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EFFECTS OF SWITCHING FREQUENCY TO SERIES LOADED SERIES RESONANT CIRCUIT

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ABSTRACT

This paper analyses the effect of switching frequency on series loaded series resonant (SLSR) converter. SLSR converter is a well-known topology typically used for applications in kilowatt-range power supplies and can operate in either continuous or discontinuous conduction modes. The modes are determined according to the relationship between the switching frequency and resonant frequency. The analysis results in a set of equations with solutions presented graphically. The development of a SLSR converter is described along with the results of computer simulation. The output waveforms obtained for each switching frequency are compared.

Keywords: switching frequency, SLSR.

INTRODUCTION

The necessity of having highly improved performance of an energy converter urges the engineers to introduce better designs of the converter. Generally, the best power converter is the one with the highest efficiency, which is measured as the ratio between the average output power and the average input power. Switching power supply is supposed to have higher efficiency of up to 70% to 80% compared to the regular linear power supply, which have the lower efficiency of 50% to 60% [1-2]. Switching frequency is one of the important parameters to measure the performance of an energy converter, in addition to power density, reliability, safety, efficiency and many others. By varying the switching frequency from low to high, the output power can be controlled, thus the efficiency of the converter will be affected.

Highly improved performance of a power converter can be achieved with a resonant converter, which is a power supply topology that works by inverting a DC inputs into AC waveforms and then rectifying the AC waveforms back into a DC signal. This switching is called soft-switching technique [3]. For this type of converter, the voltage and current waveforms are varied during one or more subintervals of each switching period. The total harmonic distortion for resonant converter is low as the first harmonic frequency is equal to the switching frequency [4]. The configuration of the resonant tank, in which includes inductor and capacitor can be applied in several methods; parallel, series or hybrid (both parallel and series). One of the most famous resonant converters that apply soft-switching is series loaded series resonant (SLSR) converter. It can be applied in high-frequency operation, provide high reliability and highest efficiency as well as low cost maintenance.

Series loaded resonant converter operates in three modes; Discontinuous Conduction Mode, Continuous Conduction Mode below resonance and Continuous Conduction Mode above resonance. Those modes are determined according to the relationship of switching frequency and resonant frequency.

To obtain high efficiency and performance, the switching frequency is often increased. Operation at higher frequencies considerably reduces the size of passive components such as transformers and filters. However, higher switching frequency is said to result in high switching loss, thus contributing in the degradation of the efficiency [5, 6]. This paper investigates the effects of switching frequency on SLSR converter and proposes a new scheme of suitable switching frequency with higher efficiency. The organization of the paper is as follows: Section II gives an analysis of the related work while the simulation is described in Section III. Section IV discusses the results obtained and Section V concludes the paper.

BACKGROUND

As stated before series loaded resonant converter operates in three different modes. When the switching frequency is less than 50% of the resonant frequency, the converter operates in the discontinuous conduction mode. The continuous conduction mode below resonance occurs when the switching frequency is 50% to 100% of the resonant frequency. As the name states, the continuous conduction mode above resonance is operated when the switching frequency is above the resonant frequency [3]. As the switch changes its state, the current or voltage will be zero. Thus, when the converter operates near resonance, the switch will operate in both zero-voltage switching (ZVS) and zero-current switching (ZCS). When the switching frequency moves away from resonance, only ZVS is performed. With these modes, the switch in the converter is turned on or off when the current or voltage across it is zero, hence switching losses are minimized [5].

Resonance occurs when the inductive and capacitive reactances are equal in magnitude but cancel each other because they are 180 degree in phase. A typical series-resonant circuit comprised of a resistor connected to

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a series combination of an inductor and a capacitor [5]. The resonant components have characteristic impedance, Z_o, and angular resonant frequency, ω_o, which are defined by

$$Z_o = \sqrt{\frac{L}{C}} \tag{1}$$

$$\omega_o = \frac{1}{\sqrt{LC}} \tag{2}$$

where

$$\omega_o = 2\pi f_o \tag{3}$$

Thus, resonant frequency, f_o, is defined as

$$f_o = \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

Z_o = impedance
L = inductor
C = capacitor
ω_o = angular resonant frequency

Hence, operating switching frequency, f_s, is defined as

$$f_s = \frac{\omega_s}{2\pi} \tag{5}$$

$$f_s = \frac{1}{2\pi\sqrt{LC}} \tag{6}$$

Where ω_s is the operating angular switching frequency?

SIMULATION SETUP

Figure-1 shows the circuit constructed and simulated in Multisim. The circuit is divided into three (3) parts: a full bridge inverter, a resonant circuit, which is made up of an inductor and a capacitor, and a load circuit. In a series resonant converter, the resonant circuit is in series with the load. Transistors Q1, Q2, Q3 and Q4 act as switches, controlled by a sinusoidal PWM. The PWM generates switching pulses to turn the transistors ON and OFF. The varying pulse rate produced by the PWM causes the switching frequency of the full bridge inverter to vary, thus the ON time and OFF time of the transistors varies in each cycle. The transistor pairs Q1, Q2 and Q3, Q4 are operating exclusively. During the first half of a cycle, transistors Q1 and Q2 are turned ON while Q3 and Q4 are OFF. In the second half of the cycle, Q3 and Q4 are then turned ON whereas Q1 and Q2 are OFF.

In this circuit, the output voltage is controlled by controlling the switching frequency of the full bridge inverter. The switching frequency controls the impedance of the resonant components (inductor and capacitor). This consequently controls the flow of power from input to the output, and also the output voltage.

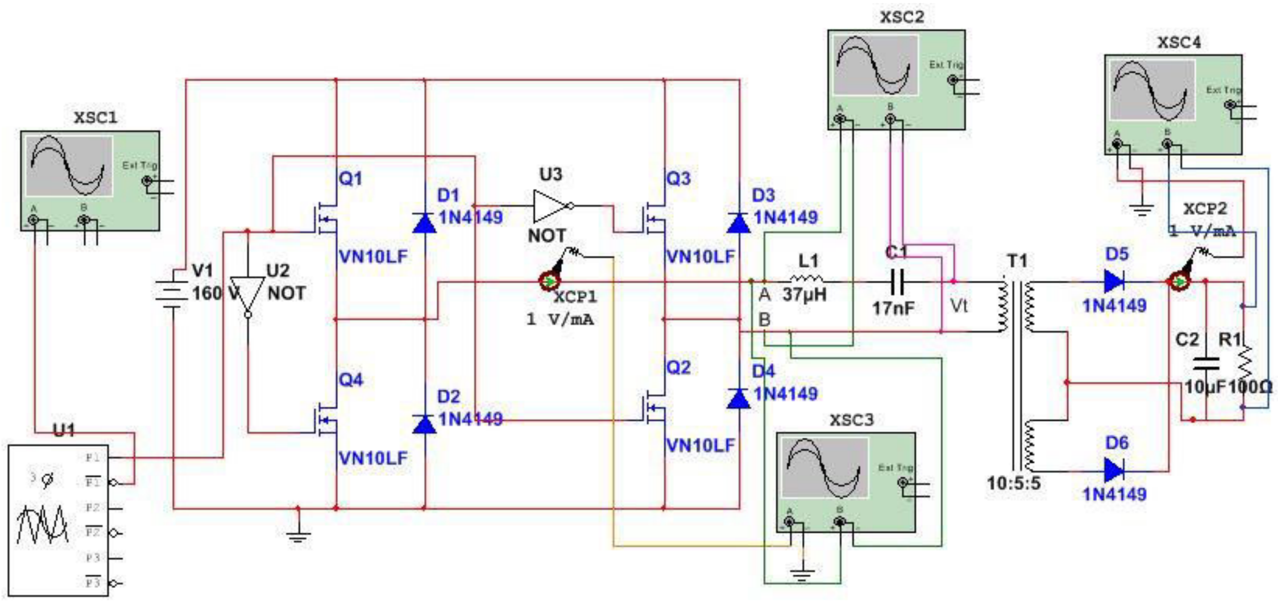

Figure-1. Series resonant converter circuit setup.

The resonant components have a specific resonant frequency value. Using equation (6) with values of L=37µF and C=10nF, the resonant frequency is calculated to be 200 kHz. At the resonant frequency, the impedance of the resonant circuit is very small, thus all of the input voltage will be transferred to the load. This means that the maximum output is obtained at the resonant frequency. However, it is preferred for the converter to

ARPN Journal of Engineering and Applied Sciences

operate in zero voltage switching (ZVS) at a frequency above the resonant frequency. This is because with ZVS, both the turn-on and turn-off losses can be effectively reduced.

There are four oscilloscopes connected at different points in the circuit. The first oscilloscope is connected to the PWM to observe the pulses generated by the PWM. The second oscilloscope is connected to the resonant circuit to measure the voltage across nodes A and B, V_{ab} and V_t and to compare the two graphs. The third oscilloscope measures the current across the resonant circuit and V_{ab}. The fourth oscilloscope measures the current and voltage at the output.

In this paper, the circuit is simulated in Multisim to observe the waveforms of the voltage across and the current through the resonant circuit. The switching frequency of the PWM is varied and the effect of the switching frequency on the waveforms produced is observed.

RESULTS AND DISCUSSIONS

Switching frequency at 10kHz

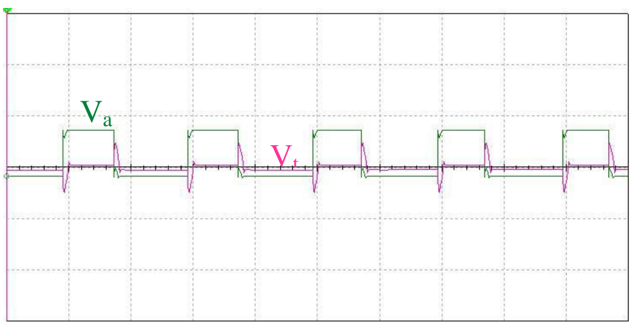

Figure-2. V_{ab} and V_t output waveforms (f_s= 10kHz).

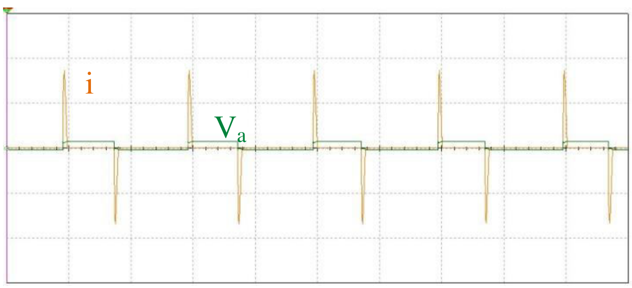

Figure-3. V_{ab} and i_L output waveforms (f_s= 10kHz).

Figure-2 and Figure-3 show the output waveforms obtained at oscilloscope 2 and 3 respectively when the switching frequency is 10 kHz, which is below the resonant frequency. The voltage V_{ab} is observed as a square wave while the current i_L is basically a sinusoidal wave with certain parts having constant values.

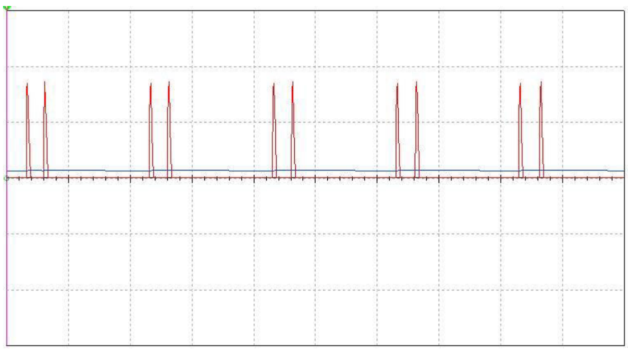

Figure-4. Output current and voltage waveforms (f_s= 10kHz).

Figure-4 plots the waveforms of the current and voltage at the output load. The output voltage is a constant value which means the output produced is a DC voltage. Meanwhile, the current is a half-wave sinusoidal. Switching frequency at 200kHz

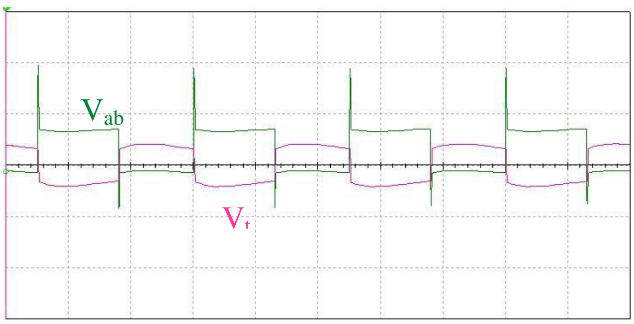

Figure-5. V_{ab} and V_t output waveforms (f_s= 200kHz).

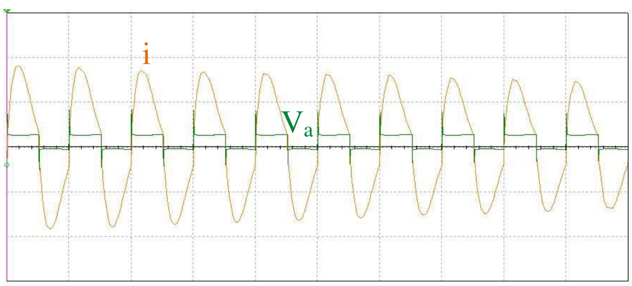

Figure-6. V_{ab} and i_L output waveforms (f_s= 200kHz).

Figures 5 and 6 show the waveforms obtained at oscilloscope 2 and oscilloscope 3 respectively when the switching frequency is 200 kHz, which is equal to the resonant frequency. From Figure-5, it can be seen that both V_{ab} and V_t are square waves with a phase difference of 180° between each other. From Figure-6, the waveform of the current through the resonant circuit, i_L is seen to be a better sinusoidal waveform shape in this case compared to when the switching frequency is below the resonant frequency. This is because at resonant frequency, the maximum output is obtained.

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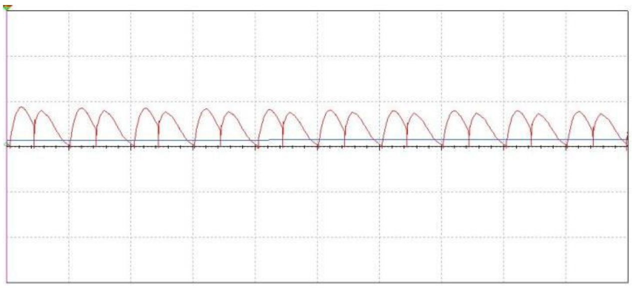

Figure-7. Output current and voltage waveforms (f_s= 200kHz).

Figure-7 shows the output current and voltage waveforms obtained at the output. Comparing this with the previous case, the current waveform is a better half-wave sinusoidal shape with no gaps. The output voltage is again a constant DC value.

Switching frequency at 500 kHz

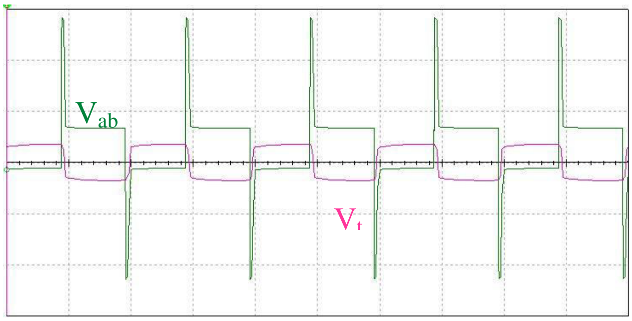

Figure-8. V_{ab} and V_t output waveforms (f_s= 500kHz).

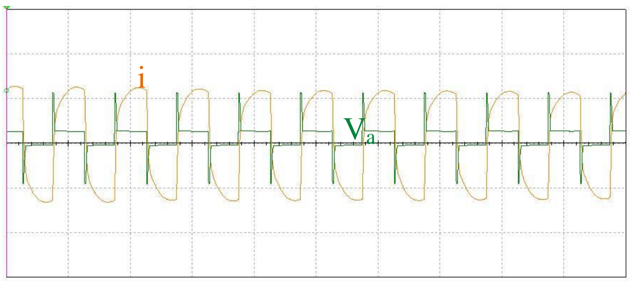

Figure-9. V_{ab} and i_L output waveforms (f_s= 500kHz).

Figures 8 and 9 show the waveforms obtained at oscilloscope 2 and oscilloscope 3 respectively when the switching frequency is 500 kHz, which is above the resonant frequency. Similar to the previous case, the waveforms of V_{ab} and V_t are both square waves in Figure 8. However, it was seen that the voltage spikes at the beginning of the on and off time are larger than the previous case. The voltages measured are also less when the switching frequency is above the resonant frequency. In Figure-9, it can be seen that the current i_L is a sinusoidal shaped waveform with a sharper edge.

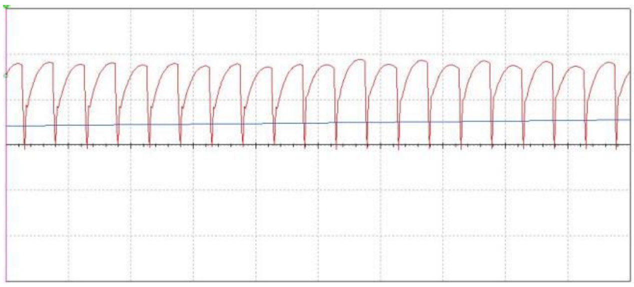

Figure-10. Output current and voltage waveforms (f_s= 500kHz)

In Figure-10, the output current and voltage are plotted. In this case, it was observed that the output current is larger than at resonance. The voltage, on the other hand, is a DC value, similar to the previous cases.

CONCLUSIONS

The switching frequency affects the series loaded series resonant converter such that when the switching frequency is equal to the resonant frequency, maximum output is obtained, and thus better output waveforms are produced. A switching frequency value at resonance produces a better waveform because a voltage spike is not produced as large compared to a value above resonance. To conclude, the objectives of this research are achieved.

REFERENCES

[1] S. Valtchev, B. Borges, K. Brandisky, and J. B. Klaassens, “Resonant Contactless Energy Transfer with Improved Efficiency,” IEEE Transactions on Power Electronics. Vol. 24, No. 3, March 2009, pp. 685-699.

[2] M. McCarthy, T. Taufik, A. Pratama and M. Anwari, “Efficiency Performance Analysis of Series Loaded Resonant Converter" in 2009 IEEE Symposium on Industrial Electronics and Applications, ISIEA 2009, 4-6 Oct. 2009,Kuala Lumpur, Malaysia.

[3] T. Taufik, M. McCarthy, S. Watkins and M. Anwari, “Performance Study of Series Loaded Resonant Converter using Super Barrier Rectifiers" In: Proceedings of 2009 IEEE Region 10 Conference: TENCON 2009. IEEE, 2010.

[4] A. J. Moradewicz, “Contactless Energy Transmission System with Rotatable Transformer - Modelling, Analyze and Design”, Ph.D dissertation, EI, Warsaw, Poland, 2003.

VOL. 11, NO. 1, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

[5] Y. Chang, "Digital Control of a Series-Loaded Resonant Converter," M.S. thesis, EEE. Dept., CU, Christchurch, NZ, March 2006.

[6] H. Choi, "Design Considerations for an LLC Resonant Converter", in Fairchild Power Seminar, 2007.

[7] J. M. Burdio, F. Canales, P. M. Barbosa, and F. C. Lee, "A Comparison Study of Fixed-Frequency Control Strategies for ZVS DC/DC Series Resonant Converters", IEEE, 2001.