Resonant Circuit Response for Contactless Energy Transfer under Variable PWM

A. Badawi, S. A. Kazmi, R. I. Boby, M. H. Shah, and K. Matter

***Abstract*—This paper presents an analysis and performance simulation of series resonant medium used for energy transfer. It uses soft switching for operating the active elements, turning them on and off without major losses. Simulation results comprise of output voltage variation based on the PWM modulation from 0% ~ 100% with step size of 20% in order to exploring appropriate relationship. The major objective of this work is to obtain the highest possible response based on the set parameters of modulation and resonant frequency. The effect of Pulse Width Modulation is studied for maximum power transfer at a given resonant frequency forcing to realizing a DC-DC converter. The converter behavior deviating from the resonant frequency is also discussed. The current distribution in the primary and the secondary turns of windings varies significantly because of the massive change in magnetizing inductance. Simulation results are representative of theoretical expectations.**

***Index Terms*—Dc-dc converter, soft switching, inverter, PWM modulation, contactless energy transfer.**

I. Introduction

Contactless power transfer is revolutionary technique in the arena of wireless power and communications among wireless technologies, which are widely integrated into versatile range of products, providing new stages of interaction, convenience, and applications. End user's expectation have elevated for better convenience, reliability and innovative products. The research idea is an innovative idea, which is not familiar model in developed within designated electrical area. The research aims to design a model and develop a small scale wireless power transfer (WPT) system via resonance inductive coupling wireless power technique to deliver the power at high resonant frequency [1] to achieve highly power efficient model.

Switched-mode Pulse Width Modulation (PWM) employing in resonant-mode converters are used in wide range of applications, comprising of computer's power supplies, office equipment, laptop, spacecraft power systems, telecom instrumentation, and DC motor drives [2].

Contactless energy transfer (CET) block diagram is as shown in Fig. 1. In a CET system is used electromagnetic waves, electric field [3, 6], light [5, 15], and in acoustic waves (ultrasonic) [4] as the "medium" of transfer. Among the most demanding implications, the core of contactless energy transfer CET systems is the characterized in terms of physical isolation between source and load by transformer as inductive, which is dominantly dependent on inductive coupling coefficient [7] between power source and load, and high frequency switching for power electronic converter for energy flow control [8].

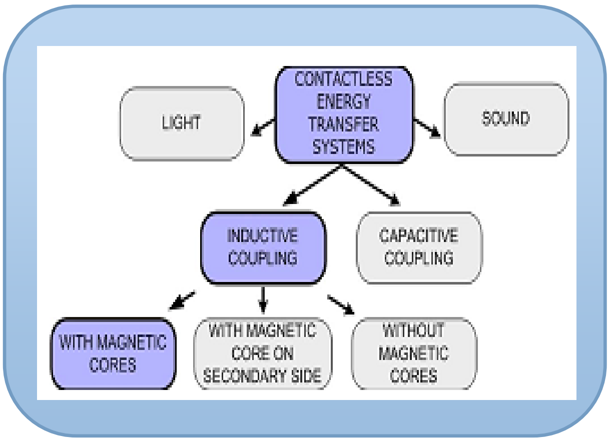

Fig. 1. Classification of CET systems.

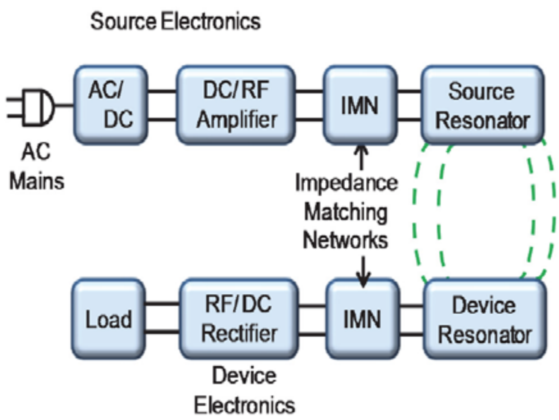

Fig. 2. Block diagram of wireless power transfer [4].

Broadly speaking the highest level of implementation for contactless power transfer by resonant circuit is the most effective wireless power Transfer techniques. High efficiency performance is one of the main reasons why the resonant circuit and especially series loaded resonant SLSR power converters are gaining popularity for use in WPT

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"Resonant Circuit Response for Contactless Energy Transfer Under Variable PWM"

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technology [9] because of their capabilities for soft-switching, high-frequency operation, minimum volume and weight—all result in low implementation and subsequent maintenance cost, high reliability and highest efficiency. The objective of this paper is to implement and analyze an SLSR converter used for contactless applications [16].

II. Power Transfer Efficiency

Based on the rate determination of gain-bandwidth (Q factor), the oscillations will lessen losses dominantly due to the radiative, and resistive losses. However, as the secondary coil voltage depends on cutting the induced field, and hence the maximum energy getting coupled to secondary greater than the losses in each cycle in primary, hence most of energy can be transferred.

The primary coil forms a series RLC circuit and the Q factor for such a coil is:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{1}$$

To build an efficient power transfer system, we need to increase Q “quality factor in which case only a small amount of the field of percentage must be coupled from one coil to the other to achieve high efficiency performance, even though the electric field linked decreases significantly with distance increase from a coil, the primary and secondary can be several centimeters apart.

It can be shown that a figure of merit for the efficiency is

$$U = \sqrt[k]{Q1Q2} \tag{2}$$

where k determines, coupling coefficient related to L1 and L2, M---the self-inductances in primary and secondary coils, and their mutual inductance, by

$$k \frac{M}{\sqrt{L1L2}} \tag{3}$$

Accordingly, Q1 and Q2 represent the quality factors of the transmitter and receiver coils. And the maximum efficiency of the wireless power transfer can be calculated by following the technique detailed in [11].

$$\eta_{opt} = \frac{U^2}{1+\sqrt{1+U^2}} \tag{4}$$

Thus, in order to increase the absolute power transfer amount, power density depends on the distance and coil technology. The voltage gain of resonantly coupled coils is directly proportional to the square root of the ratio of secondary and primary inductances [11] for parallel and series topology of wireless power transfer.

$$A = \Big)\frac{L2}{L1} \tag{5}$$

Resonance inductive coupling wireless power transfer technique is developed for transferring of energy in high frequency (MHz) range. At this frequency and the Impedance is matched between source and load to maximize the power transfer. The circuit is oscillating at resonant frequency causing impedance between input and output is equivalent or minimum and transfers function at maximum [10]. The resonant frequency is given by,

$$fr = \frac{1}{2\lambda\sqrt{LC}} \tag{6}$$

It is proved that the maximum power transfer efficiency occurs at the resonance Frequency, f0, and the maximum power is transferred at this frequency or fL and fH at obtained as:

$$fL = \frac{fo}{\sqrt{1+k}}, \quad fH = \frac{fo}{1-k} \tag{7}$$

There are two frequencies, fL and fH, over which the input and transfer powers reach their maximum values. The maximum transfer efficiency at the resonance frequency, f0, located in the frequency boundary of fL< f0 <fH the desirable frequency range, over which acceptable transferred power and efficiency are obtained, can be obtained as:

$$BW = fH - fL \tag{8}$$

III. Series LC and Parallel LC Power Transfer Efficiency

There are two resonant typologies (LC parallel and LC series) in order to transfer power wirelessly. The difference between series and parallel LC circuits for their performances and efficiency is interesting to be explored, showing series loaded series resonant (SLSR) as most popular for use in power converters [9].

The characteristics of series resonant converter become more predictable and reliable based on combination of resonant capacitor and series transformer reactance [9]. The transmitter side, it is proven that the voltage source in parallel resonant mode is interchangeable with the current source in series resonant mode, under a certain transfer equation, in such a way to have the same output status. And on the receiver end, the topology selection is proven to be related with load. For heavy load, the parallel topology has more advantages, while for light load; the series topology is a more preferable choice. The equation of the critical load point is deduced in [12].

Due to physical electric contacts elimination factor, this may consider to be safer and consistent power transfer to various devices in very harsh environments implications for instance material handling, semiconductor manufacturing workshops and transportation. Moreover, power converters pertain the circuit transient process is are complex and hard to analyses. In consequence, any sort of unexpected current and voltage overshoots during initializing and load transients can spoil the switching devices or other components [13].

IV. Methodology

PWM is generated at resonant frequency to transfer the max power by the mean of switching and contactless energy transfer technique.

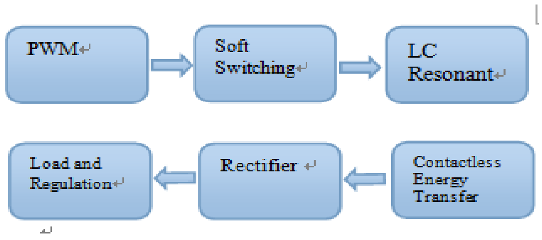

Fig. 3. Block diagram of methodology process.

The ratio of on-time to the total time period (the sum of both on-time and off-time) is called the duty cycle and ranges from 0% to 100% [9].

V. Simulation and Results

The parameters have been adjusted in such a way that a PWM sequence is generated at resonant frequency of 38 kHz with 20V voltage level. The oscilloscopes are allocated in such a way that the output can be seen for varying duty cycle of PWM providing us an analysis of output achieved to maximum voltage level for corresponding duty cycle of PWM of DC-to-DC convertor.

Oscilloscope 1 presents the connections of PWM whereas oscilloscope 2 shows the connection of VT and current wave-shape accordingly for above shown circuit in Fig. 4.

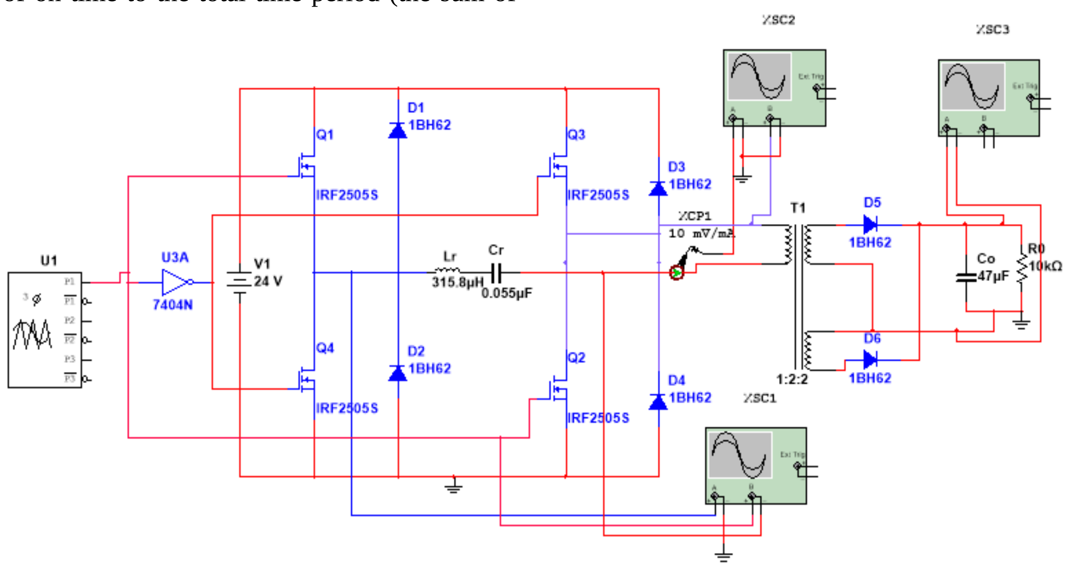

Fig. 4. Circuit schematic simulation.

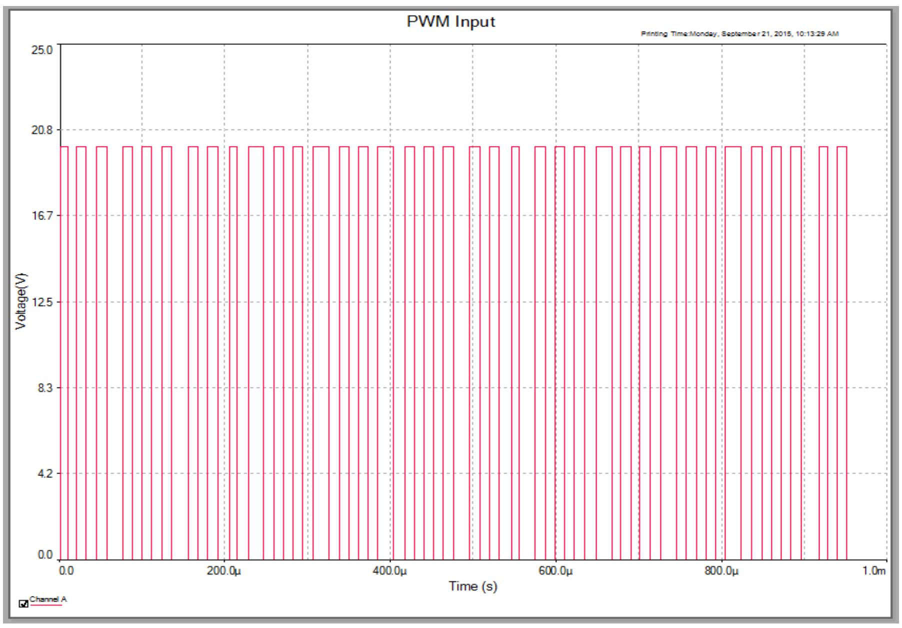

Fig. 5. PWM input to MOSFETs.

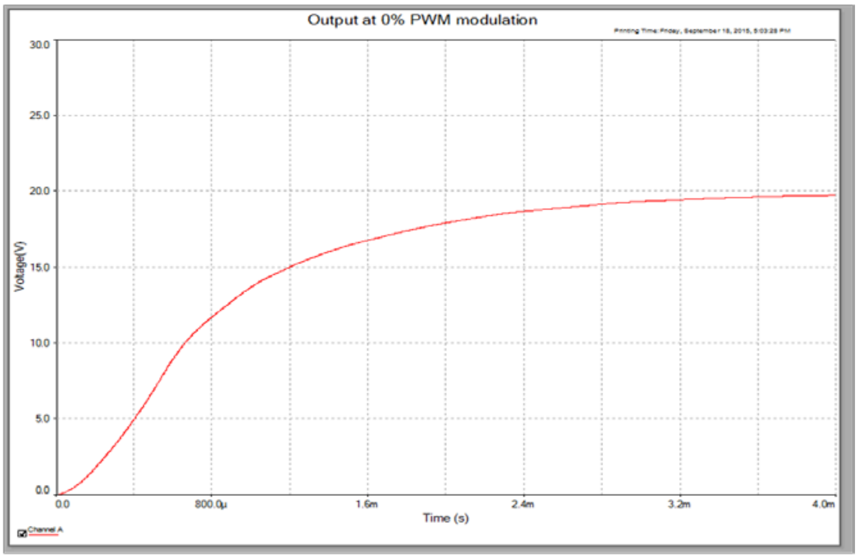

Fig. 6. Output at 0 % PWM.

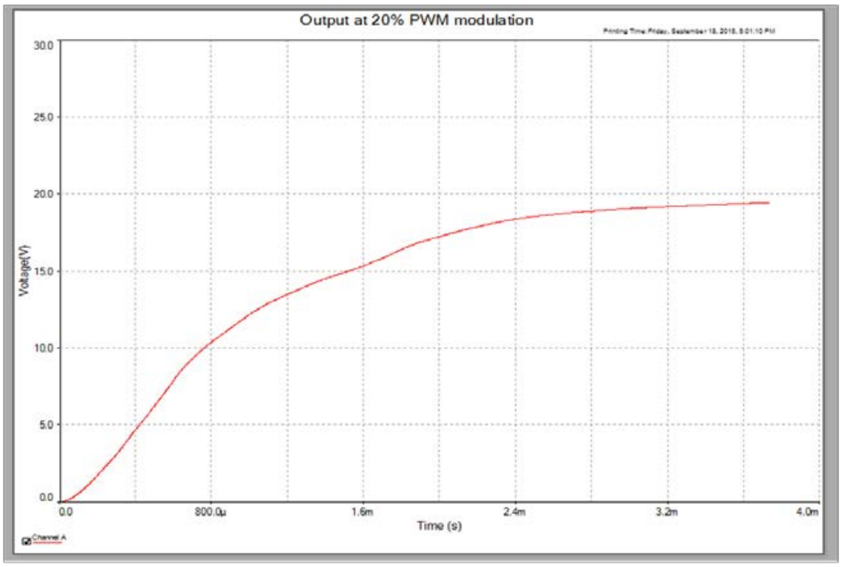

Fig. 7. Output at 20 % PWM.

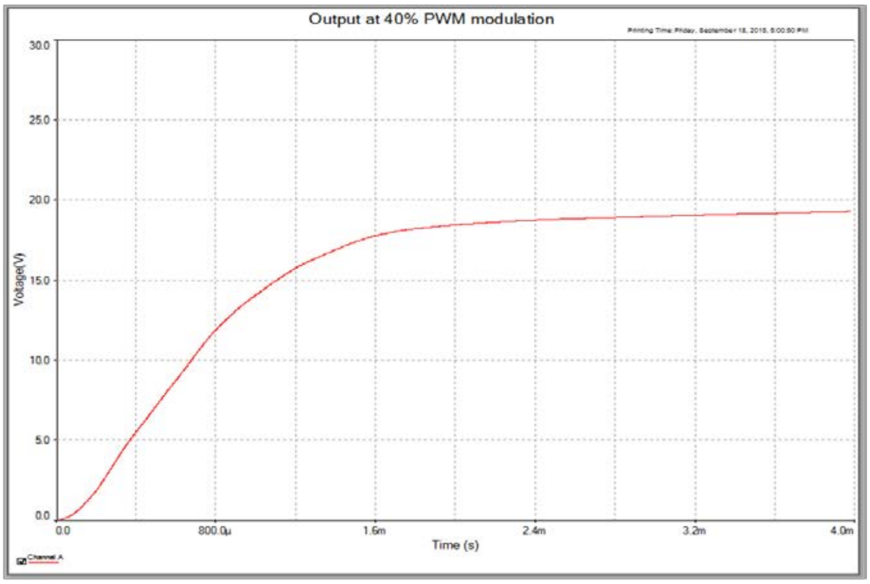

Fig. 8. Output at 40 % PWM.

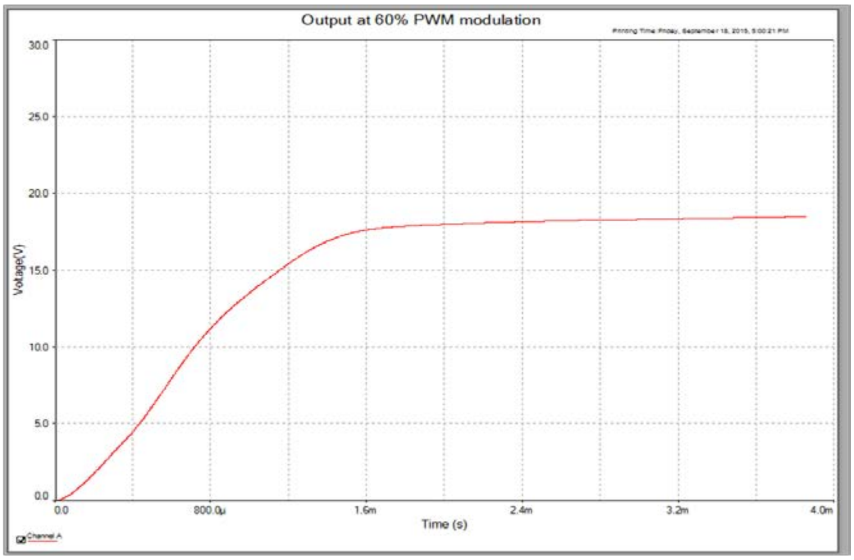

Fig. 9. Output at 60 % PWM.

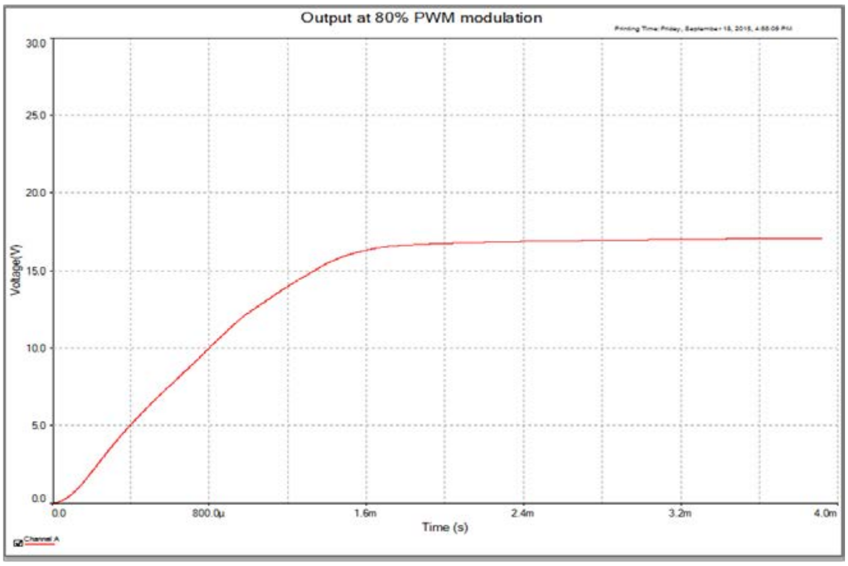

Fig. 10. Output at 80 % PWM.

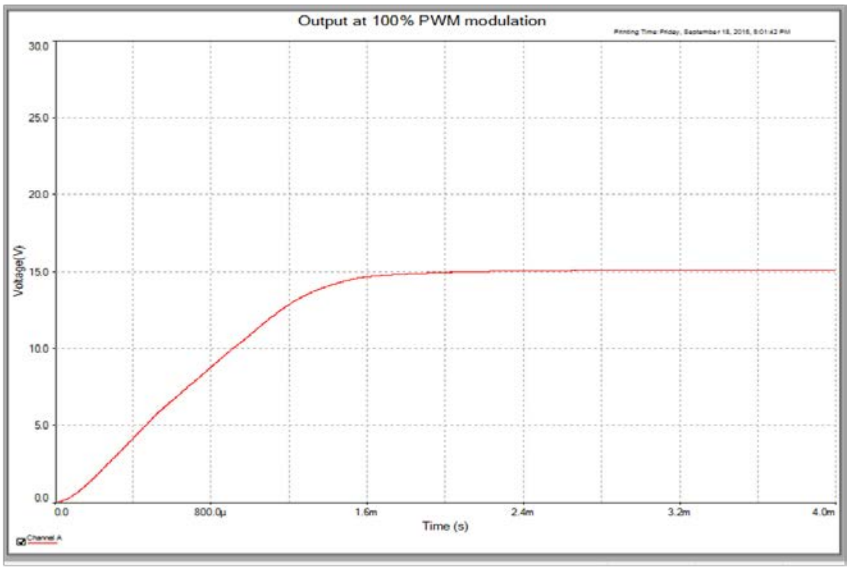

Fig. 11. Output at 100 % PWM.

Initially, the percentage of PWM modulation is set to 0% in Fig. 5 the output was almost at maximum voltage level which was 20VDC and as it became 20% the resultant DC voltages was 19V DC and the percentage of modulation is increased in steps of 20% in order to analyze the output voltage effect based on PWM modulation percentage. Higher the level of PWM modulation the lower the value of output we achieved. The blue color shows that the PWM voltage the red color determines the VAB voltage waveform. (See Fig. 6-Fig. 11).

VI. Conclusion

Based on above simulation and discussion it has been concluded that the reliable estimation can be done in order to implement in practical applications the SLSR converter while working with a coupled transformer. The combination varies PWM modulation and series resonant converter more predictable and reliable. The presented simulation has shown output variation with the varying the PWM modulation. As the percentage of modulation is increased with step of 20% the output will decrease as shown. By controlling the modulation, magnetic link and considering the losses and coupling coefficient factors can be a good approximation. This approach is under the focus of authors for better efficiency with faster and secures controlling strategies.

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