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Phase-shifted Series Resonant Converter with Zero Voltage Switching Turn-on and Variable Frequency Control

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ABSTRACT

This paper presents a phase shifted series resonant converter with step up high frequency transformer to achieve the functions of high output voltage, high power density and wide range of Zero Voltage Switching (ZVS). In this approach, the output voltage is controlled by varying the switching frequency. The controller has been designed to achieve a good stability under different load conditions. The converter will react to the load variation by varying its switching frequency to satisfy the output voltage requirements. Therefore in order to maintain constant output voltage, for light load (50% of the load), the switching frequency will be decreased to meet the desired output, while for the full load (100%) conditions, the switching frequency will be increased. Since the controlled switching frequency is limited by the range between the higher and lower resonant frequencies($f_{r1} \leq f_s \geq f_r$), the switches can be turned on under ZVS. In this study, a laboratory experiment has been conducted to verify the effectiveness of the system performance.

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1. INTRODUCTION

Switching mode of dc-dc converters have been extensively researched and developed to satisfy most industrial power electronics requirements such as efficient conversion, higher power density, small size with light weight, and so on [1]-[3]. In order to achieve these demands, the converters must be switched by high frequency. However, it is impractical to raise the frequency of operation due to increase of the switching losses and electromagnetic interferes (EMI) [4]-[6]. Resonant converters with soft switching (Zero-voltage switching and Zero-current switching) have been proposed, and undoubtedly they are favored than hard switching conventional converters due to their ability to work at high frequency and reduce switching losses [2],[7]-[12]. The behavior of the resonant converter can be classified into many categories based on frequency ratio, switching technique and operating mode. When the resonant frequency is lower than the converter switching frequency, the converter will operate in continuous mode with turned on ZVS [13]-[15]. Meanwhile, ZCS could be achieved if the switching frequency is lower than operating frequency [16]-[18]. Series resonant converter has been recommended by several researchers according to its simplicity and popularity in many applications, where the LC components are connected in series with the rectifier-load network [19]-[22]. The drawback of the series resonant converters is that the input voltage is split between the resonant impedance and the load, which makes the DC gain of SRC is always lower than unity [9],[23]. In case of light load or no-load condition, it is difficult to control the output voltage. Thus, the zero voltage switching is limited to specific load conditions and input voltage ranges [16]. Several schemes have been developed to solve these problems, such as LLC series resonant converter topologies, which have gained attention due to their merit of efficient conversion and high voltage gain [24],[25]. These converters have been introduced with full or half bridge inverters and either center tapped or full bridge rectifiers [26],[27]. Another series resonant converter with two series transformer has been presented in [16] to turn on all the switches at ZVS with wide load conditions and input voltage ranges. Many control topologies can be used to control the series resonant converters as mentioned in the literature, for instance, the current and voltage frequency control [28], diode conduction control [29], and pulse destiny modulation [30]. The phase shift control has been applied to regulate the voltage of full bridge resonant converters [31], which could be considered as a primary control for the switching signal. Moreover, to improve the performance of control system, some advanced strategies using adaptive controls have been reported in [32],[33], such as passivity-based control and auto disturbance- rejection control (ADRC). Meanwhile, in [31], phase shift control has been applied to regulate the resonant current, as a result the control performance has been improved compared to the conventional PSRC control system. In this study, phase shifted series resonant converter is combined with step up high frequency transformer to produce high conversion efficiency and high power density. The output voltage is controlled by varying the switching frequency. The controller has been designed to achieve a good stability under different load conditions with the ability to produce wide range of ZVS to all switches. Laboratory experiment has been conducted to demonstrate the system performance and to prove the validation of the theoretical parts.

2. CIRCUIT CONFIGURATION

Figure 1 shows the circuit configuration of the phase shifted series resonant converter with variable frequency control. The design steps of this converter consists of four main stages. Firstly, full bridge controlled switching network (CSN) is supplied by DC voltage source to produce a square wave phase shifted voltage to be fed to the resonant tank. Then, the resonant tank network (RTN) is connected in series between both legs of the switching network. The resonant tank consists of resonant inductive Lr, resonant capacitor Cr and magnetizing inductance Lm of the HF step up transformer respectively, to generate sinusoidal voltage and current signals. The aim of using HF step up transformer is to provide a wide range of ZVS and to increase the output voltage for eliminating the series resonant converter limitations. Meanwhile, a full bridge diode network with low pass filter (DR_LPF) is connected with the secondary part to rectify and filter the AC variables to produce the desired DC output voltage. Finally, the control part is attached with the circuit to regulate the output voltage by varying or tuning the switching frequency fs.

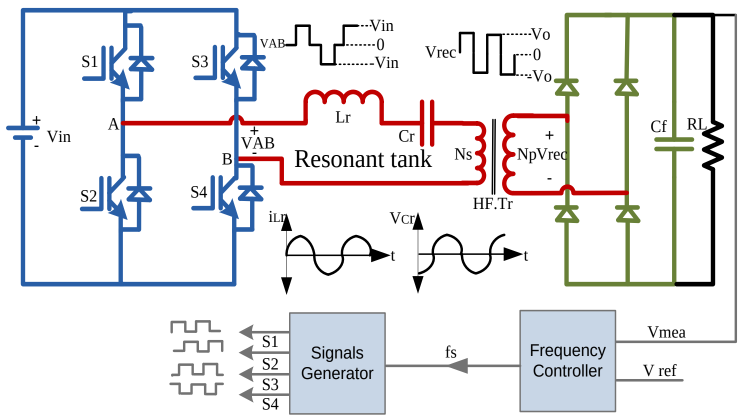
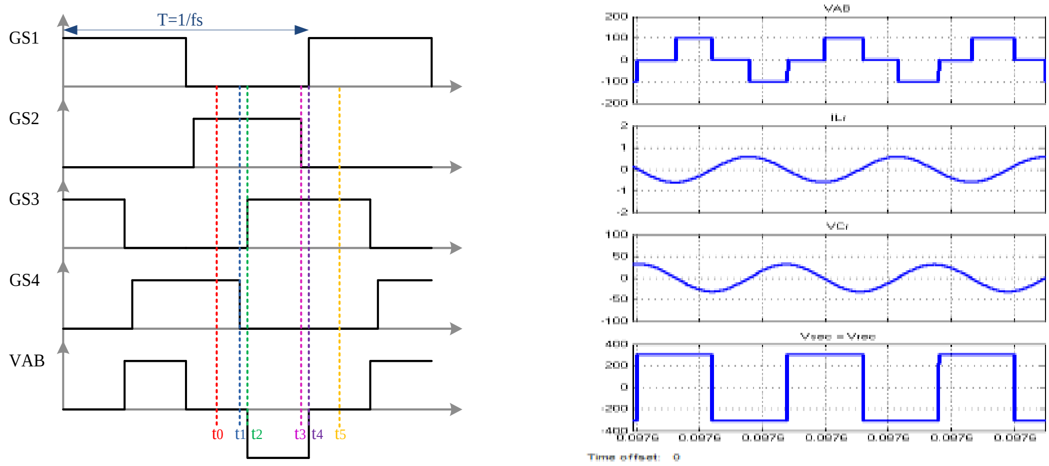


Figure 1. Circuit configuration of the phase shifted series resonant converter

3. OPERATION PRINCIPLE

Figure 2(a) shows the controlled gate signals of the four switches (S_1 to S_4) for the PS –SRC. The turn on time of all switches is equal to half of switching period S_1 and S_2 which will work alternately, but a small dead time must be introduced to avoid signals interfaces and to allow zero voltage switching to occur. Switches S_3 and S_4 also work alternately, with an angular phase shift from the first two switches that is almost equal to quarter of switching period. Figure 2(b) shows the simulated results of the resonant tank variables waveforms using Matlab Simulink to simplify and summarize the circuit operating mode behavior.



(a) (b)

Figure 2. (a) The controlled gate signals and output voltage of the full bridge (b) The simulated waveforms of the system V_{AB}, I_{Lr}, V_{Cr} and secondary voltage respectively

3.1. Mode I: Energy conversion state (between t_0 and t_1)

In this mode, the switches S_2 and S_4 are turned on, causes the resonant current i_{Lr} starts to increase. The tank energy is delivered to the secondary part through the transformer. Thus, the rectifier diodes conduct and the output capacitor C_f is charged.

3.2. Mode II: Resonance state (between t_1 and t_2)

At the beginning of this mode, switch S_4 is turned off, thus i_{Lr} reaches its maximum value and stops increasing, therefore the voltage between the emitter and the collector of the S_4 will be equal to the source voltage. Meanwhile, the tank inductance and capacitance starts resonated. The freewheeling diode of the S_3 will be conducted at the end of this mode.

3.3. Mode III: Discharging state (between t_2 and t_3)

Since, the freewheeling diode of the S_3 is conducted, S_3 is turned on at ZVS. Thus, the resonant capacitor voltage V_{cr} starts to rise. Meanwhile, the energy stored in resonant inductance starts to be transferred to the secondary. Thus, the resonant current i_{Lr} decreases.

3.4. Mode IV: Second resonance state (between t_3 and t_4)

This mode starts once the S_2 turns off, thus the resonant current i_{Lr} changes its polarity (zero crossing) while the resonant capacitor voltage V_{cr} reaches the maximum value (fully charged). Based on these reasons, the resonance stops at this mode because the tank inductance is not capable to deliver the required energy to the secondary. Moreover, the resonant inductor energy must be larger than that stored in the resonant capacitor to achieve ZVS. Before this mode ends, the freewheeling diode of the switch S_1 is conducted.

3.5. Mode V: Commutation state (between t_4 and t_5)

Due the conducting of the freewheeling diode of switch S_1 at the end of last mode, the switch S_1 is turned on at ZVS at the beginning of this mode. Also, the tank inductor starts to charge while the resonant capacitor energy starts to decrease. Therefore, at the end of this mode, the tank will gain its capability to deliver the energy to the secondary once again. Thus, the other rectifier diodes starts to conduct and the output filter C_f will be recharged. Consequently, the circuit operation in the first half cycle is completed, and with the same manner, the switches S_2 and S_4 will be turned on with ZVS in the next half cycle.

4. SYSTEM ANALYSIS AND CONTROLLER DESIGN

The voltage gain of the power converter circuit can be classified into two main parts, which are the gain of the resonant tank and the gain of the high frequency transformer. The gain of the transformer is considered constant based on the primary to secondary turn ratio. Meanwhile, the gain of the resonant tank is a function of switching frequency to resonant frequency ratio($F = \frac{f_s}{fr}$), load quality factor (Q), and the relation between the resonant inductor to magnetizing inductance of the transformer (K). These factors and K are considered as fixed values for all operation modes in the circuit design. The gain function can be derived as Equation (1), where the output voltage is controlled by varying the switching frequency. The tank has two resonant frequencies: the higher resonant frequency f_r, which is contributed by the resonant elements Lr and Cr, while the f_{r1} is obtained by all the tank parameters, as defined in Equation (2). The gain curves for a wide switching frequency range and different load factors are diagramed in Figure 3.

$$M = \frac{V_o}{V_{in}} = \frac{F^2(K-1)}{\sqrt{(\frac{f_s{}^2}{f^2{}_{r1}}-1)^2+(Q(F^3-F)^2(K-1))^2}} \quad (1)$$

$$f_r = f_{max} = \frac{1}{2\pi\sqrt{L_r C_r}} = 42.5 \text{ Khz}, f_{r1} = f_{min} = \frac{1}{2\pi\sqrt{(L_r+L_m)C_r}} = 32.5 \text{ Khz} \quad (2)$$

where $K = \frac{L_r+L_m}{L_r}$, $Q = \frac{\sqrt{L_r/C_r}}{R_{ac}}$, $R_{ac} = \frac{8n^2}{\pi^2}R_L$.and $n = \frac{N_P}{N_s} = 0.166$.

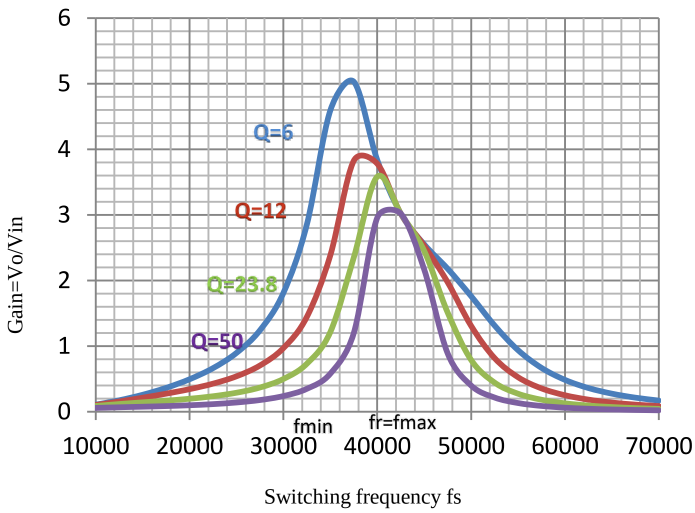


Figure 3. The gain characteristics for wide switching frequency, with different load factor (load conditions)

The function of the controller as presented in Figure 1 is to vary the operating frequency to meet the required load level, to maintain the output voltage of the converter constant at any condition. Moreover, the error between the measured voltage and the constant desired voltage (reference voltage) $V_{err} = V_{ref} - V_{meas}$ is applied to PI controller (Kp=3000, Ki=0.002). Therefore, whenever any deviation is noted from the required output and based on the error sign, the controller works to increase or decrease the switching frequency in accordance to the desired output voltage. Therefore, the signal that is sent to IGBTs1 is in opposition to the signal sent to IGBTs2, while the signals that are sent to IGBTs3 and IGBTs4 are in opposition to each other, and they are shifted by 60° from the first two signals to achieve the required phase shifted voltage V_{AB}. Furthermore, to ensure that ZVS can be fulfilled for all switches, the controlled switching frequency variation is limited by the range that between the higher and lower resonant frequencies($f_{r1} \leq f_s \geq f_r$). Meanwhile, if the switching frequency is found to be lower value than the required range, the chosen frequency will be equal to the minimum frequency value. With the same manner, if it is found to be higher than the limited range, the switching frequency will be set at resonant frequency.

5. EXPERIMENTAL RESULTS

In order to verify the effectiveness of the designed power circuit and the controller response, a laboratory prototype had been evaluated shown as in Figure 4. The specifications of the circuit design and the component parameters are shown in Table 1. Figure 5 presents the test signals waveforms for application to the switches (gate driver outputs). It can be clearly seen that switch S_1 and S_2 complement each other. Signals to the S_3 and S_4 are phase shifted from the first two switches and complement each other as well. It was found that there were dead times 0.5µs before turning on the switches. Figure 6 illustrates the tank waveforms at full load (Io=3A). The switching full bridge generated phase-shifted square wave V_{AB} voltage that excited the resonant tank and created the sinusoidal wave forms. It was obvious that the resonant current started by a negative polarity at each half cycle, which allowed the ZVS to be achieved. Figure 7 shows the measured gate voltage and collector voltage of all switches (S_1-S_4) at full load condition. The collector voltage V_{CE} dropped to zero, before the switches were turned on. Thus, all the switches were turned on at ZVS.

Table 1. Circuit specifications and component parameters

Parameters	value or type
Input voltage V_{in}	100 V
Output voltage	300 V
Switching frequency	32.5-42.5 kHz
Active Switches (*S1-S4*)	IRGP35B60PDPBF
Resonant inductance L_r	200µH
Resonant capacintance C_r	70µF
Magnatizing inductnce L_m	143µH
Output capacitance C_f	4700µH
At full load R_L	100 Ω
Microcontroller	TMS320F28335

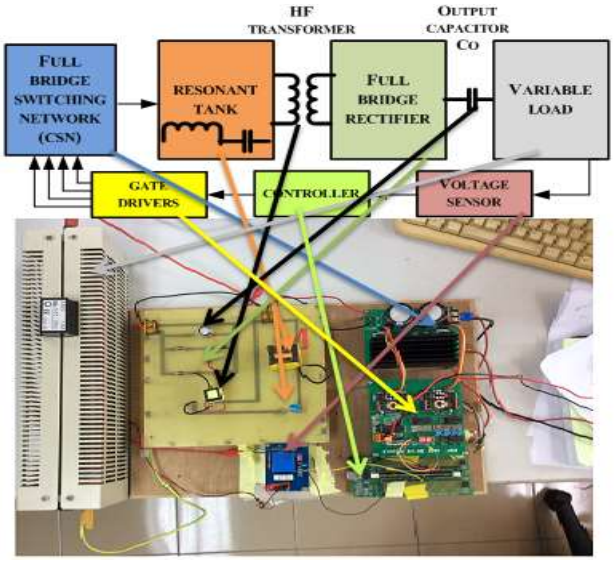


Figure 4. Laboratory prototype of the proposed converter

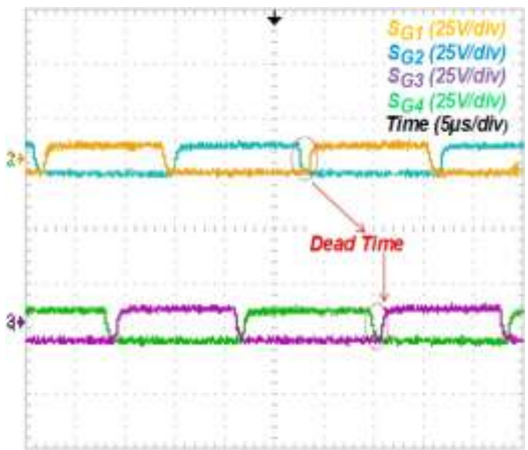


Figure 5. Measured waveforms gate signals before being applied to S1-S4

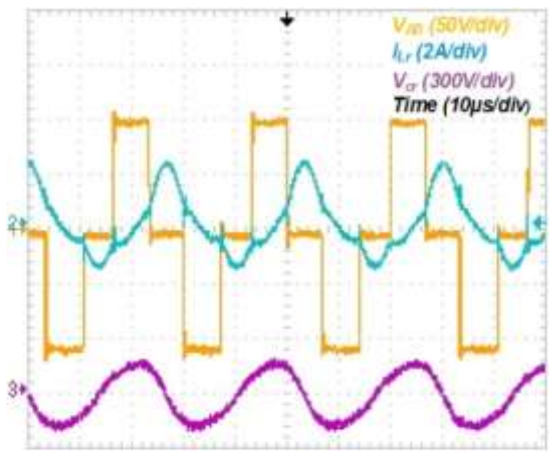


Figure 6. Measured results of the of the resonant tank input voltage V_{AB}, resonant inductor current i_{Lr} and resonant capacitor voltage Vcr at full load condition

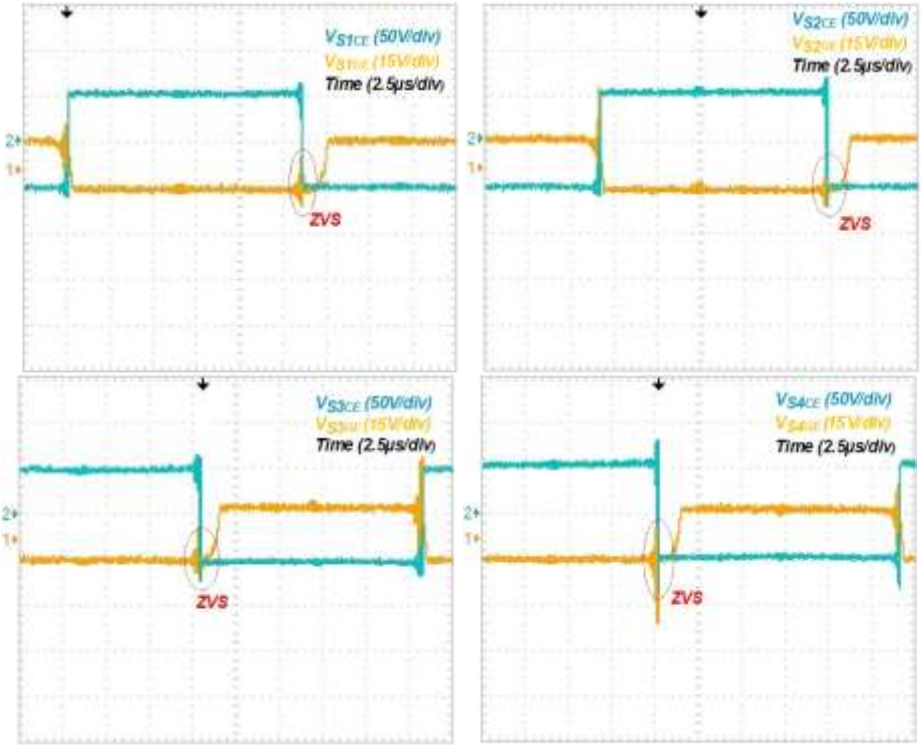
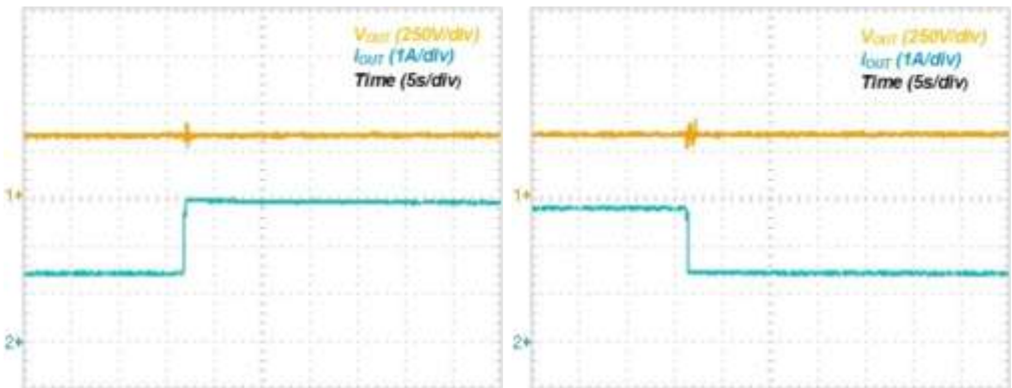


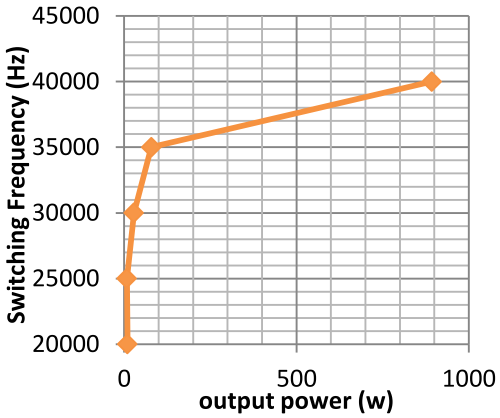
Figure 7. Measured waveforms of the gate voltage and collector voltage for all the switches at 100% load

In order to investigate the designed voltage controller stability, the system had been tested under load variation conditions. Figure 8 shows that the the output voltage (Vo) remained constant in both situations, whereas the output current changes based on the load variations. It can be clearly seen that the system had good dynamic characteristics. The converter responded well to the load variation, by varying its switching frequency to satisfy the output voltage requirements. Thus, for light load (50% of the load) the switching frequency was decreased to 37 kHz to meet the desired output, while for the full load (100%) conditions, the switching frequency was increased to 42.5 kHz to obtain the constant voltage. Moreover, Figure 9 shows that the maximum output power of the proposed converter was 890 W, recorded at operating frequency of 40 kHz, with the efficiency of 82%. .

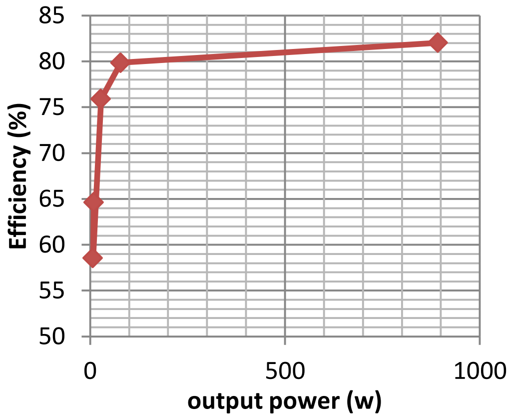


(a) Step-up load condition (b) Step-down load condition

Figure 8. Measured results of the output voltage and current



(a)



(b)

Figure 9. (a) Measured switching frequencies with different load conditions, (b) Measured efficiencies for different load conditions

6. CONCLUSION

This paper has presented the design considerations of phase shifted series resonant converter with step up high frequency transformer. The main feature of the proposed converter is to enhance the resonant tank inductivity in order to eliminate the resonant converter limitations, by increasing converter gain and to provide a wide ZVS range for all the switches. Therefore, the proposed converter is suitable for low input voltage and high load current applications. Fixed duty cycle with switching control is adopted to regulate the output voltage. The control strategy is limited to specific frequency range to ensure that all the switches have the ability to be turned on at ZVS. Moreover, the controller is designed to operate with wide load variations. The converter reacts to the load variation, by varying its switching frequency to satisfy the output voltage requirements. For light load (50% load), the switching frequency is decreased to 37 kHz to meet the desired output, while at full load (100%) condition, the switching frequency is increased to 42.5 kHz to obtain constant voltage. The proposed system design, operation modes and the controller behavior have been discussed in detail in this paper. Laboratory experiments results have proven the system performance and verified the effectiveness of the theoretical parts.

REFERENCES

[1] Y. K. Lo, *et al.*, "Phase-shifted full-bridge series-resonant DC-DC converters for wide load variations," *IEEE Transactions on Industrial Electronics,* vol. 58, pp. 2572-2575, 2011.
[2] C. H. Chien, *et al.*, "Analysis of a novel resonant converter with series connected transformers," *IET Power Electronics,* vol. 6, pp. 611-623, 2013.
[3] M. Alam, *et al.*, "A Hybrid Resonant Pulse-Width Modulation Bridgeless AC-DC Power Factor Correction Converter," *IEEE Transactions on Industry Applications*, pp. 1-1, 2016.
[4] G. Catona, *et al.*, "An isolated semi-resonant dc/dc converter for high power applications," *IEEE Transactions on Industry Applications,* pp. 1-1, 2016.
[5] M. Salem, *et al.*, "ZVS Full Bridge Series Resonant Boost Converter with Series-Connected Transformer," *International Journal of Power Electronics and Drive Systems (IJPEDS),* vol. 8, 2017.
[6] M. Salem, *et al.*, "Implementing buck converter for battery charger using soft switching techniques," in *Power Engineering and Optimization Conference (PEOCO), 2013 IEEE 7th International*, pp. 188-192, 2013.
[7] M. Jabbari and F. Barati, "New resonant LCL boost converter," *IET Power Electronics,* vol. 7, pp. 1770-1776, 2014.
[8] K. H. Yi and G. W. Moon, "Novel two-phase interleaved LLC series-resonant converter using a phase of the resonant capacitor," *IEEE Transactions on Industrial Electronics,* vol. 56, pp. 1815-1819, 2009.
[9] R. L. Steigerwald, "A comparison of half-bridge resonant converter topologies," *IEEE Transactions on power electronics,* vol. 3, pp. 174-182, 1988.
[10] M. T. Outeiro and G. Buja, "Comparison of resonant power converters with two, three, and four energy storage elements," *Industrial Electronics Society, IECON 2015-41st Annual Conference of the IEEE*, pp. 1406-1411, 2015.
[11] C. Du, *et al.*, "Design methodology of resonant inductor in a ZVS inverter," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 3, pp. 1142-1150, 2015.
[12] I. Alhamrouni, *et al.*, "Application of DC-DC converter for E.V battery charger using PWM technique and hybrid resonant," in *2016 IEEE International Conference on Power and Energy (PECon)*, pp. 133-138, 2016.

[13] M. Salem, *et al.*, “Steady state and generalized state space averaging analysis of the series resonant converter,” in *Clean Energy and Technology (CEAT) 2014, 3rd IET International Conference on*, pp. 1-5, 2014.
[14] M. Salem, *et al.*, “Performance study of series resonant converter using zero voltage switching,” in *Energy Conversion (CENCON), 2014 IEEE Conference on*, pp. 96-100, 2014.
[15] M. Salem, *et al.*, “Extension of Zero Voltage Switching range for series resonant converter,” in *Energy Conversion (CENCON), 2015 IEEE Conference*, pp. 171 - 175, 2015.
[16] B. R. Lin and S. F. Wu, “ZVS resonant converter with series-connected transformers,” *IEEE Transactions on Industrial Electronics*, vol. 58, pp. 3547-3554, 2011.
[17] S. Hu, *et al.*, “Optimal design of line level control resonant converters in plug-in hybrid electric vehicle battery chargers,” *IET Electrical Systems in Transportation,* vol. 4, pp. 21-28, 2014.
[18] M. Salem, *et al.*, “Modeling and simulation of generalized state space averaging for series resonant converter,” in *Power Engineering Conference (AUPEC), 2014 Australasian Universities*, pp. 1-5, 2014.
[19] H. Chan, *et al.*, “Phase-shift controlled DC-DC convertor with bi-directional power flow,” *IEE Proceedings-Electric Power Applications,* vol. 148, pp. 193-201, 2001.
[20] C. H. Chien, *et al.*, “Series Resonant Converter with Series-Parallel transformers for high input voltage applications,” in *TENCON 2011-2011 IEEE Region 10 Conference*, pp. 873-877, 2011.
[21] X. Xie, *et al.*, “Analysis and optimization of LLC resonant converter with a novel over-current protection circuit,” *IEEE Transactions on Power Electronics,* vol. 22, pp. 435-443, 2007.
[22] M. Salem, *et al.*, “A Review of an Inductive Power Transfer System for EV Battery Charger,” *European Journal of Scientific Research* vol. 134, pp. 41-56, 2015.
[23] M. T. Outeiro, *et al.*, “Resonant Power Converters: An Overview with Multiple Elements in the Resonant Tank Network,” *IEEE Industrial Electronics Magazine,* vol. 10, pp. 21-45, 2016.
[24] S. D. Simone, *et al.*, “Design guideline for magnetic integration in LLC resonant converters,” in *Power Electronics, Electrical Drives, Automation and Motion, SPEEDAM 2008. International Symposium on*, pp. 950-957, 2008.
[25] C. H. Chang, *et al.*, “Modeling and design of the llc resonant converter used as a solar-array simulator,” *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 2, pp. 833-841, 2014.
[26] G. Ivensky, *et al.*, “Approximate analysis of resonant LLC DC-DC converter,” *IEEE Transactions on power electronics,* vol. 26, pp. 3274-3284, 2011.
[27] M. K. Kazimierczuk and D. Czarkowski, “Resonant power converters,” John Wiley & Sons, 2012.
[28] A. Aboushady, *et al.*, “Steady-state analysis of full-bridge series resonant converter with phase-shift and frequency control,” in *Power Electronics, Machines and Drives, 5th IET International Conference on*, pp. 1-6, 2010.
[29] T. Stuart, “Inherent overload protection for the series resonant converter,” *IEEE transactions on aerospace and electronic systems,* pp. 820-830, 1983.
[30] O. Lucia, *et al.*, “Load-adaptive control algorithm of half-bridge series resonant inverter for domestic induction heating,” *IEEE transactions on industrial electronics*, vol. 56, pp. 3106-3116, 2009.
[31] Y. Lu, *et al.*, “Quasi current mode control for the phase-shifted series resonant converter,” *IEEE transactions on power electronics,* vol. 23, pp. 353-358, 2008.
[32] Y. Lu, *et al.*, “Auto-disturbance-rejection control for phase-shifted resonant converter,” *IEE Proceedings-Electric Power Applications,* vol. 153, pp. 711-718, 2006.
[33] Y. Lu, *et al.*, “Passivity-based control of a phase-shifted resonant converter,” *IEE Proceedings-Electric Power Applications,* vol. 152, pp. 1509-1515, 2005.

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