Performance Analysis of Wireless Power Transfer to the Implantable Drug Delivery System using Helical Antenna with Inductive Coupling

Ravi Jon, Charlie Eapen, A.Ashhok, Nishita Sahoo, Anil Kumar

Abstract- In this paper, we explore the feasibility of wireless power transfer(WPT) to the drug delivery system(DDS) using helical antenna .We investigated the efficiency through different parameters of helical antenna. Helical Antenna (HA) is used here as a primary and secondary coil which works based on the inductive coupling. Through this technology we can reduce the wires or we eliminate the complications and infections caused by the wires. The aim of the system is transfer the power efficiently to the drug delivery system implanted in human body. We studied the inductive coupling and coupling coefficient of the primary and secondary coil and we studied the electrical characteristics of the antenna with equivalent circuit. Inductive power transfer is the most common method of wireless power transfer to the implantable drug delivery system. For good inductive coupling and better efficiency the inductors should have high inductance.

Keywords- Wireless power transfer, Helical antenna, Inductive coupling.

I. INTRODUCTION

Nicola Tesla introduced the concept of wirelessly transmitting electrical power in 1891. In the field of wireless power transfer the main issue is transfer the power with high efficiency. In this paper we use inductive coupling to transfer the power to the implantable devices. The progress in the field of wireless power transfer in the last few years is remarkable. The Implantable biomedical devices like pacemakers, monitoring devices, LVADs, and artificial hearts require power supply for long term operation. Traditionally implantable lithium-ion batteries and percutaneous link power supply systems are used for power transfer to the devices. But life span and energy storage is limited in batteries and infection risks across the Skin are high in percutaneous links. Wireless systems have been developed to transfer the power for implantable biomedical devices which can be much smaller than batteries especially when high power outputs are required. But power flow regulation with high efficiency is a major challenge in wireless power supply especially when systems have high load and coupling variations. Frequency of transmitting antenna and receiving antenna play important role in wireless power transfer system. We analyze the inductance of the primary and secondary coil and what are the effects on the efficiency of inductance, resistance, coupling coefficient in the section IV.

II. II. INDUCTIVE COUPLING

This is one of the most popular wireless power transfer system. This system transfer's energy from the transmitting antenna to the receiving antennas using the magnetic field generated when current passes through the transmitting antenna. However, this system has a really limited range at 1cm or 2cm, and the efficiency severely drops outside of the range. Lately, a system to transfer the energy at a high frequency (kHz range) is developed. This allows this system to be used at an approximately 10-20cm range. In figure-3 a pacemaker is example of inductive coupling as given blew. Figure-1 [2] shows the transmitting and receiving antenna.figure-2 [8] shows the proposed system of wireless power transfer to the Drug Delivery system with helical antenna.

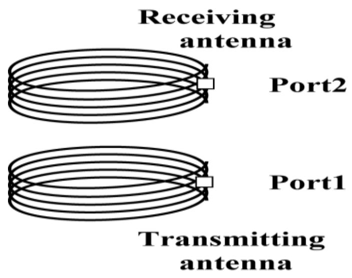

Figure-1.Transmitting and receiving antenna

Manuscript Received on June 22, 2012.
Ravi Jon, Department of Electronics and communication Sam Higginbottom Institute of Agriculture, Technology & Sciences Allahabad-211007
Charlie Eapen, Department of Electronics and communication Sam Higginbottom Institute of Agriculture, Technology & Sciences Allahabad-211007
A.Ashhok Department of Electronics and communication Sam Higginbottom Institute of Agriculture, Technology & Sciences Allahabad-211007
Nishita Sahoo, Department of Electronics and communication Sam Higginbottom Institute of Agriculture, Technology & Sciences Allahabad-211007
Anil Kumar, Department of Electronics and communication Sam Higginbottom Institute of Agriculture, Technology & Sciences Allahabad-211007.

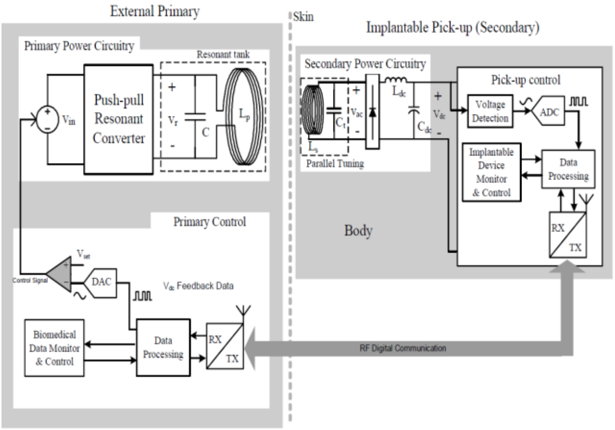

Figure-2.Proposed system of drug delivery syatem with primary and secondry coil.

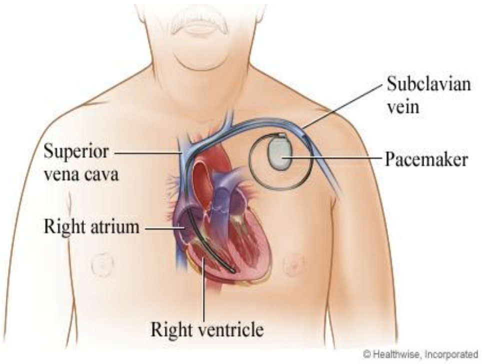

Figure-3.A pacemaker system implanted in body

III. EQUIVALENT CIRCUIT FOR WPT

In this section, we studied about the equivalent circuit of wireless power transfer, since the system will be used in a maglev application based on repulsive forces between coils and permanent magnets; the use of iron or ferrites is prohibited. In addition, the use of cores will limit the stroke of the system. Therefore, a coreless or air core inductive coupling is used to transfer the energy. To keep the efficiency of an air core inductive coupling high a resonant capacitor is used for both the primary and the secondary coil. Moreover, due to the position dependent coupling, a series resonant capacitor is used for both coils to ensure that the resonant frequency of the circuit does not depend on the coupling. The electric circuit of the WPT system is shown in Fig. 4, where *V*1 is the RMS voltage of the power supply, *I*1 the RMS current supplied by the power supply, *I*2 the RMS current induced in the secondary circuit. *C*1 and *C*2 are the series resonant capacitors in the primary and secondary circuit, respectively, *R*1 the resistance of the primary coil, *R*2 is the resistance of the secondary coil, *L*1 and *L*2 are the self inductance of the primary and secondary coil, respectively, *k* is the inductive coupling factor between the primary and secondary coil and *RL* is the resistance of the load. The load *RL* represents the rectifier and additional power electronics.

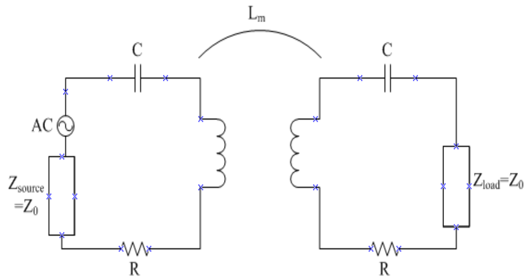

Figure -4. Equivalent circuit of wireless power transfer.

Where M is the mutual inductance of the primary and secondary coil, C_1, C_2 is the capacitance of the primary and secondary coil, and angular frequency ω. RL is the load resistance of the system.L1 and L2 is the primary and secondary inductance of circuit.

$$M = k\sqrt{L_1 L_2}$$

$$V_1 = R_1 I_1 + j\left(\omega L_1 - \frac{1}{\omega c_1}\right) I_1 - j\omega M I_2$$

$$j\omega M I_1 = (R_2 + R_L) I_2 + j\left(\omega L_2 - \frac{1}{\omega c_2}\right) I_2$$

$$c_2 = \frac{1}{\omega_0^2 L_2}$$

$$c_1 = \frac{1}{\omega_0^2 L_1}$$

$$Z_2 = R_2 + R_L\, j\left(\omega_0 L_2 - \frac{1}{\omega_0 c_2}\right)$$

$$Z_R = \frac{\omega_0^2 M^2}{Z_2} = \frac{\omega_0^2 k^2 L_1 L_2}{R_2 + R_L}$$

$$Z_1 = R_1 + j\left(\omega_0 L_1 - \frac{1}{\omega_0 c_1}\right) + Z_R$$

$$Z_1 = R_1 + \frac{\omega_0^2 k^2 L_1 L_2}{R_2 + R_L}$$

$$\omega = \omega_o$$

$$I_2 = K I_1$$

$$K = j\frac{\omega_o M}{R_2 + R_L}$$

$|K|$ is a coupling coefficient of the primary and secondary binding. I1 is the current of the primary binding.

$$P_{in} = I_1^2 Z_1$$

$$P_{out} = |K|^2 I_1^2 R_L$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{|K|^2 R_L}{Z_1}$$

η is the efficiency of wireless power transfer system K is the coupling coefficient and RL is the load resistance Z1 is the impedance of coil

IV. RESULT AND DISCUSSION WITH MATLAB

Table-1 Nominal values for circuit

parameter	value	dimension
fo	100	kHz
ωo	2πfo	Rad/s
L1	50	μH
L2	50	μH
k	0.5	Ω
RL	100	Ω
R1	0.5	Ω
R2	0.5	Ω

EFFICIENCY Vs. FREQUENCY

Figure -6 shows the variation in frequency Vs efficiency. It is observed that as the frequency increases, the efficiency increases exponentially up to a certain point. When the frequency is 1 KHz, efficiency is 0, and when we increase the frequency to 10 KHz the efficiency of power transfer is also increased to 0.1%, when the frequency is 100 kHz, the efficiency is 0.8%. When the frequency is 1 MHz the efficiency is approximately 1 %. Efficiency remains same with further increase in frequency beyond 1MHZ.

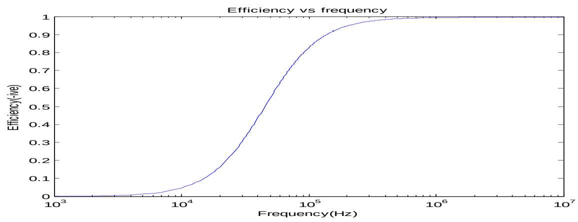

Figure-5. efficiency vs. frequency

EFFICIENCY Vs. INDUCTANCE L1 OF PRIMARY COIL.

Figure-6 shows the variation in efficiency Vs inductance of the primary coil. It is observed that increasing the inductance of the primary coil brings in efficiency increase up to certain point. The primary coil should be managed in such a way that, it is separated to secondary coil for contactless energy power transfer system. A high voltage will be necessary to force the current in the primary coil. The voltage will be generated by the power supply but mostly by the resonance of the capacitor and coil. It is observed that, when the inductance of the coil is 10^{-4}H; the efficiency is 0.9%. Increasing the inductance of primary coil up to 10^{-2}H brings in efficiency increase up to 1. Thereafter, increase in inductance, brings no changes in efficiency and remains same.

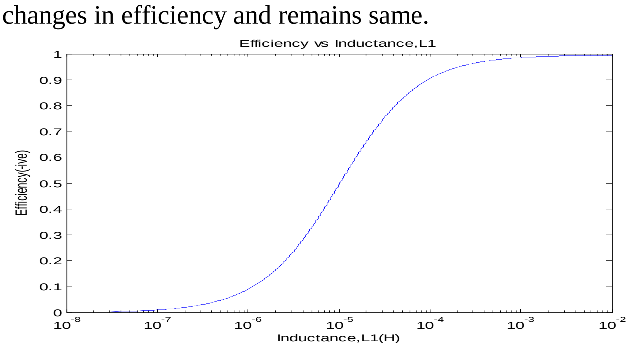

Figure-6 efficiency vs. inductance L1

EFFICIENCY Vs. INDUCTANCE L2 OF SECONDRY COIL

Figure-7 shows the variation in inductance of the secondary coil Vs efficiency, L1 and L2 are the self inductance of the primary and secondary coil respectively. It is observed that on increasing the inductance of the primary coil the inductance of the secondary coil also increases, which results in higher efficiency, this is because the inductance of secondary coil depends on the inductance of primary coil. It is observed that, when inductance of the coil is 10^{-4}H, efficiency is 0.9%, furthermore increase in the inductance of primary coil up to 10^{-2}H the efficiency achieved 1. Thereafter, further increase in inductance brings no further change in efficiency.

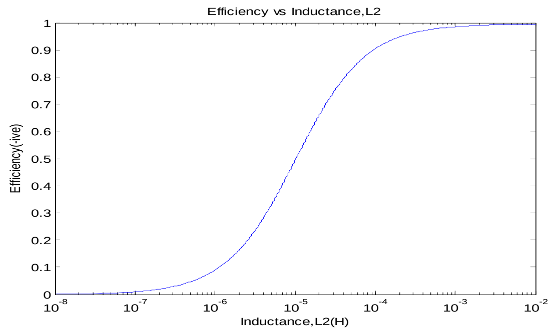

Figure-7 efficiency vs. inductance L2

EFFICIENCY Vs. COUPLING COEFFICIENT

Figure-8 shows the variation in coupling coefficient vs. efficiency. The coupling coefficient is directly proportional to the mutual inductance, and this mutual inductance is inversely proportional to the air gap between transmitting and receiving antenna. It is observed that, when the coupling coefficient is 0, the efficiency will be 0. For higher efficiency, the coupling coefficient should be K ≤1. If we increase the gap between transmitting and receiving antenna the coupling coefficient become small and efficiency increases

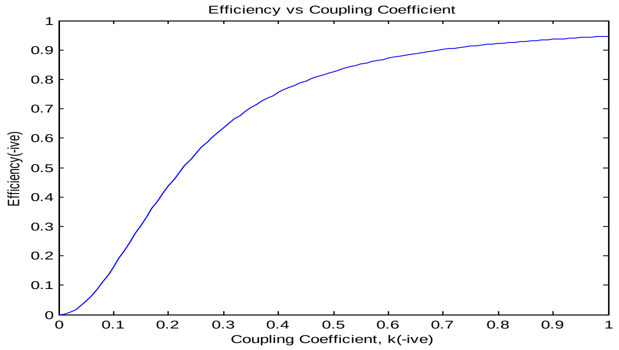

Figure-8 efficiency vs. coupling coefficient K

V. CONCLUSION

In this paper, we have studied the technology of wireless power transfer to the drug delivery system like pacemaker, artificial heart with inductive coupling we conclude that the efficiency is affected by the Various parameters of the helical antenna like, operating frequency, inductance of the coil, resistance of the primary and secondary coil has been considered. Coupling coefficient has been changed to analyze the output efficiency. Coupling coefficient should be greater than 1 for better efficiency.

REFERENCES

1. Andre Kurs, Aristeidis Karalis, Robert Mofatt, J.D. Joannopoulos, Peter Fisher, Marin Soljacic, “Wireless Power Transfer via Strongly Coupled Magnetic Resonance”, Science Express, 7 June 2007, Vol. 3.17 no.5834,pp.83-86
2. Takehiro Imura, Hiroyuki Okabe, Yoichi Hori, “Basic Experimental Study on Helical Antennas of Wireless Power Transfer for Electric Vehicles by using Magnetic Resonant Couplings”, Vehicle Power and Propulsion Conference, 2009. IEEE Pages 936-940
3. Edelman E.R. et al Journal of Biomedical Materials Research 1985, 67-83.
4. Amer S. & Badawy W. Current Pharmaceutical Biotechnology 2005, 57-64.
5. R. Puers and G. Vandevoorde, "Recent progress on transcutaneous energy transfer for total artificial heart systems," Artificial Organs, Vol. 25, Issue 5, pp. 400-405, May 2001.
6. P. Si, A. P. Hu, D. Budgett, S. Malpas, J. Yang and J. Gao, "Stabilizing the operating frequency of a resonant converter for wireless power transfer to implantable biomedical sensors," in Proc. 1st International Conference on Sensing Technology, Palmerston North, New Zealand, 2005.
7. S. I. Babic, C. Akyel, “Calculating Mutual Inductance Between Circular Coils with Inclined Axes in Air,” IEEE Trans. Magnetics, vol. 44, no. 7, pp. 1745, July 2008 .
8. P. Si, A. P. HuJ. W. HsuM. Chiang, Y. Wang, S. Malpas, and D. Budgett, “Wireless Power Supply for Implantable Biomedical Device Based on Primary Input Voltage Regulation”.

AUTHORS PROFILE

Ravi Jon working as Teaching Assistant in the Department of Electronics and Communication Engineering SHIATS Allahabad. He received his M.Tech degree from SHIATS Allahabad India. His research is focus on wireless Power Transfer and its applications in biomedical engineering, Nanoparticles & Application.

Charlie Eapen working as a Assistant professor in the Department of Electronics and Communication Engineering SHIATS Allahabad. He received his B.Tech degree pursuing M.Tech from SHIATS Allahabad. His research is focus on beamforming techniques in wireless sensor networks.

A.Ashok working as a Assistant professor in the Department of Electronics and Communication Engineering SHIATS Allahabad. He received his B.E degree from Anna University, Chennai and pursuing M.Tech from SHIATS Allahabad. His research is focus on Digital Signal Processing & Application.

Nishita Sahoo working as a Assistant professor in the Department of Electronics and Communication Engineering SHIATS Allahabad. He received his B.Tech degree pursuing M.Tech from SHIATS Allahabad. His research is focus on Microstrip Antenna & Application.

Anil Kumar working as a Assistant professor in the Department of Electronics and Communication Engineering SHIATS Allahabad. He received his B.Tech degree from D.D.V Gorakhpur University Gorakhpur, M.Tech from BHU Varanasi & Pursuing PhD from SHIATS Allahabad. His research is focus on Microstrip Antenna & Application, Artificial Neural Network.