers can operate with power losses smaller by a factor of about 2.3, as compared with conventional Class-B or -C amplifiers using the same transistor at the same frequency and output power. Class-E amplifiers can be designed for

narrow-band operation or for fixed-tuned operation over frequency bands as wide such as 225-400 MHz's.
The class E amplifier is a high efficient switch mode resonant converter. The high efficiency results from the reduced power losses in the transistor. The higher efficiency of the switch can be achieved by:
a. Using the transistor as a switch to reduce the power
b. Reducing the switching losses which result from finite transition time between ON and OFF states of the transistor.

Transmitter and Receiver: The transmitter and receiver pair is resonantly coupled so that maximum power is transmitted.

Mode of transmission through Magnetic Resonance coupling: Magnetic resonance coupling involves creating an LC resonance and transferring the power with the electromagnetic coupling without radiating electromagnetic waves. The resonance frequency changes as coupling factor k changes and the maximum efficiency power transfer occurs at the resonance frequency.

Conditions for Impedance matching: Impedance matching is a technique commonly used in power transfer system and communication system to improve the efficiency. It involves inserting a matching network (such as in LC circuit) to minimize the power reflection ratio to the power source. Power transferred to the load reaches maximum when source impedance is equal to load impedance.
Reflection Coefficient: It is equal to the ratio of the amplitude of the reflected wave to the incident wave.

Rectifier: it converts this power received to Dc and supplies to load.

III. DESIGN OF THE PROPOSED SYSTEM

Design of DC-Dc converter:
Input Voltage V_{in} = 12 V
Output Voltage V_0 = 70 V
Switching frequency f = 100 KHz
Transformer turns ratio n = 2
Output R = 100 Ω

The duty cycle D is calculated as

$$D=1-\frac{V_{IN(1+N)}}{V}$$

$$D=1-\frac{12(1+2)}{70}$$

D = 0.485 =48.5%

The boundary magnetizing inductance is found as,

$$L_{mB}=\frac{T_{LB}R}{F}$$

Where T_{LB} is boundary normalized magnetizing time Constant

$$T_{LB}=\frac{D(1-D)^2}{(1+n)^2}$$

$$T_{LB}=\frac{0.485(1-0.4885)^2}{(1+2)^2}$$

T_{LB}=7.1371*10^-3 s

Therefore
Boundary magnetizing inductance is

$$L_{mB}=\frac{7.1371*10^{-3}*100}{50*10^3}$$

L_{mB}=14.257uH

Class E power amplifier design:

The supply voltage (V_{CC}) of the class E power amplifier is 70v.
The equation for voltage across drain and source is given as:

$$V_{DS}=\frac{BV}{3.56}.SF$$

Where BV is Breakdown voltage
SF is Safety Factor and safety factor range has been taken as 0.8
Now finding Breakdown voltage

$$BV=\frac{3.56*Vcc}{SF}$$

$$BV=\frac{3.56*70}{0.8}=311.5V$$

The Mosfet is taken with breakdown voltage more than 311.5V
Output power is given by equation:

$$P=\frac{((Vcc^2))}{R_L}\left(\frac{2}{\frac{\pi}{4}+1}\right)f(Q_L)$$

$$P=\frac{((Vcc^2))}{R_L}*0.576801\left(1.001245-\frac{0.451759}{Q_L}-\frac{0.451759}{Q^2{}_L}\right)$$

Hence Load Resistance (R_L) is given by

$$R_L=\frac{((Vcc^2))}{P}*0.576801\left(1.001245-\frac{0.451759}{Q_L}-\frac{0.451759}{Q^2{}_L}\right)$$

The value of QL is taken by the designer, for a duty cycle of 50%; the minimum value of QL is 1.7879. The value of QL is taken to be 2.134 and maximum Power Output as 60 W,

$$R_L=\frac{(70^2)}{60}*0.576801\left(1.001245-\frac{0.451759}{2.134}-\frac{0.451759}{2.134^2}\right)$$

R_L = 32.98Ω
In design of class E power amplifier's design a shunt capacitor is connected across the switch

$$C4=\frac{1}{2\pi R_L f_o}*\frac{1}{(\frac{\pi^2}{4}+1)\frac{\pi}{2}}*(0.99866+\frac{0.91424}{Q_L}-\frac{1.03175}{Q^2{}_L})+\frac{0.6}{(2\pi f_o)2L_1}$$

$$C4=\frac{1}{34.2219R_L f_o}*(0.99866+\frac{0.91424}{Q_L}-\frac{1.03175}{Q^2{}_L})+\frac{0.6}{(2\pi f_o)2L_1}$$

Operating frequency f_o is chosen as 13.56MHz and by substituting these values in above equation we get

$$C4=8.02pF+\frac{0.6}{(2\pi f_o)2L_1}$$

Generally X_L is chosen 30 times more that of X_c
That is X_L >30> X_c

Therefore $L1>\frac{30}{\omega^2 c4}$

L1>79.4pF
So assume L1=80pF

Similarly Capacitor C5 is obtained fro

$$C5= \frac{1}{2\pi R_L f_o}*(\frac{1}{Q_L-0.104823})\ (1.00121+\frac{1.01468}{Q_L-0.104823}) - \frac{0.2}{(2\pi f_o)2L_1}$$

Here R_L=32.98Ω,
Q_L= 2.134,
f_o=13.56MHz,

$$C5= \frac{1}{2\pi*32.98*13.56*10^{\wedge}6}*(\frac{1}{2.134-0.104823})\ (1.00121+\frac{1.01468}{2.134-0.104823}) - \frac{0.2}{(2\pi*13.56*10^{\wedge}6)2*80*10^{\wedge}-12)}$$

Therefore C5=689.9127pF

The value of inductor L2 is determined by

$$L2= Q_L \frac{R_L}{2\pi fo}$$

By substituting respected values

L2= 0.9 uH

IV. SIMULATION STUDY

The simulation of the proposed wireless power transmission model has been carried out using MATLAB/SIMULINK as shown in Fig 2. The proposed model has been given with an input voltage of 12V from the solar panel. This output voltage of solar panel is given as input to DC to DC converter. And Table 1 shows the parameter and its values.

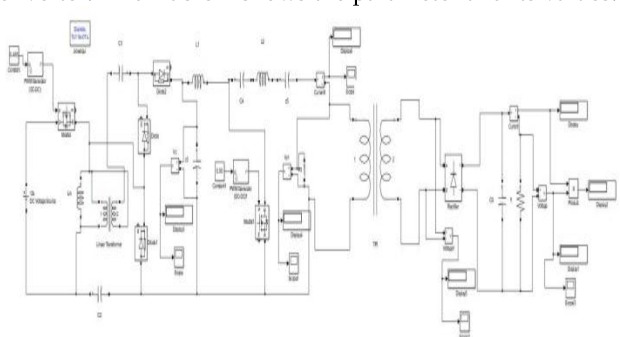

Fig. 2 Matlab Simulink model of proposed system

This DC to DC converter boosts the voltage from 12v to 70v. And this 70V DC is given as input to class-E power amplifier, where this class-E power amplifier converts 70V DC to 90V AC with a frequency of 13.56MHz. This value is given as input to the transmitting coil (Transmitter). Fig 3 shows the output of class E power amplifier.

Table 1. Parameter values

S.NO	PARAMETER	VALUE
1	Lm	15uH
2	C1	47uF
3	C2	47uF
4	C3	470uF
5	Duty Ratio of S1	48.5%
6	Turns Ratio of T1	2
7	L1	80uH
1	L2	0.9uH
2	C4	690pF
3	C5	132pF
5	C0	680uf
6	R0	300ohms
7	Duty ratio of S2	50%

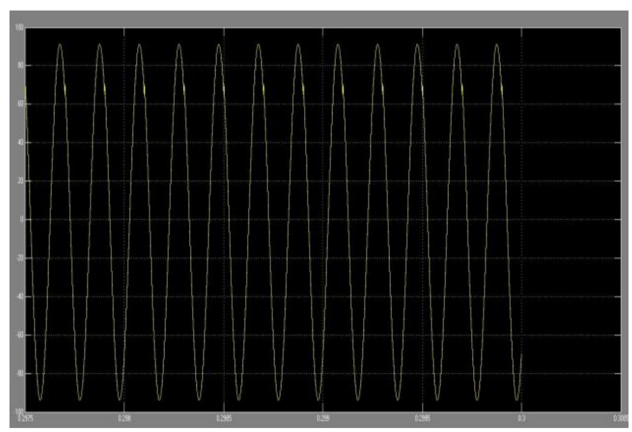

Fig 3. Output voltage of Class E power amplifier (X axis – Time; Y axis – Voltage)

From the receiver the voltage obtained is 80V AC at frequency of 13.56 MHZ. Then after the rectification through rectifier circuit the voltage acquired is 75.6 V DC, with Power value 21Watts.

V. CONCLUSION

This paper successfully designed the WPT system for the transmission of electrical power. From the solar panel, the input value 12V DC is given to the circuit; Class – E amplifier enhances the voltage to 90 V AC with frequency of 13.56 MHz which has been given as input to the transmitter and the voltage obtained after the receiving coil is 80V AC. Finally after the rectifier circuit around 75.6 V DC with the power value of 21 Watts has been obtained.

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