SINGLE PHASE ZVT SINUSOIDAL PWM FULL-BRIDGE INVERTER WITH ACTIVE SNUBBER CELL

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Abstract- In this paper, a novel single phase zero voltage transition (ZVT) full bridge voltage source inverter with active snubber cell is proposed. The snubber cell of the proposed inverter has a modular structure. There is an auxiliary circuit for each main switch of inverter. Also, it can be apply three phase inverters. In the proposed novel inverter, all of the semiconductor devices turn on and off with soft switching. The main switches of the full bridge inverter turn on with Zero Voltage Transition (ZVT) and turn off with Zero Voltage Switching (ZVS). Also, the auxiliary switches turn on with Zero Current Switching (ZCS) and turn off with Zero Current Transition (ZCT). The theoretical analysis of the proposed converter is made. The operating modes and the simulation results of the proposed converter operated for 750 W and 50 kHz is given in detail.

Keywords- Sinusoidal PWM, Full Bridge Inverter, Zero Voltage Transition, Zero Current Transition, Soft Switching (SS).

I. INTRODUCTION

Pulse width modulation (PWM) inverters are widely used in applications as renewable energy, uninterruptible power supplies, electrical motor speed control systems, solar energy systems etc. These inverters are two kind as voltage source inverter (VSI) and current source inverter (CSI) [1, 2]. In these inverters, harmonic content is an important problem. Harmonic distortion of the output voltage is depend on modulation technique used [3]. One of the most common modulation techniques is sinusoidal PWM. Sinusoidal PWM full-bridge inverters have many advantages as higher efficiency, dc link utilization and lower current ripple [4].

It is desired that PWM converters have high power density, fast dynamic response, low output harmonic distortion, simple structure and control. The switching frequency should be increased to obtain these features [5, 6]. Especially, PWM techniques decrease size of filter and minimize noise at high frequency as over 20 kHz [3]. However, the high switching frequency leads to high switching power losses and electromagnetic interference (EMI) noise. So, it causes to a bad performance and low efficiency. These adverse effects can be eliminated by soft switching (SS) techniques [1-7].

A lot of soft switching techniques for inverters have been proposed in literature such as resonant pole inverters, resonant DC link and AC link inverters [8-15]. Several of these inverters have some disadvantages. In [8], the first resonant DC link inverter is proposed. In this inverter, the snubber cell has a series inductor and a parallel capacitor. The disadvantage of this converter is that the additional voltage stress occurs on inverter switches. Also, the traditional PWM technique cannot be used in this inverter. In [9] and [10], the auxiliary switches are turned off with hard switching (HS). The inverter proposed in [11] has soft switching conditionals but the additional voltage stress occurs on the inverter switches and its value is twice of the input voltage. In [12], the main switches of inverter turn off with ZCT and the auxiliary switches turn on with ZCS. However, the main switches turn on with HS.

Each switch of the inverter proposed in [13] operates with soft switching. In the inverter, the switches turn on with ZVT and turn off with ZVS. Also, the auxiliary switches turn on with ZCS and turn off with ZCT. The zero voltage interval of the DC link should be controlled in the switching techniques as space vector pulse width modulation (SVPWM). However, zero voltage interval of the DC link cannot be controlled in inverters [14] and [15].
In this paper, a novel single phase ZVT full bridge VSI is proposed by considering all of these disadvantages belonging to the previously proposed soft switching inverters. The basic circuit scheme of the proposed a novel single phase ZVT full bridge voltage source inverter is shown in Fig. 1.

In the proposed novel inverter, the main switches turn on with ZVT and turn off with ZVS. The auxiliary switches turn on with ZCS and turn off with ZCT. The other semiconductor devices operate under soft switching. Also, extra voltage stress does not occur on the semiconductor elements. There is an auxiliary circuit for each main switch of inverter. Also, it can be apply three phase inverters. The snubber cell of the proposed inverter has a modular structure. In the snubber circuit, an auxiliary switch, a resonance inductor, a resonance capacitor and an auxiliary diode are used. In addition to the proposed novel inverter can be operate a wide input voltage range by soft switching.
Firstly, theoretical analysis of the inverter is made. Then, the proposed inverter is operated by prototype 750 W and 50 kHz in Power Simulation (PSIM) program. The simulation results are suitable with theoretical analysis.
In the proposed inverter, V_i is DC input voltage source, S_1, S_2, S_3 and S_4 are inverter main switches; L_o and R_o are resistive-inductive load; C_{S1}, C_{S2}, C_{S3} and

C_{S4} are parasitic capacitors of the main switches. In the active snubber cell, S_{1a}, S_{2a}, S_{3a} and S_{4a} are auxiliary switches; $D_{r1,}$ D_{r2}, D_{r3} and D_{r4} are auxiliary diodes; $L_{r1,}$ L_{r2}, L_{r3} and L_{r4} are resonance inductors; $C_{r1,}$ C_{r2}, C_{r3} and C_{r4} are resonance capacitors.

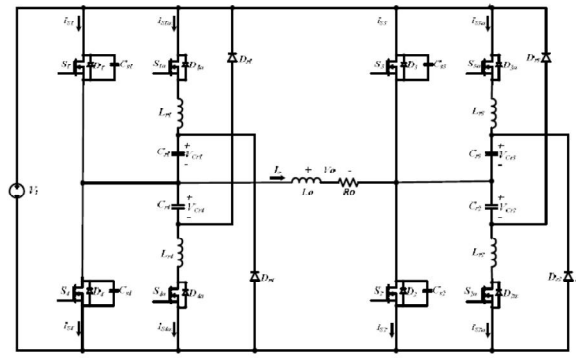


Fig.1 The basic circuit cheme of the proposed novel single phase ZVT sinusoidal PWM full bridge inverter with active snubber circuit

II. OPERATING MODES OF THE PROPOSED NOVEL INVERTER

The following assumptions are made to simplify theoretical analysis.

- The input voltage V_i is constant.
- The output current can be considered as constant because the switching frequency is much greater than the output voltage frequency.
- All of the semiconductor devices are ideal.
- The reverse recoveries of diodes are neglected.

In the proposed inverter, there is an active snubber cell for each switch. Considering the symmetrical operation existing between positive and negative period, one phase inverter leg is used to illustrate the operating principle. So, eight operation modes occur for each switch in the steady state operation during one switching period. In positive period, the equivalent circuits of upper switch operating modes for the first phase arm are shown in Fig. 2. In here, the operating modes are examined when S_1 switch is turned on and off while S_4 switch is at off state. The same modes are actualized for each switch.

Mode 1 [$t_0 < t < t_1$: Fig. 2(a)]

Before this mode, the first phase arm is inactive and the voltage of C_{r1} is zero. The output current flows through S_2 switch and the body diode of S_4 switch. At the beginning of this mode (at $t = t_0$), a control signal is applied the auxiliary switch S_{1a} and it turns on with ZCS due to resonance between L_{r1} and C_{r1}. While the current of S_{1a} is increasing, the current of D_4 decreases and C_{r1} is charged.

At $t = t_1$, when the current of resonance inductor L_{r1} reaches to I_o, D_4 turns off with ZCS and this mode ends.

Mode 2 [$t_1 < t < t_2$: Fig. 2(b)]

In this mode, a resonance begins via $C_{s1} - S_{1a} - L_{r1} - C_{r1}$. C_{s1} is discharged while the current of L_{r1} and voltage of C_{r1} are increasing. Also, the voltage of C_{s4} increases to input voltage simultaneously since total voltage of C_{s1} and C_{s4} needs to be equal to input voltage.

At $t = t_2$, when the voltage of C_{s1} falls to zero and the voltage of C_{s4} reaches to input voltage, the current of L_{r1} and the voltage of C_{r1} reaches to a valid and this mode ends.

Mode 3 [$t_2 < t < t_3$: Fig. 2(c)]

In this mode, the resonance between L_{r1} and C_{r1} continues through D_1 diode. While the voltage of C_{r1} is increasing, the current of L_{r1} decreases since the voltage across L_{r1} is equal to $-V_{Cr1}$. This mode is *ZVT interval*. At anytime of this interval, a control signal is applied to the main switch S_1 when its body diode is at on state. Thus, the main switch S_1 turns on with ZVT.

At $t = t_3$, when the current of L_{r1} falls to zero, the voltage of C_{r1} reaches to maximum and this mode ends.

Mode 4 [$t_3 < t < t_4$: Fig. 2(d-a), Fig. 2(d-b)]

In this mode, the resonance between L_{r1} and C_{r1} continues with adverse way via $C_{r1} - L_{r1} - D_{1a} - S_1$. While the voltage of C_{r1} is decreasing, the current of L_{r1} increases in negative direction. The control signal of S_{1a} is removed when its body diode is at on state. So, the auxiliary switch S_{1a} turns off with ZCT. After the voltage of C_{r1} falls to zero and the current of L_{r1} reaches to maximum value in negative direction, the resonance continues in adverse way.

At $t = t_4$, when the current of L_{r1} falls to zero and the voltage of C_{r1} reaches to maximum value in negative direction and this mode ends.

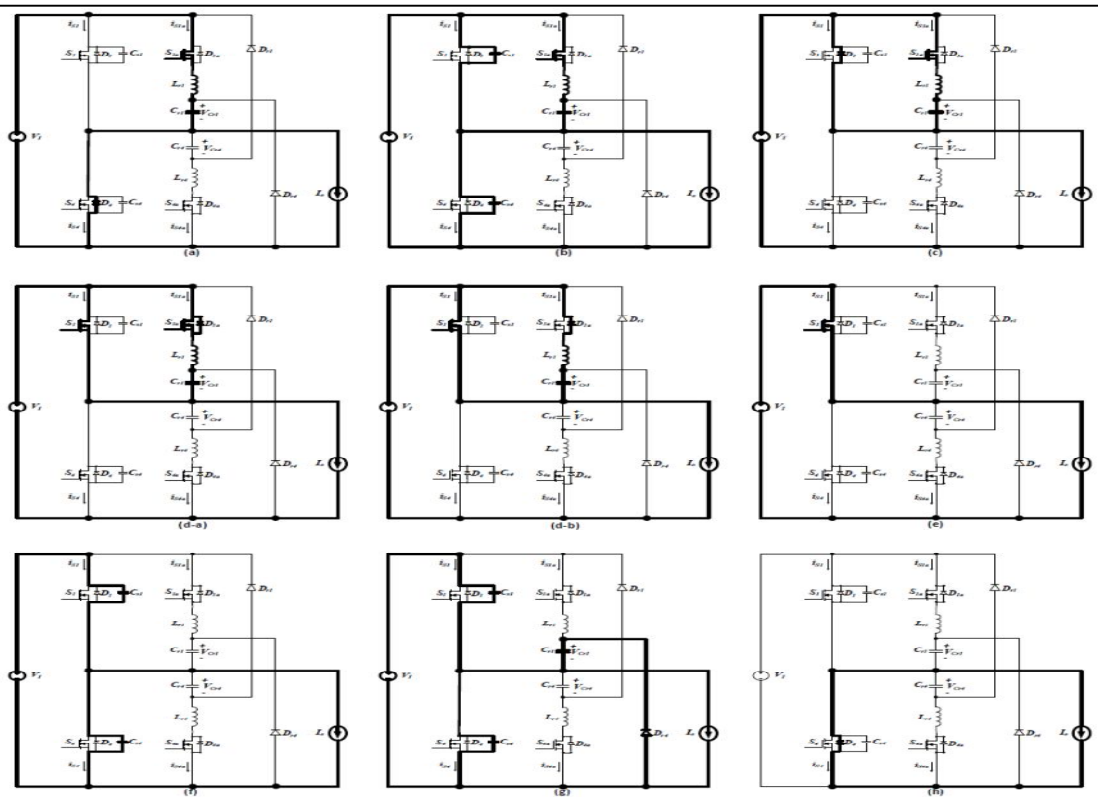


Fig.2 Equivalent circuits of the operating modes in the proposed single phase ZVT Sinusoidal PWM full bridge inverter with active snubber cell

Mode 5 [$t_4 < t < t_5$: Figure 2(e)]
This mode is equivalent to positive period of inverter. During this mode, the energy is transferred from source to load.

At $t = t_5$, when the control signal of the main switch S_1 is removed, S_1 switch turns off with ZVS due to C_{s1} and this mode ends.

Mode 6 [$t_5 < t < t_6$: Fig. 2(f)]

In this mode, C_{s1} capacitor is charged while C_{s4} capacitor is discharged. At the end of this mode (At $t = t_6$), the voltage of C_{s1} capacitor reaches to the voltage of C_{r1} and D_{r4} turns on with ZVS. So, this mode ends.

Mode 7 [$t_6 < t < t_7$: Fig. 2(g)]

In this mode, C_{s1} capacitor and C_{r1} capacitor is charged together while C_{s4} capacitor continues to discharge. At the end of this mode (At $t = t_7$), when the voltage of C_{s1} capacitor reaches to the input voltage and C_{s4} capacitor falls to zero, D_4 turns on with ZVS. So, this mode ends.

Mode 8 [$t_7 < t < t_8$: Fig. 2(h)]

In this mode, the first phase arm is inactive and the voltage of C_{r1} is zero. The output current flows through S_2 switch and the body diode of S_4 switch. So, a switching cycle is completed for a main switch of inverter. The same modes are repeated for the other main switches.

III. SIMULATION RESULTS

It is realized a prototype of proposed novel single phase ZVT sinusoidal PWM full bridge inverter with an active snubber cell by 750 W and 50 kHz in PSIM 9.1.1 simulation program. The simulations results are shown Fig. 3–6. The voltage values of switches are scaled 1/10 ratio in Fig. 3-5 in order to see the current and the voltage waveforms in the same figure clearly.

Table I The Components Values of Proposed New Converter

P_o	750 W	L_{r1}, L_{r2}, L_{r3}, L_{r4}	4 µH
f_s	50 kHz	C_{r1}, C_{r2}, C_{r3}, C_{r4}	30 nF
V_i	200 V_{dc}	L_o, R_o	470 mH, 20 ohm
V_o	200 V_{rms}	C_{s1}, C_{s2}, C_{s3}, C_{s4}	4.7 nF
$I_{o\text{-}rms}$	8.5 A	$I_{i\text{-}avg}$	3.75 A

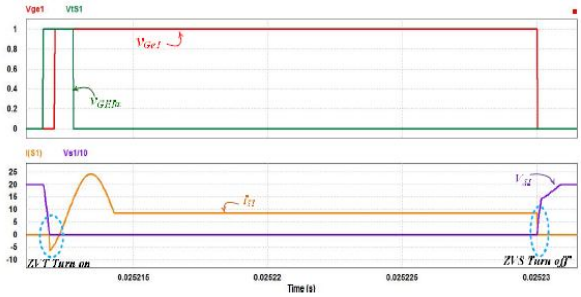


Fig.3 To down from up respectively; the control signals of the S_1 switch and the S_{1a} auxiliary switch, the current and voltage waveforms of S_1 switch

The control signals of the S_1 switch and the S_{1a} auxiliary switch, the current and voltage waveforms of S_1 switch are shown in Fig. 3. As shown in figures, the main switch of inverter S_1 turns on with ZVT and

turns off with ZVS. Also, it is shown that the extra voltage stress does not occur on the main switch.

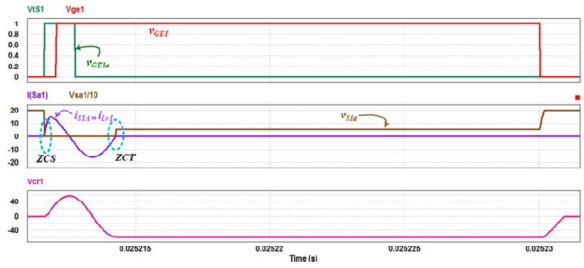


Fig.4 To down from up respectively; the control signals of the S_1 switch and the S_{1a} auxiliary switch, the current and voltage waveforms of S_{1a}, and voltage waveform of resonance capacitor C_{r1}

The control signals of the S_1 switch and the S_{1a} auxiliary switch, the current and voltage waveforms of S_{1a}, and voltage waveform of resonance capacitor C_{r1} are shown in Fig. 4. As shown in figure, the auxiliary switch S_{1a} turns on with ZCS and turns off with ZCT. There is no additional voltage stress across the auxiliary switch S_{1a}.

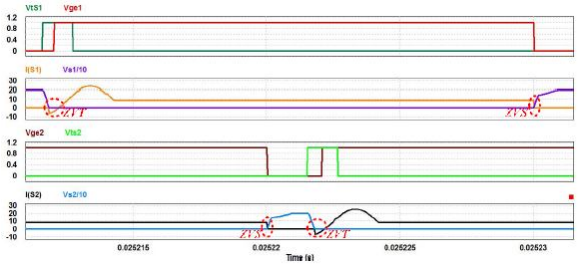


Fig.5 The control signals, current and voltage waveforms of first and second phase arm switches S_1 and S_2.

In Fig. 5, the control signals, current and voltage waveforms of first and second phase arm switches S_1 and S_2. It can be see that switches on the second phase arm operate with soft switching as in first phase arm. The switch of the second phase arm S_2 turns on with ZVT and turns off with ZVS. Also, there is no extra voltage stress on S_2.

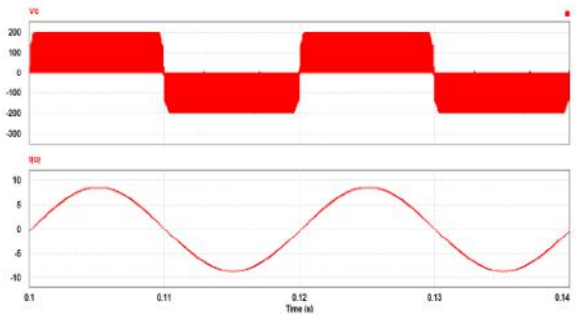


Fig.6 To down from up respectively; output voltage, output current

The output voltage and output current waveforms are shown in Fig. 6. As shown in figure, sinusoidal and an AC current is obtained in outside. Total harmonic distortion of this current is quite lower.

CONCLUSIONS

In this paper, a novel single phase ZVT sinusoidal PWM dull bridge inverter with active snubber cell is proposed. The operating modes and the simulation results of new proposed converter are given in detail. In this inverter, the main switches turn on with ZVT and turn off with ZVS. The auxiliary switches turn on with ZCS and turn off with ZCT. The auxiliary diodes turn on and off with ZVS. The control signals are obtained with sinusoidal PWM. There are no extra voltage stress on the switches and diodes in the proposed inverter.

In the proposed full bridge inverter, the operating with soft switching is maintained in light load conditions and the soft switching is ensured in a wide input voltage range. Additionally, the proposed study has low THD for output current.

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