A COMPREHENSIVE STUDY OF HIGH FREQUENCY INDUCTIVE POWER TRANSFER TECHNOLOGY BASED ON PARALLEL TRANSMITTING COILS

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Abstract
Inductive power transfer technology is a challenging, and very attractive research area. Recently, enhanced advancement in inductive power transfer technology is made to charge different electronic devices wirelessly. A similar approach is implemented in this article. This paper demonstrates the analysis of inductive parallel transmitting source and multiple receiving coils. The circuit analysis of the inductive power transfer system is validated by the circuit simulations in Matlab/Simulink environment. The proposed IPT is tested to charge wirelessly four electronic mobile smart phones simultaneously.The proposed research is implemented by using high frequency 1-5MHz Half-Bridge topology to mitigate the four parallel transmitting coil size up to 5cm and four receiving coil size up to 3cm. This paper entrust out the numerical, simulation results and hardware implementation for inductive power transfer with maximum efficiency.
Keywords—Wireless power transfer; Inductive power transfer.

1. INTRODUCTION

The wireless power transfer technology has the capability to transfer is electrical energy from a primary source to a load irrespective of some physical contact. It is a wide and interdisciplinary research area. This new technology is capable to charge mobile devices wirelessly and is becoming a popular research field due to the rising interest in charging electronic devices wirelessly such as Laptops, Tablets and Smart Phones. Elimination of cables and connectors increase reliability and maintenance-free operation of such as critical system as in biomedical and multi sensor. To implement a wireless power transfer system, a “Wireless-Transfer-Coupler” is essential for providing power from a power source to a load without physical contact. In Wireless power transfer, an inductive transmitter coupled to a power source transfers the field energy across an intervening distance to one or more receivers’ coils, where it is converted back to an electrical power and then used. Wireless power techniques are divided into two categories, Non radiative and radiative. In non-radioactive techniques, power is is typically conveyed by magnetic fields using inductive coupling between two coils. By means of electromagnetic radiation, power is also transferred in radiative far field techniques like microwave.

The wireless power transfer can be entrust out by means of acoustic techniques, capacitive, microwave, light/laser, inductive power transfer and wireless power transfer strong coupled magnetically resonance. From the above technologies it can be concluded [1], that acoustic techniques has very short distance. Similarly, Capacitive techniques has low efficiency as well as short distance up to 1mm and Microwave, light techniques has reduced efficiency up to 25%. The latest usable inductive contactless energy transfer and wireless power transfer strong coupled magnetically resonance have importance to focus on these because of high efficiency. By looking to the low maintenance cost, higher efficiency and maximum output power (MW), the inductive contactless energy transfer is a big solution for wireless power transfer. [1]- [3].The latest research on inductive power transfer system for electronic devices is to increase its efficiency, distance and frequency. The latest work done on inductive power transfer system for mobile phones are as follows, an inductive power transfer system with an air gap of 3.8cm and coil length 30cm were designed with frequency 8.3 MHz with low efficiency under 10% [2]. For maximum power transfer, impedance matching technique is used. Another inductive power transfer system was designed with 113cm transmission coil size and 30cm receiver coil size with 6.5MHZ frequency. For an efficient system reducing the coil size is essential. Reduction of coil size can be achieved by using higher frequency. Our proposed work is based on non-radioactive technique called inductive power transfer technique. Here we used high frequency Inductive power transfer technique to transmit power through four multiple transmitter coil each of radius 5cm which are connected in parallel. Also we have four multiple receiver coil each of radius 3.5cm receives power and mange to charge all four smart phones. The proposed inductive power transfer smart table can be extended to charge multiple devices wirelessly of different power requirements for example, Laptops, iPads, Mobile phones biomedical sensitive equipment and multi sensors. The configuration and analysis are presented in Section II along with simulation results which are carried out using MATLAB/Simulink environment while section III provides measurements results. Section VI provides a brief conclusion about results obtained

2. THEORETICAL AND SIMULATION MODEL

A. Theoritical Model

In inductive power transfer, it does not certainly guarantee that maximum power will be transferred when maximum efficiency occurs. Also maximum power is transferred only when resonance occur between transmitting and receiving coil. Fig 1 shows a deriving source of frequency with magnetically-coupled resonant circuit. The resonance frequency is represented of Tx by ω_{tx} and for Rx coil by ω_{rx}.

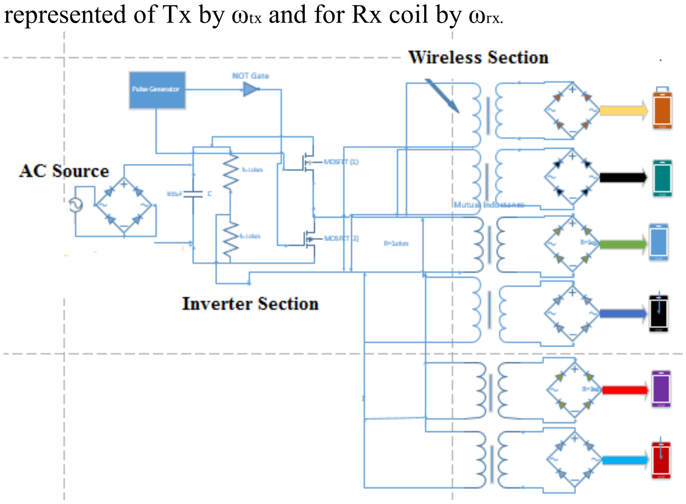

Figure:01 Theoretical Model of proposed multiple wireless charging inductive power transfer.

$$\omega_{rx} = 1\ \sqrt{LrxC2} \quad (1)$$

$$\omega_{tx} = 1/\sqrt{LtxC1} \quad (2)$$

Fig. 1 clearly demonstrates the configuration of the proposed IPT system with multiple receivers. It consists of four transmitting coils and four receivers. The transmitting coil is powered by AC voltage source, and each receiver contain with an Rx coil. The proposed IPT system can deliver power to multiple devices by using four Tx coil. Multiple four identical receivers are simultaneously placed on the corresponding identical Tx coil. To reduce the mutual inductance change due to lateral misalignment of devices, a specific position has been assigned on smart table surfaces to each receiver in hardware implementation. The efficiency η can be defined as the ratio between the total power dissipation in the receiver coils and the total power supplied by the transmitting coils [2].

$$\eta = \frac{R_L|I_2|^2}{(R_S+R_P)|I_1|^2+(R_L+R_P)|I_2|^2} L \quad (3)$$

Also we can obtain maximum efficiency in terms of combined quality factor of two inductors [1].

$$\eta = k_2Q_2/(1+\sqrt{1}+k_2Q_2)\hat{}2 \quad (4)$$

Q represents the combined quality factor of transmitting and receiving inductors. In case of two inductors, it can be defined

$$Q = \sqrt{(Q\_1\ Q\_2)} \quad (5)$$

Q depend on self-inductance and frequency.

As $$k = \frac{M}{L} \quad (6)$$

And $$M = k\sqrt{L_1L_2} \quad (7)$$

The maximum transferred power of the IPT can be expressed as:

$$P_{out=V_1I_1K^2Q_2} \quad (8)$$

Transmitting and receiving coils are designed using copper coil in spiral shape. The coil size is reduced due to H-Bridge high frequency inverter topology. Fig 2 show the spiral shape of transmitting coil. The planar transmitting coil source that maintain loop currents using circular loops is used to create uniform magnetic fields or uniform mutual inductances with respect to the lateral displacement. The proposed parallel Tx coils that has an N turn with the maximum diameter 5cm and also we have parallel Rx coils with maximum diameter of 3.5cm which receive power and operates 4 multiple charging devices. "K" represents the coupling coefficient of a wireless transfer and "Q" represents the quality of a coil. The KQ product is found by multiplying k and Q, and indicates the essential performance of a wireless transfer. The higher value of KQ indicates the higher ability for transferring power. Coupling coefficient "K" inversely related with power transfer, it was believed that transmission efficiency would decline Q factor: if the Q factor is high, the transfer potential can increase even over long distances, that is, when k is low. This proved that it is possible to construct a highly efficient power transfer link if the product of "k' and "Q" is high. For the estimation of KQ product we Consider two coils (loops) are placed near to each other. When a high-frequency current flows in one coil, a current is induced in the other coil. When depicted in a circuit diagram, this is equivalent to a transformer. When the self-inductance of the coil is expressed as L and the mutual inductance between the coils as M, the coupling coefficient is k = M/L. If the angular frequency of the high-frequency power source is ω and the internal resistance of the coil is R, the Q factor is Q = ωL/R. From this, KQ = ωM/R. It was discovered that the kQ product has the following relationship with the maximum efficiency η max of a wireless transfer.

KQ=Tang2α, η max=Tang. Tangα; Where Alpha is efficiency tangent.

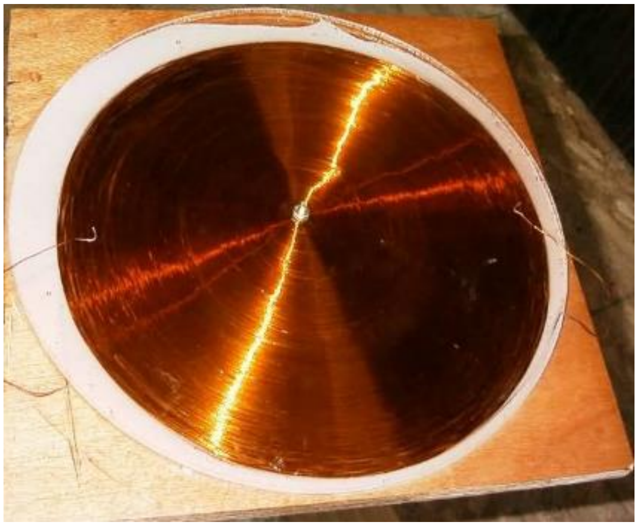

Figure 2 Spiral Coil consisting a number of turns

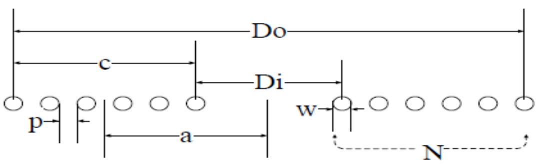

Figure 03. Cross sectional view of spiral flat coil

$$D_i = D_o - 2N(w + p) \quad (9)$$

$$I = \frac{1}{2}N\Pi(D_O + D_i) \quad (10)$$

$$a = \frac{1}{4}(D_O + D_i) \quad (11)$$

$$c = \frac{1}{2}(D_0 + D_i) \quad (12)$$

Flat Spiral coil self-inductance can be found by means of Wheeler approximations. In two cases this formulas cannot be valid when coils have lesser turns and when pitch is smaller than the diameter of coil. Inductance has very less value in such cases so both conditions are not suitable in wireless power transfer. Inductance value is very important parameter in resonance condition. For a single helical layer L will be,

$$L = \frac{N^2((D_{out}-N(w+p))^2 \times 39.37)}{16D_{out}+28N(w+p)\times 10^6} \quad (13)$$

Pitch and No. of turns affects the capacitance of a coil. Capacitance is also depending on relative permittivity and diameter of the coil. It is difficult to calculate C When number of turns increasers because of adjacent winding capacitance. The effect of capacitance on desigh topology is less because C is small and in few pF. Capacitance of coil can be calculated generally as

$$C = \frac{1}{(2\pi f)2L} \quad (14)$$

B. Representation of the Simulation Results

The simulations of the proposed work are done in Matlab software. Some results are shown in Table. I which calculated on the basis of simulation parameters.

Table .I Simulation results

K	F(MHz)	Q	M	ŋ	P_r
0	0.043	9.55	0	0	0
0.02	0.043	9.55	1.4E-06	0.895	0.0004
0.04	0.043	9.55	2.8E-06	3.402	0.0016
0.08	0.043	9.55	5.7E-06	11.44	0.0064
0.1	0.043	9.55	7.1E-06	16.06	0.010
0.15	0.043	9.55	1.1E-05	27.19	0.022
0.18	0.043	9.55	1.3E-05	33.07	0.032
0.2	0.043	9.55	1.4E-05	36.62	0.040
0.22	0.043	9.55	1.6E-05	39.87	0.049
0.26	0.043	9.55	1.8E-05	45.6	0.068
0.28	0.043	9.55	2E-05	48.11	0.079
0.3	0.043	9.55	2.1E-05	50.42	0.091
0.36	0.128	28.4	2.5E-05	82.27	0.3900
0.38	0.128	28.4	2.7E-05	83.12	0.4300
0.4	0.128	28.4	2.8E-05	83.89	0.4800
0.52	0.128	28.4	3.7E-05	87.35	0.8100
0.56	0.128	28.4	4E-05	88.2	0.9400
0.58	0.128	28.4	4.1E-05	88.58	1.0100
0.60	0.128	27.1	4.2E-05	88.42	1.0300
0.64	0.128	27.1	4.5E-05	89.1	1.1700
0.67	0.128	27.1	4.7E-05	89.56	1.2800
0.70	0.128	27.1	4.9E-05	89.99	1.4000
0.72	0.128	27.1	5.1E-05	90.25	1.4800
0.76	0.128	27.1	5.4E-05	90.74	1.6500
0.78	0.128	27.1	5.5E-05	90.96	1.7400
0.80	0.128	27.1	5.7E-05	91.18	1.8300
0.82	0.128	27.1	5.8E-05	91.39	1.9300
0.85	0.128	27.1	6E-05	91.68	2.0700
0.90	0.128	27.1	6.4E-05	92.12	2.3200
0.94	0.128	27.1	6.6E-05	92.44	2.5300
0.98	0.128	27.1	6.9E-05	92.74	2.7500

1.00	0.128	27.1	7.1E-05	92.88	3.0000

A bridge rectifier has been used as a first part of transmitting section to rectify the AC voltage. The same output rectified signal is feed into a high frequency signal to change frequency up to MHz limit. MOSFTES are used for generating high-frequency switching in inverter section. The inverted high frequency voltage is fed through a coil to generate a magnetic field. This magnetic-field is linked with a secondary coil through mutual induction. Power is transferred wirelessly by means of mutual induction in wireless section. Ability of power transferring is inversely related with air gap between primary and secondary coils. Efficient is mostly depending on quality factor of coils.

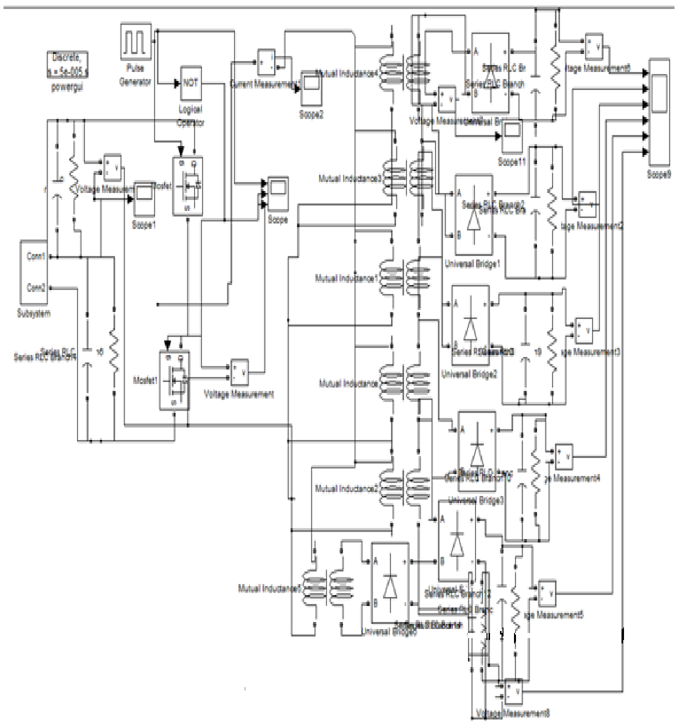

Figure 3 MATLAB/Simulink Simulation Model

Graphical results obtained from above simulation model are shown below in figure 4.

C. SIMUALTION RESULTS

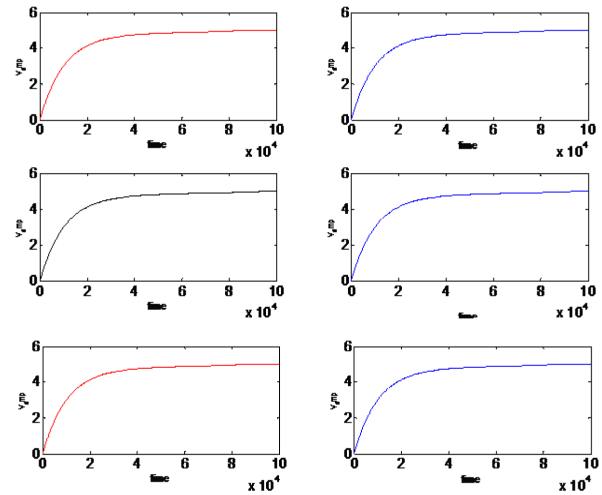

Figure 4.Output voltage at transmitting coils

Hardware set Up are given below in figure 05.

Figure 5: Hardware set up consisting of four receivers coils on the top of Table.

Four receiving coils are shown above smart table while transmitting coils are merged under the table.

3. CONCLUSION

The proposed wireless power transmission through inductive Coupling worked on the principal of mutual inductance. The inductive power transfer technique was implemented here. The System was analyzed numerically for higher efficiency above 85% with smaller coil size. The same theoretically model was implemented in MATLAB/Simulink environment. Simulation results were matched with numerical results. Using parallel transmitting coils, power can be transferred safely to receivers without abrupt change in voltage.

4. REFRENCES

[1] M. P. Kazmierkowski, R. M. Miskiewicz, and A. J. Moradewicz, "Inductive coupled contactless energy transfer systems-A review," *2015 Sel. Probl. Electr. Eng. Electron. WZEE 2015*, 2016.

[2] B. L. Cannon, S. Member, J. F. Hoburg, D. D. Stancil, S. C. Goldstein, and S. Member, "Magnetic Resonant Coupling As a Potential Means for Wireless Power Transfer to Multiple Small Receivers," *IEEE Trans. Power Electron.*, vol. 24, no. 7, pp. 1819–1825, 2009.

[3] D. Ahn and S. Hong, "Effect of Coupling Between Multiple Transmitters or Multiple Receivers on Wireless Power Transfer,"*IEEE Trans. Ind. Electron.*, vol. 60, no. 7, pp. 2602–2613, 2013.

[4] J. Kim, D. Kim, S. Member, and Y. Park, "Free-Positioning Wireless Power Transfer to Multiple Devices Using a Planar

[5] Transmitting Coil and Switchable Impedance Matching Networks," *IEEE Trans. Microw. Theory Tech.*, pp. 1–9, 2016.

[6] Mandip Jung Sibakoti and Joey Hambleton Cornell College, Professor Derin Sherman PHY312, "Wireless Power Transmission Using Magnetic Resonance" December 2011.

[7] Muhammad H. Rashid, ―Power Electronics: Circuits, Devices, and Applications, pp.37-63, 2nd Edition, 2000.

[8] S. Yoshida, M. Tanomura, R. A. Chinga, J. Lin, Wei-ting Chen: "A 13.56 MHz Rectifier with Efficiency-Improving Harmonic-Termination Circuit for Wireless Power Transmission Systems".

[9] Switchable Impedance Matching Networks," IEEE Trans. Microw. Theory Tech., pp. 1–9, 2016.

[10] J. Zhang, C. Zhu, and C. C. Chan, "A Wireless Power Charging Method for Automated Guided Vehicle," 2014 IEEE Int. Electr. Veh.