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Loads Estimation for Multi-Receiver Wireless Power Transfer System

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Abstract—It is still a delusion that the transmitter coil is able to drive multiple loads (electrical/electronic devices) in multi-receiver Wireless Power Transfer (WPT) system. Nevertheless, it is found that for a fixed design, the number of receiver load coils that can be driven with their stipulated power level is not selected randomly rather with definite number. The circuit model analysis of series-series compensated multiple-receiver WPT system is proposed in order to estimate the number of loads with respect to the transmitter coil. Both theoretical simulation and experimental studies have proven this finding, and the results obtained are important for designing an effective multiple-receiver WPT system.

1. INTRODUCTION

Wireless power transfer mechanism for driving multiple loads is recently in demand due to gigantic advancement in consumer portable electronic devices. The feasibility of the wireless power transfer to multiple loads has been widely well studied and proven to be efficient as well as comparatively better in terms of power delivery ability [1–6]. Multi-receiver WPT systems have gained many successful applications with the provision of power division and control among the receivers as well as selective power transfer to the receiver [7–14]. However, depending on the application, a multi-receiver WPT system requires to transport predestined power level to the loads which necessitates the estimation of the driving capabilities of the system. This letter reports the investigation on the number of loads that will be driven by the transmitter coil in the multi-receiver WPT system fulfilling the predefined power level at the load. It has been found that with a required load power level, the number of receivers that will be driven must be less than or equal to the estimated value, which merely depend on the frequency of operation (f), the designed dependant parameter (M), and the load impedance (R_L).

2. ELECTROMAGNETIC CIRCUIT MODEL ANALYSIS

The circuit equivalent model of a typical series-series compensated multi-receiver WPT system is illustrated in Fig. 1. With n number of similar receiving coils, the reflected impedances (Z_r) seen at the transmitter side calculated [15, 16] are as follows:

$$Z_{r(i=1,2,\ldots,n)} = \frac{(\omega M_{0i})^2}{Z_{Ri}} = \frac{(\omega M_{0i})^2 \left(R_{Ri} + R_{Li} - j\omega L_{Ri} - \dfrac{j}{\omega C_{Ri}}\right)}{(R_{Ri} + R_{Li})^2 + \left(\omega L_{Ri} - \dfrac{1}{\omega C_{Ri}}\right)^2} \tag{1}$$

where M_{0i} = Mutual inductance between the transmitting and receiving coils.

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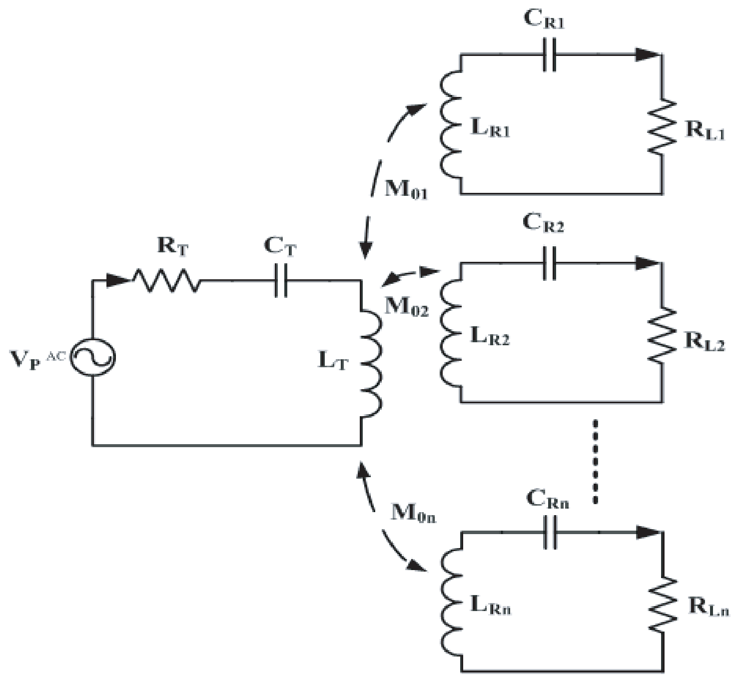

Figure 1. Circuit equivalent model of multi-receiver WPT system.

R_{Li} = Load resistance of the ith receiving coil.
R_{Ri} = Effective series resistance of the ith receiving coil.
R_{Ri} = Effective series resistance of the ith receiving coil.
R_T = Effective series resistance of the transmitting coil.
L_{Ri} = Inductance of the ith receiving coil.
C_{Ri} = External capacitance connected in series with the ith receiving coil.
ω = Frequency of operation in radian.

Considering that all the receiving loads are equi-spaced with respect to the transmitter, the mutual coupling coefficient can be expressed as:

$$M_{01} = M_{02} = \ldots = M_{0n} = M$$

The parameter M indicates the mutual inductance between transmitting and receiving coils which is defined as the emf induced in one coil as a result of unit rate of change of current in the neighboring coil. It is very much specific to the design and dimension of the coils used.

The received load power at each individual receiving load will be given by:

$$P_{L(i=1,2,\ldots,n)} = \frac{P_R}{R_{Ri} + R_{Li}} R_{Li} = \left[\frac{V_P}{R_T + \sum_{i=1}^{n} \frac{(\omega M)^2}{R_{Ri} + R_{Li}}} \right]^2 \frac{(\omega M)^2}{(R_{Ri} + R_{Li})^2} R_{Li} \tag{2}$$

where P_R = Power received at the receiving coil and V_p = RMS value of the supply voltage.

By ignoring R_T, Equation (2) is simplified as:

$$P_{Load(i=1,2,\ldots,n)} = \frac{V_P^2 R_{Li}}{n^2 (\omega M)^2} \tag{3}$$

The total load power delivered to n number of identical loads (R_L) will be

$$P_{Load} = \frac{V_P^2 R_L}{n (\omega M)^2} \tag{4}$$

From Equation (4), with a required rated load power (P_{Rated}), the number of loads that can be driven through the WPT system will be

$$n = \frac{V_P^2 R_L}{P_{Rated} \cdot (\omega M)^2} \tag{5}$$

From the aforementioned equation, with a required load power level, the number of loads that can be driven depends on the frequency of operation (f), the designed dependant parameter (M), and the load impedance (R_L).

3. EXPERIMENTAL DESIGN SETUP FOR MULTI-RECEIVER WPT SYSTEM

The experimental setup shown in Fig. 2 has been designed for a three-load receiver coils WPT system to verify the theoretical analysis based on the circuit parameters. The transmitter coil is connected to a high frequency input power source of 5 V_{RMS} through a high frequency power amplifier. All the coils resonate at a particular frequency as they are all dimensionally equal. The three receiver coils with identical load are kept at the same vertical plane with an air gap 5 cm apart from the transmitter coil. In order to accomplish the experiment, load resistors of different values are connected in series with the receiver coils.

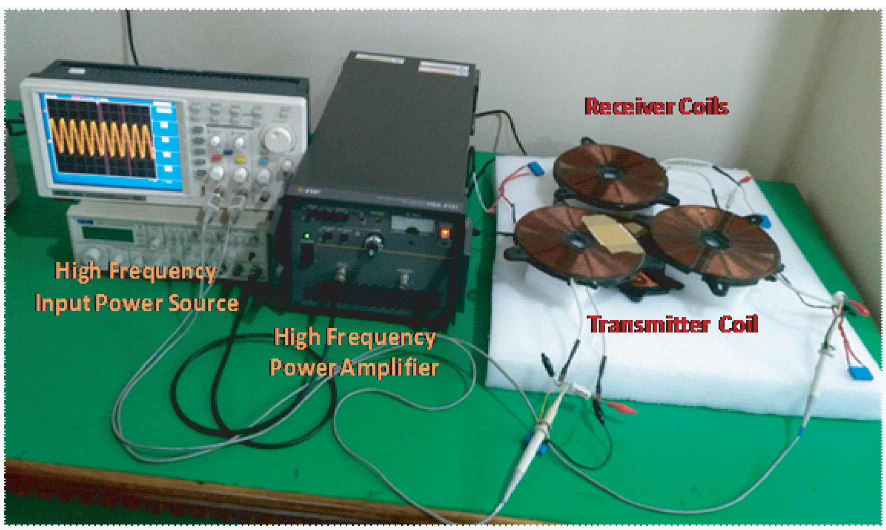

Figure 2. Experimental set up for three-Load WPT system.

The transmitting coil and all receiving load coils are made up of copper wire, identical circularly configured having number of turns 14, each with radius 0.075 m and pitch of 0.01 m. All the coils have inductance around 18.4 µH and effective series resistance of 1.1211 Ω. Series/Parallel staggered external capacitors of single capacitance value 4.7 nF are connected in series with the receiver coils to drive them at different resonant frequencies. The equivalent series resistance of capacitors and source internal resistance are very small, so can be ignored. The mutual inductance between the transmitting coil and individual receiving coil is measured to be 0.574 µH, when centre-to-centre air gap is 5 cm.

4. RESULTS AND DISCUSSION

The theoretical simulation and experimental results of multi-receiver WPT system are elucidated in this section to demonstrate the delivered load power characteristics. The load power characteristics correspond to different operating frequencies in two-load, three-load, and five-load receiver WPT systems have been exemplified in Fig. 3. It is observed that the delivered load power gradually decreases as the number of load receiver coils increases.

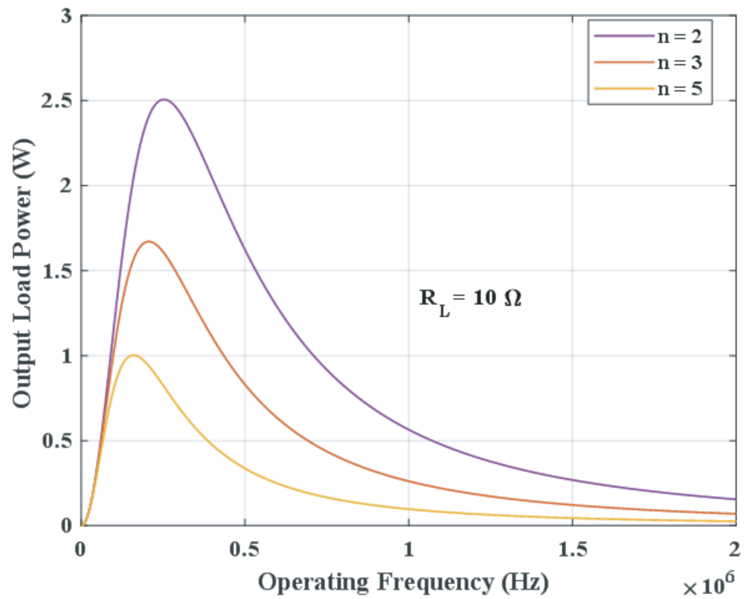

Figure 3. Frequency characteristics of output load power.

Again, it has been found that there is an optimal load value that corresponds to maximum power delivered to the loads in a multi-receiver WPT system. The optimal load values differ as the number of receiver coils changes. The best load value increases as the number of receiver coils in the multi-receiver WPT system increases.

The calculated and experimental results of delivered load power versus receivers load resistance for three-load at resonance frequency of 0.2 MHz are illustrated in Fig. 4.

The results show that the maximum load power from the experiment is 1.42 W when the load resistance is 11 Ω, compared to the calculated value 1.68 W for load resistance 12 Ω. Hence, it is

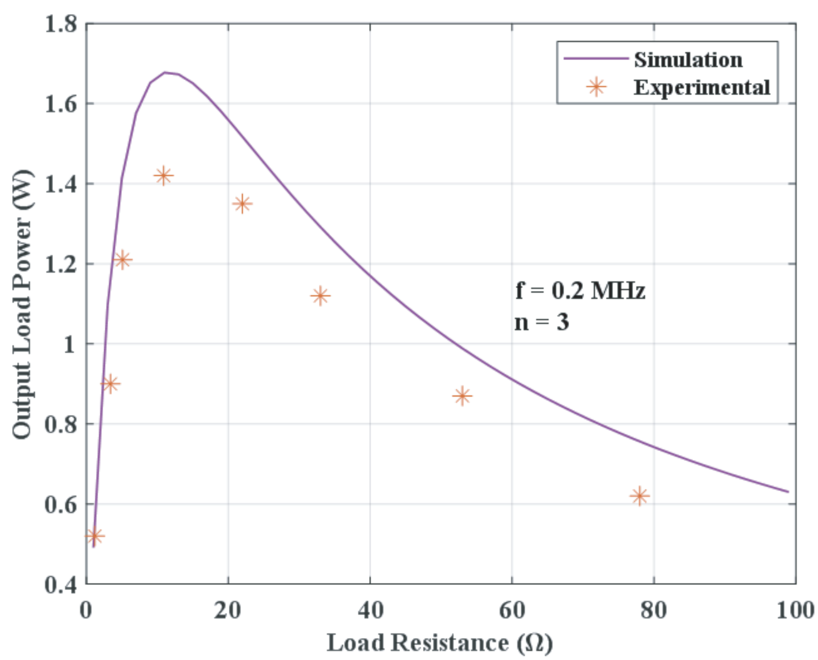

Figure 4. Calculated and experimental results for three-load WPT system.

ascertained that this system can drive three-loads with a maximum output load rated power of 1.42 W. If we need to drive loads with more rated power as above, then the number of receiver loads must be reduced. Evidently, an optimal load exists for a given number of loads corresponding to the resonant frequency, which is well agreed from the results.

5. CONCLUSION

Both theoretical and experimental measurements are carried out to analyze the load power characteristics. It is found that power levels across the loads decline with increase in the number of receiver load coils corresponding to a particular operating frequency. So, it necessitates the estimation of load in a multi-receiver WPT system to drive them at their predetermined power level. Again, it has been found that there is an optimal load value that corresponds to maximum power delivered to the loads. The optimal load value differs as the number of receiver coils changes. The results obtained will be important in designing an effective multi-receiver load WPT system.

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