A Review on Wireless Power Transfer

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Abstract: ***This paper is a review of the various designs put forward by various people regarding the Wireless Power Transfer (WPT). Here the designs have been discussed, along with the purpose that the design can be used for, the efficiency of the power produced and also the ways to improve the efficiency of the design. The values of various parameters and diagrams used are based on the experimental results of various researchers. Finally, a suitable conclusion has been drawn regarding the best design, which can be used for WPT taking into consideration the various associated factors that have been discussed here.***

Keywords: Wireless Power T (WPT), Inductive Coupling-coil Optimization, Class E^2 DC-DC converter, Maximum DC-DC efficiency, Particle Swarm Optimization, Class E rectifier, Resonant wireless power transfer, Power Conversion Efficiency (PCE).

1. Introduction

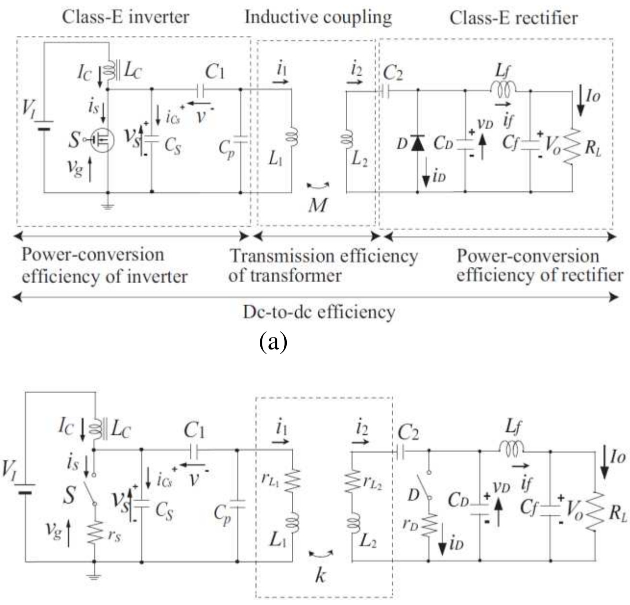
Today's world is governed by various new invention and technological advancements. Life is now quite easier; everything is just a click away. We have wireless Internet, phones, laptops, earphones and so on; wireless pieces of stuff are the new trend of the generation. Still, at some point of the day, we are still tied to the codes as all those devices have batteries, which need to be recharged and for that, we have to plug in the devices. So why not design a Wireless Power Transfer (WPT) device. Wireless Power Transfer (WPT) will be of great help not only for our day-to-day lives but also in the medical field. In our day-to-day lives, we will not have to limit ourselves to the use of a cord. In medical, it will be a convenient way to supply power to small implanted devices such as pacemakers and many more. Now we know Wireless Power Transfer (WPT) can be of great use, but with that, a series of questions arise like: Is WPT even possible? If yes, then how to construct such a device that will provide WPT? What will be its efficiency? …and many more.

There are numerous researches going on with WPT and various designs are being put forward having different efficiency levels depending upon the purpose they are going to serve. In this paper, some of the designs will be reviewed and respective uses and efficiency will be discussed.

2. Wireless Power Transfer Designs

Wireless power transfer (WPT) is the transmission of electrical energy from a power source to an electrical load, such as an electrical power grid or a consuming device, without the use of discrete human-made conductors. The various designs discussed in this paper are as follows:

(i) Researchers Takumi Noda *et al*. in their research titled "Design Procedure for Wireless Power Transfer System with Inductive Coupling Coil Optimization Using PSO" [2], presented a design procedure for the WPT system based on the class-E^2 dc-dc converter, taking into account the inductive coupling-coil optimization.



(a)

(b)

Fig. 1: Class-E^2 WPT System: (a) System Overview (b) Equivalent circuit model for dc-to-dc efficiency calculation

Here dc-to-dc efficiency, defined as the ratio of the output power to the input power namely the dc-to-dc efficiency, includes the transmission efficiency of the coupling coils, and power conversion efficiency of the power converter. A class-E switching circuit is used because the class-E inverter and the class-E rectifier satisfy zero-voltage switching and the Zero-Derivative Switching (ZVS/ZDS) condition and the WPT can achieve a high dc-to-dc efficiency at high frequencies because of the zero switching loss in the power converter.

By using the analytic expression, the authors mentioned that it was possible to express the coupling part as a transformer model with low coupling coefficient, which is a function of the physical parameter such as a coil diameter, coil height and so on. The Particle Swarm Optimization (PSO) is used for reducing the computational complexity. Moreover, the laboratory measurements agreed with analytical design predictions, which show the validity and usefulness of the proposed design procedure. The dc-to-dc efficiency is a cost function with is maximized by using PSO algorithm. They used an air core coil as the core materials are limited by the operating frequencies and it is difficult to obtain a desired shape of the core.

The main challenge faced while constructing this type of WPT is the necessity to obtain proper components value accurately, which is a design problem of class-E circuit design. Through experimental verification, it is seen that the measured dc-to-dc efficiency at 3.0 cm coil distance was 81.1% at 12.8 W output and 1MHz operational frequency. The efficiency can further be increased by using class-EF or class-E/F^3 inverters as they produce 43% and 24% more power than that of a class-E inverter respectively.

(ii) Authors Pham Tuan Anh and M. Chen in their research titled "Design and Optimization of High Efficiency Resonant Wireless Power Transfer System" [3], have used the concept of magnetic resonant coupling as it is the most promising candidate for the midrange transfer of power because of its long range and compact dimension. And also the concept of high-efficiency Resonant Wireless Power Transfer (RWPT) system as it discusses the optimal parameters for maintaining high power transfer efficiency with respect to distance and load variation.

The circuit representations are shown below in Figures 2(a), 2(b) and 2(c).

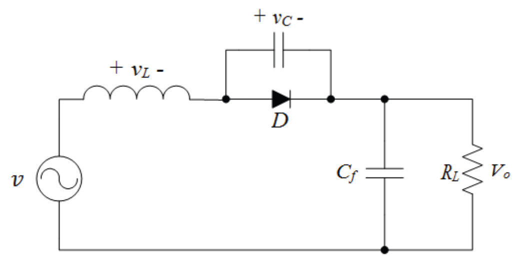


Fig. 2(a): Class E resonant voltage-driven low dv/dt rectifier circuit.

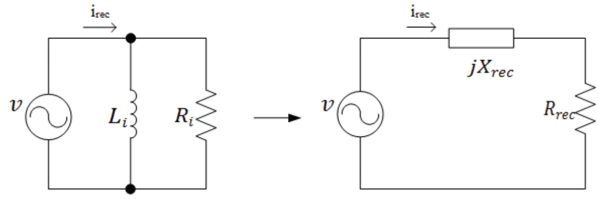


Fig. 2(b): Circuit model for the input impedance of the class E resonant voltage-driven low dv/dt rectifier

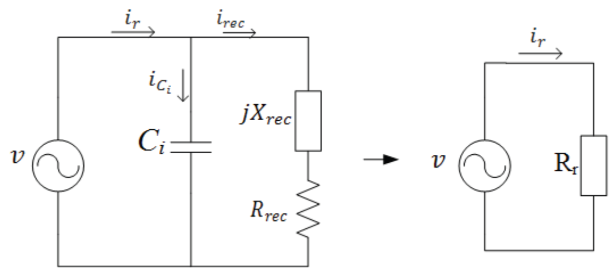


Fig. 2(c): Rectifier impedance with a parallel capacitor

The proposed system consists of a class-E amplifier with a 6.78 MHz resonant frequency coupling coils and a class E rectifier. It can be used in a variety of application such as biomedical devices, automotive systems, industrial manufacturing and some consumer electronics while operating at high levels (such as 6.78 MHz and 13.56 MHz), which can enable charging multiple devices simultaneously.

The output voltage V_0 produced in this case is DC and ripple free. To minimize the voltage and current stress on the diode, as shown in Fig. 2(a), a class-E rectifier is usually designed to have a 50% duty cycle for the rectifying diode. In addition, to improve the power factor of the rectifier a capacitor is introduced in parallel with Z_i as seen in Fig. 2(c). The power factor of the combined load capacitor impedance is unity.

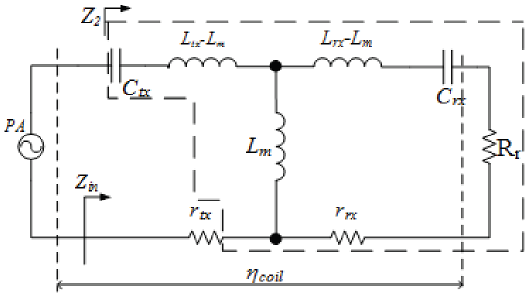


Fig. 2(d): Circuit model of coupling coils

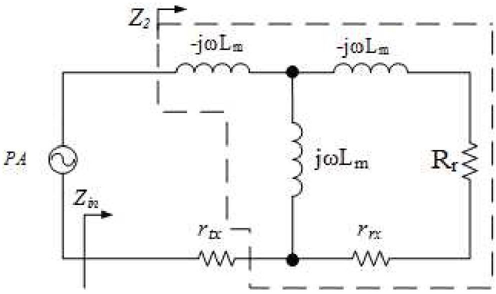


Fig. 2(e): Circuit model of coupling coils at resonant frequency

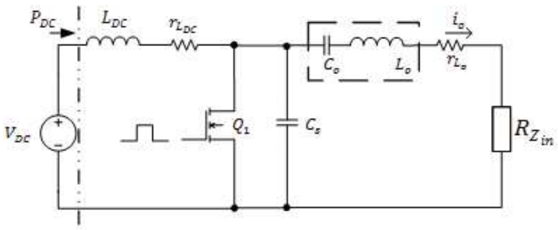


Fig. 2(f): Circuit model of the class E power amplifier

The Figures 2(d), 2(e), and 2(f) represent the circuit model of coupling coils, the circuit model of coupling coils at the resonant frequency and the circuit model of the class-E power amplifier respectively.

After stimulating the RWPT system using MATLAB Simulink, a resonant efficiency of 93% was achieved when the mutual inductance coefficient of k = 0.2 was taken at a resonant frequency of 6.78 MHz.

(iii) The authors Hiroto Sakaki *et al.* in their research titled "A Novel Wide Dynamic Design for Wireless Power Transfer System" [1], proposed a novel wide dynamic range rectifier for Microwave Wireless Power Transfer (MPT). The key component of MPT is a high-efficiency RECTENNA (Rectifier + Antenna). They proposed a new topology for a wide range dynamic rectifier without switches (i.e. no switching loss at all) that achieves high RF-DC power conversion efficiency. This idea is founded on two types of diode that have different threshold voltages. One is a low threshold voltage diode (HSMS-285: Avago Tech). The other is a high threshold voltage diode (HSMS-286: Avago Tech). The circuit representation is shown below in Figures 3(a) and 3(b).

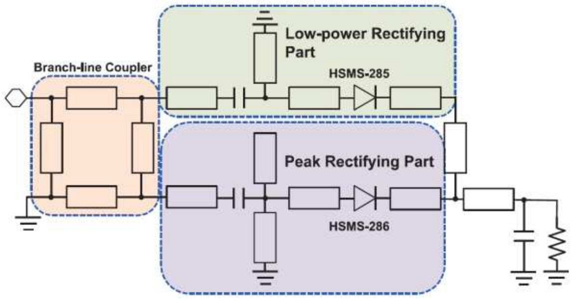


Fig. 3(a): Proposed wide dynamic range rectifier

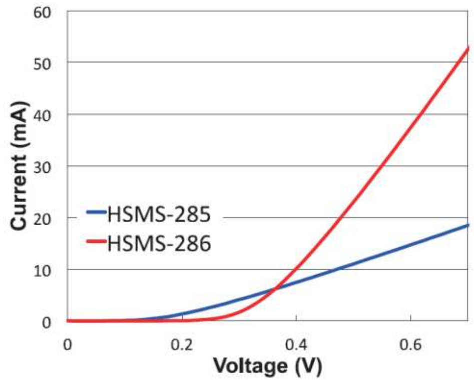


Fig. 3(b): Current-Voltage Characteristics of these diodes

The red line is for HSMS-285 and the blue line for HSMS-286. HSMS-285 deals in case of low input power; whereas HSMS-286 deals with high input power (HSMS-285 is also active at high input power). The proposed rectifier configuration at two different configurations can be better understood from Figures 3(c) and Fig. 3(d), which represent the operation at low-level input and at high-level input.

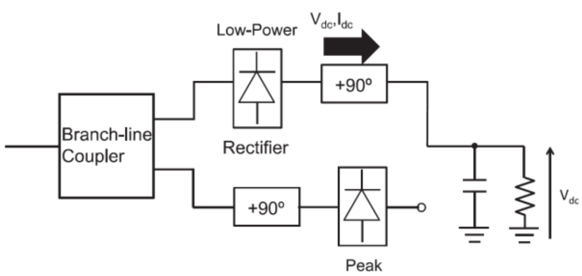


Fig. 3(c): Proposed Rectifier Configuration (Operation at low input levels)

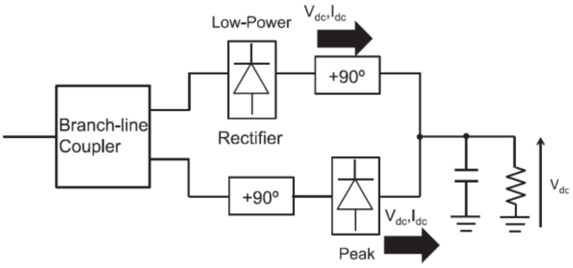


Fig. 3(d): Proposed Rectifier Configuration (Operation at high input levels)

During the low input level, only low-power rectifying part is active whereas the peak rectifying park is inactive as the input power is not enough to turn on the peak rectifier. But, in case of high input level both the parts, namely low power rectifying part and peaking rectifying part are active. The F-DC power conversion efficiency is given by:

$$\eta = \frac{V_{in}^{2}}{P_{in} \bullet R_{out}} \times 100$$

where η, P_{in}, V_{in}, R_{out} are Power Conversion Co-efficient, RF Input Power, DC Output Power, and Optimum Load Resistance respectively. The dynamic range of power conversion efficiency in excess of 50% is 4 dB higher than those alternatives reported in the research [1], which validates the proposal. The net efficiency of this model is 89%.

3. Conclusion

Wireless Power Transfer (WPT) is the transmission of electrical energy from a power source to an electrical load, such as an electrical power grid or a consuming device, without the use of discrete human-made conductors. We have discussed three different designs for WPT having different efficiency levels when operated at their respective domains. Out of these three pieces of research reviewed here, the model proposed by P. T. Anh and M. Chen [3] can be considered the most efficient of all at its respective domain. Other than that; for more dynamic design, the design proposed by H. Sakaki *et al.* [1] can be used as it offers more flexibility regarding performance. For more details, one can refer to their respective analysis. Various other designs for WPT are also available, one can choose depending on its requirements.

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