

# A New ZVZCS Isolated Dual Series Resonant DC-DC Converter with EMC Considerations

A. Nemati\* and M. Pakdel\*\*

**Abstract:** A novel ZVZCS isolated dual series-resonant active-clamp dc–dc converter is proposed to obtain high efficiency. The proposed converter employs an active-clamp technique, while a series-resonant scheme controls the output voltage with the complementary pulse width modulation controller. The active-clamp circuit serves to recycle the energy stored in the leakage inductance or the magnetizing inductance and provides zero-voltage and zero-current turn-on and turn off switching. The voltage stresses of the main switch are clamped. The voltage transient spikes across the dual series active clamp circuit and the current stress of the current-fed side switches are limited by auxiliary active clamping circuits on both sides, and ZVZCS is achieved. The operating principles and design considerations are discussed and verified by simulations using PSIM software. Also, the EMI reduction techniques from EMC point of view in the circuits related to converters has been pointed out.

**Keywords:** Converter, EMC, Series-Resonant, Soft-Switching.

## 1 Introduction

In switching mode power supplies, as the switching frequency increases for high power density and with small size, switching losses associated with the turn-on and turn-off of the devices in the power converter are increased. These losses are so significant that the operations of the power converters at high frequency are limited. To overcome these problems, a number of full, quasi-, and multi-resonant dc–dc converter topologies have been investigated in [1], [2]. However, although resonant mode power conversion achieves low switching loss at high frequency compared to the pulse-width modulation (PWM) converter, these converters have some difficulties such as size reduction, EMI noise, and filter design because a wide variety of switching frequency is needed to control the output voltage. Also, the resonant converters typically have large component stresses due to high peak currents and voltages. Therefore, the trend in power processing technology has been toward combining the simplicity of PWM converters with the soft-switching characteristics of the resonant converters [3]–[10].

As discussed in [11], the phase-shifted zero-voltage switching full-bridge converter is one of the most attractive techniques, as it allows all switches to operate at zero-voltage turn-on switching (ZVS) by utilizing the leakage inductance of the power transformer without an auxiliary switch [12]–[14]. However, the complexity of the full-bridge is almost the highest due to its increased switches and complicated control. Therefore, the active-clamp circuit and the half-bridge circuit composed of two switches and operated by the asymmetrical PWM controller are other typical examples to successfully realize ZVS for the switches by utilizing leakage inductance, magnetizing inductance, and parasitic capacitance [15]–[21]. In particular, the forward converters and the flyback converters using these circuits provide the zero-current turn-off switching (ZCS) of the output diodes by the resonant-current formed by the leakage inductance of the transformer and the clamp capacitor (or blocking capacitor). However, since these converters transfer the input energy to the output stage, when the main switch is only in the on-state or off-state, the transformer utilization is reduced in comparison with the dc–dc converter such as the push–pull, full-bridge converters.

In addition, dc–dc converters such as the conventional forward and flyback converters have a severe difficulty in surge occurrence due to leakage inductance of the transformer and the reverse-recovery problem of output diodes. To absorb the surge energy and achieve the ZVS operation, the active-clamp technique was proposed and its stability was analyzed

Iranian Journal of Electrical & Electronic Engineering, 2010.

Paper first received 29 Aug. 2009 and in revised form 13 July 2010.

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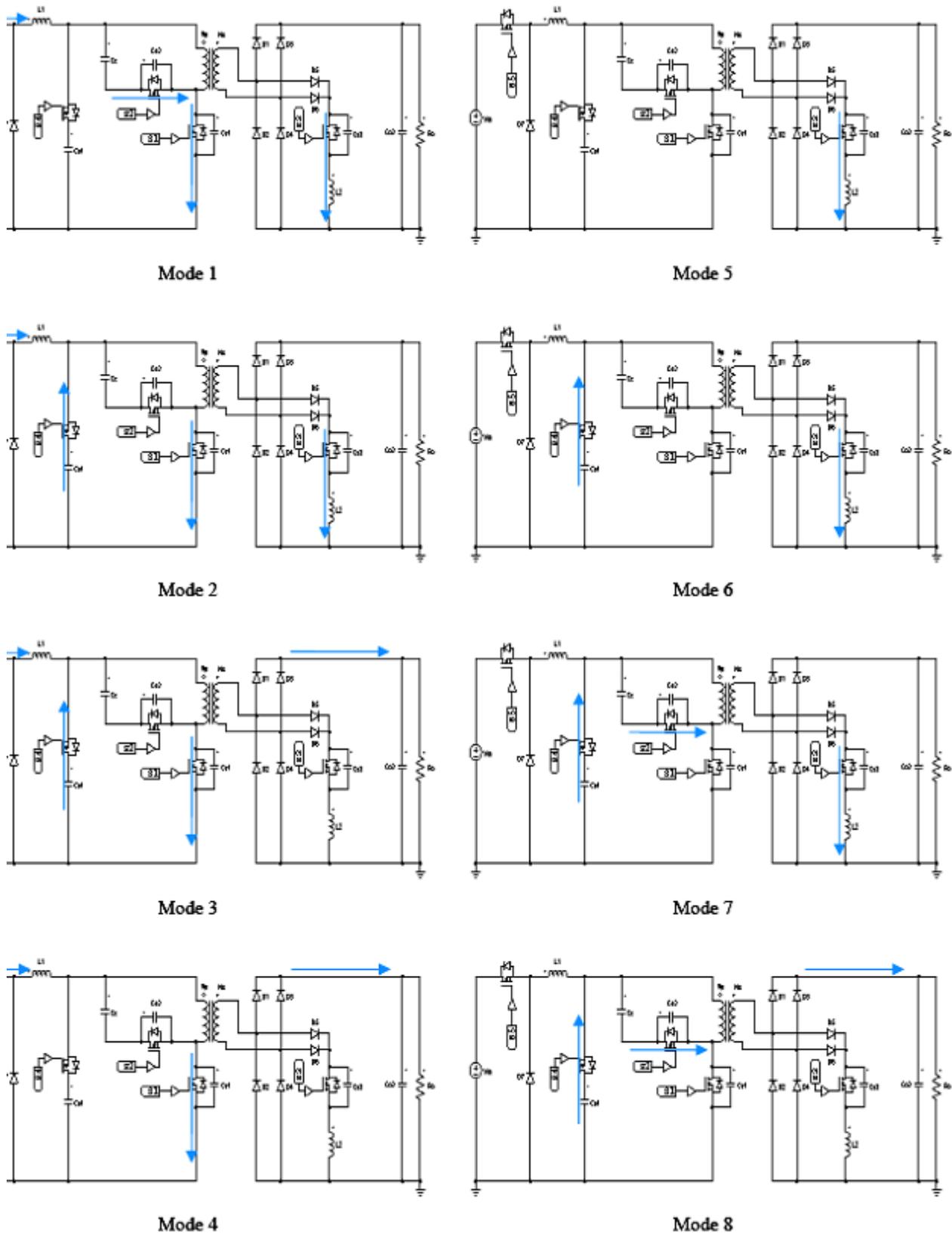


Fig. 2 Equivalent Circuit of Operation Modes.

**Mode 6:** At this mode, switch  $S_4$  is turned on after  $1\mu s$ , and the capacitor  $C_{O1}$  is also discharged through the resonant circuit.

**Mode 7:** At this mode, switch  $S_2$  is turned on and the capacitor  $C_C$  is charged through the resonant circuit.

**Mode 8:** At this mode, switch  $S_3$  is turned off and the current is flowed to the load.

### 3 Analysis of Circuit Parameters

In this section, the design equations of the proposed ZVZCS isolated dual series-resonant dc–dc converter using the active-clamp mechanism operated by the complementary PWM controller are introduced. As in [11], the ripple component of the clamp capacitor  $C_C$  voltage  $V_C$  can be neglected by the large clamp capacitor value. Therefore, the average voltages across switches  $S_1$  and  $S_2$  are the sum of the dc-input voltage  $V_{in}$  and the average clamp capacitor voltage  $V_C$  is as follow [11]:

$$V_{S1} = V_{S2} = V_{in} + V_C = \frac{1}{1-D} V_{in} \quad (1)$$

Thus, if voltages  $V_{S1}$  and  $V_{S2}$  are determined by considering the voltage-rating, and the voltage-margin of the switches  $S_1$ ,  $S_2$  and the dc-input voltage  $V$  are selected, the duty ratio  $D$  can be calculated from (1).

If the leakage inductance of the transformer is a very small value compared to the magnetizing inductance, the voltage transfer function of the proposed converter then becomes that of an isolated boost converter. Therefore, although this paper does not manage the step-up applications, the proposed converter can be considered as the isolated boost converter suitable for the step-up applications. Turns ratio  $n$  of the transformer is thus obtained as [11]:

$$n = \frac{V_o}{V_{in}} (1-D) \quad (2)$$

The soft switching of the auxiliary switch  $S_2$  is naturally achieved by the stored energy in the leakage inductance  $L_{lk}$  and the magnetizing inductance  $L_m$ . However, The ZVS design of the main switch  $S_1$  is determined by the magnetizing inductance  $L_m$  and the output power  $P_o$ . If the maximum output power  $P_{O,max}$  of the converter is selected, from the turn-on ZVS condition [27] to meet the soft switching of the main switch  $S_1$ , the magnetizing inductance value  $L_m$  can be determined as:

$$L_m < \frac{D(1-D)^2 V_o^2}{2 n^2 f_s P_{o,max}} \quad (3)$$

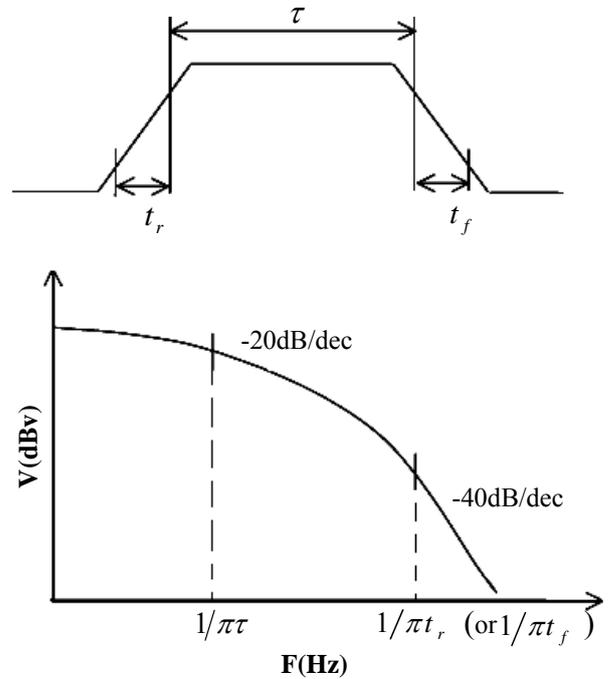
where  $f_s$  is the switching frequency? The critical angular resonant frequency  $\omega_{rc}$  for the turn-off ZCS design of the output diodes  $D_1$  and  $D_2$  is determined according to the duty ratio  $D$ . If the duty ratio  $D$  is smaller than 0.5 at the selected constant input voltage  $V_{in}$ , the critical angular resonant frequency  $\omega_{rc}$  can be obtained as follows [11]:

$$\omega_{rc} = \frac{\pi}{D} f_s \quad (4)$$

### 4 EMC Consideration

For EMI reduction from EMC point of view in converters and related circuits can be used from the following methods [28]:

- use of the common mode current, ferrite-bead and optocoupler on the transmission lines,
- use of the suitable input filtering;
- use of the trace termination to do impedance matching in transmission lines between source, transmission line and load Impedances;
- EMI reduction through reduction of clock signal edge rate or increase of its rise/fall time. With decreasing the clock signal edge rate can delete many of the clock signal undesirable harmonics in



**Fig. 3** Clock signal with related Fourier transform.

Frequency Spectrum, specially in radio frequency (RF) according Fig 3.

e. EMI reduction through reduction of the line length.

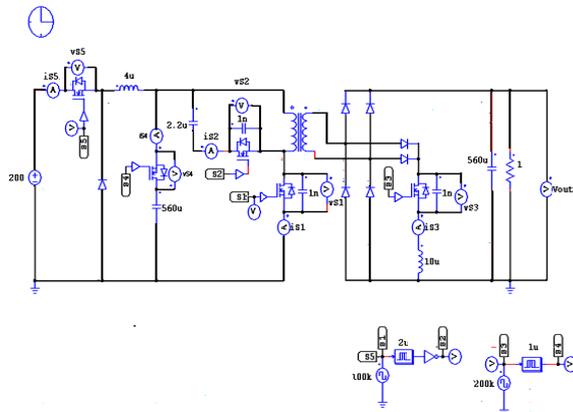
### 5 Simulation Results

To verify the theoretical analysis of the proposed topology, the simulation results using PSIM software are given. The proposed topology and control strategy in PSIM workspace is shown in Fig. 4, the following parameters have been chosen in simulation circuit:  $V_m = 200V$ ,  $L_1 = 4\mu H$ ,  $C_{O1} = 560\mu F$ ,  $C_C = 2.2\mu F$ ,  $L_2 = 10\mu H$ ,  $C_{S1} = C_{S2} = C_{S3} = 1nF$ ,  $L_m = 500\mu H$ ,  $N_p/N_s = 40/14$ ,  $C_{O2} = 560\mu F$ ,  $R_o = 1\Omega$ .

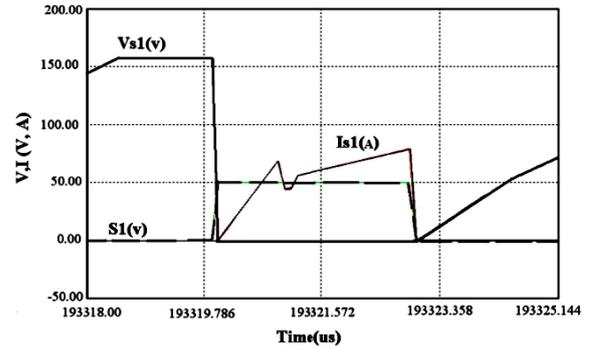
The current and voltage across the switch and drive signal ZVZCS waveforms of switches  $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$  and  $S_5$  are shown in Figs. 5-9 respectively. Also, the waveform of output voltage,  $V_{out}$ , is shown in Fig. 10. The output power of the ZVZCS isolated dual series resonant dc-dc converter is about  $650W$ . As shown in Figs. 4-9, the proposed topology for dc-dc converter has lower power losses and higher efficiency and soft-switching zero-voltage or zero-current or both of the conditions take place in turn on and turn off of all the switches.

### 6 Experimental Results

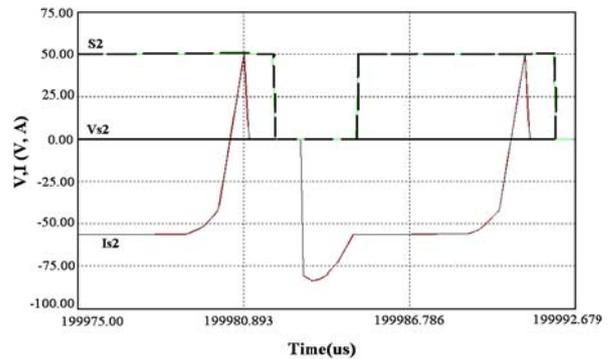
Fig. 11 illustrates the experimental circuit of the study and figures 12-18 show the obtained results of experimental circuit of the present study. In this circuit as discussed in part 4, the EMC Techniques such as input filtering, clock signal edge rate reduction and using common mode choke, ferrite bead and optocoupler have been used for EMI reduction. The clock signal frequency is 50 kHz and is shown in Fig. 12. The voltage  $V_{DS}$  for switches  $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$  and  $S_5$  are shown in Figs. 13-18. Also, the DC output voltage is shown in Fig. 18.



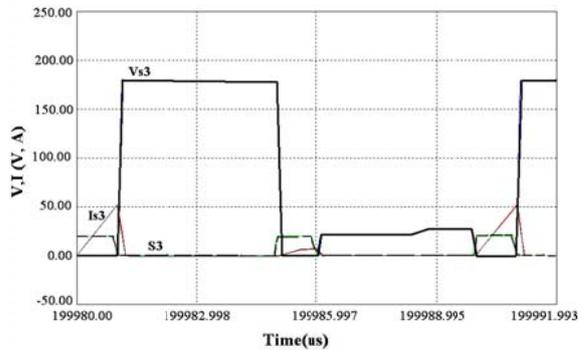
**Fig. 4** The proposed topology and control strategy using PSIM software.



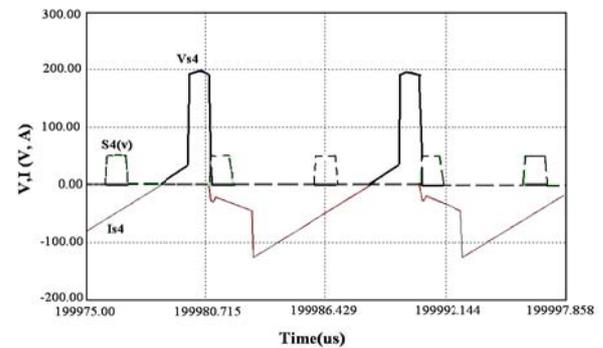
**Fig. 5** ZVZCS waveforms of  $I_{S1}$ ,  $V_{S1}$ , and  $S_1$  drive signal.



**Fig. 6** ZVZCS waveforms of  $I_{S2}$ ,  $V_{S2}$ , and  $S_2$  drive signal.



**Fig. 7** ZVZCS waveforms of  $I_{S3}$ ,  $V_{S3}$ , and  $S_3$  drive signal.



**Fig. 8** ZVZCS waveforms of  $I_{S4}$ ,  $V_{S4}$  and  $S_4$  drive signal.

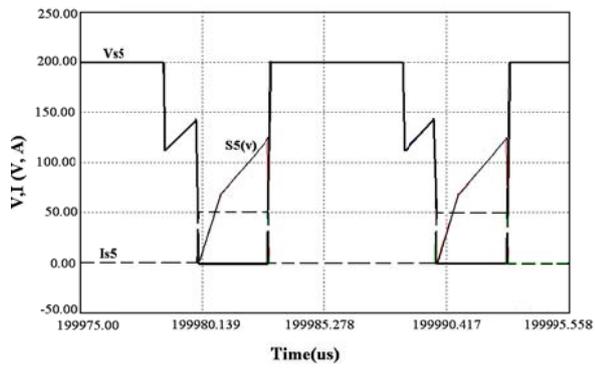


Fig. 9 ZVZCS waveforms of  $I_{S_4}$ ,  $V_{S_4}$  and  $S_5$  drive signal.

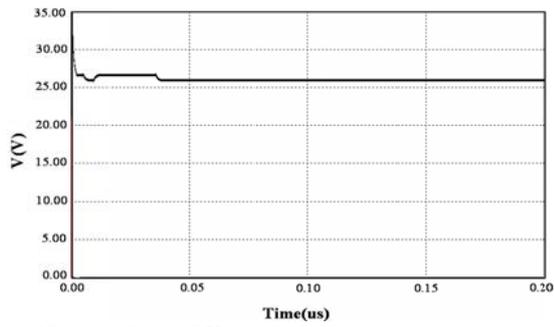


Fig. 10 Waveform of  $V_{out}$ .

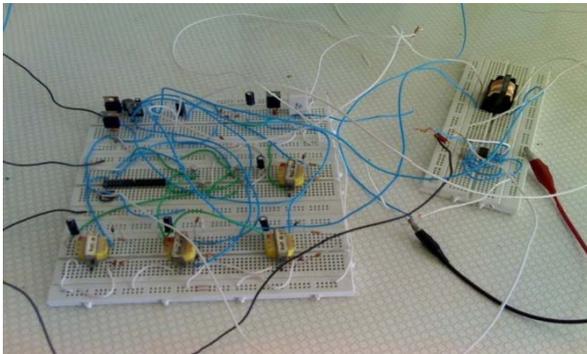


Fig. 11 Experimental Circuit.

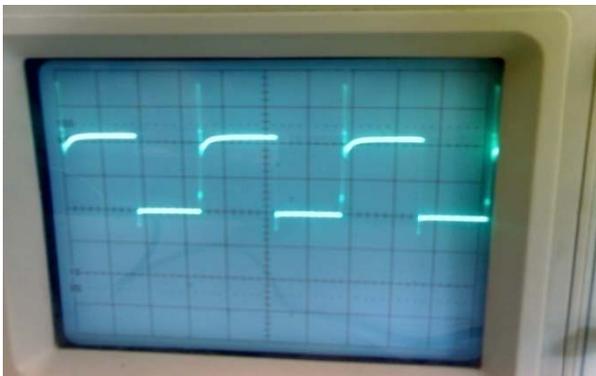


Fig. 12 Clock Signal.

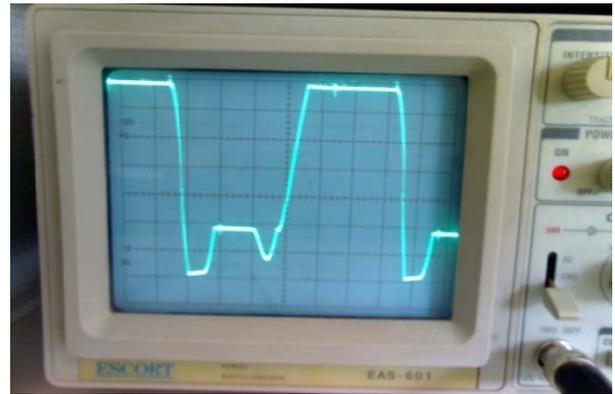


Fig. 13  $V_{DS}$  for switch  $S_1$ .

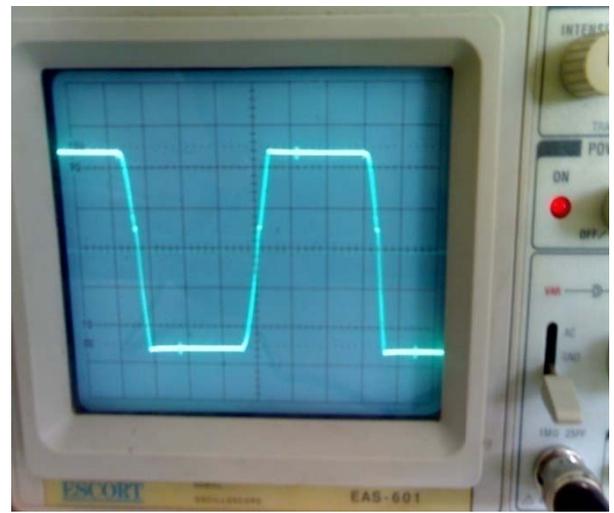


Fig. 14  $V_{DS}$  for switch  $S_2$ .

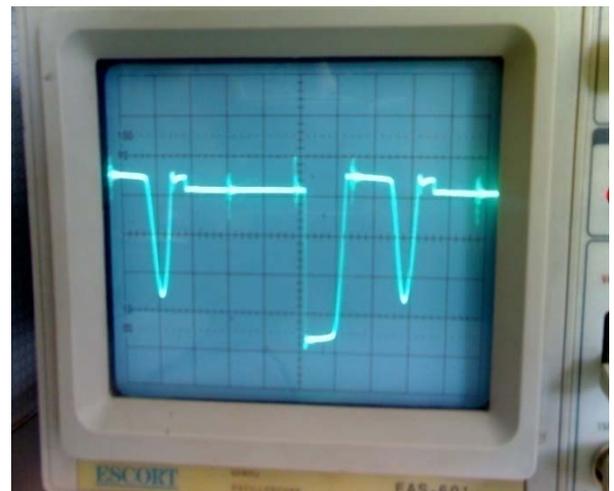


Fig. 15  $V_{DS}$  for switch  $S_3$ .

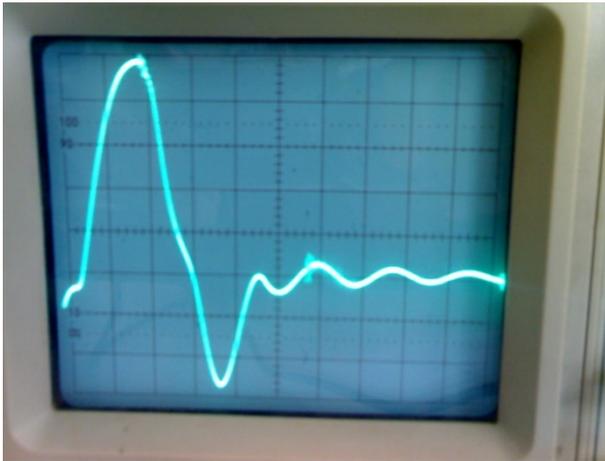


Fig. 16  $V_{DS}$  for switch  $S_4$ .

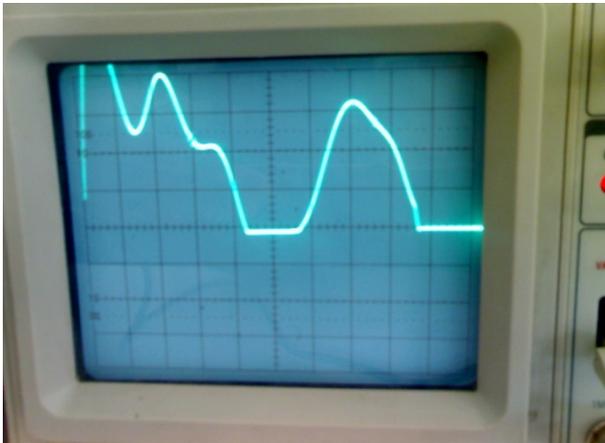


Fig. 17  $V_{DS}$  for switch  $S_5$ .

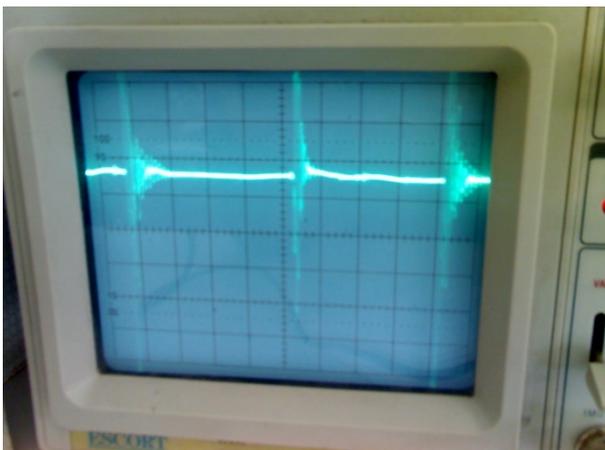


Fig. 18 Waveform of DC output voltage ( $V_{out}$ ).

## 7 Conclusion

A ZVZCS isolated dual series resonant dc-dc converter with high efficiency has been proposed. Analysis, design, and simulation and experimental results for the proposed converter have also been

presented. This proposed converter combines the active-clamp circuit and the dual series-resonant circuit across the power transformer proposed in [12] with the topology proposed for soft switching dc-dc converter in [25]. The dual series-resonant circuit provides two resonant-current paths formed by the leakage inductance of the power transformer and the resonant capacitors. In addition, the turn-on and turn-off ZVS and ZCS mechanism of the switches by the active-clamp and auxiliary input and output switches, they reduce the switching losses and the reverse-recovery losses. Therefore, the proposed converter provides high efficiency at the full load. EMC Important techniques used in the converter circuit reduce EMI and increase performance in the circuit.

## Acknowledgment

I would like to extend our greatest gratitude to the Islamic Azad University-Tehran South Branch, Young Researchers Club that supported me to do the present research project.

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