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Dc-Ac Single Phase Resonant Inverter Using Soft Switching Boost Converter with Resistive Load

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ABSTRACT

In this paper, a novel DC-AC single phase inverter is proposed. When the switches are turned on and off, a conventional inverter generates switching loss because of the hard switching. Thus, the inverter loss is increased. Proposed system contains auxiliary circuit. The converter stage switches perform soft switching because of the auxiliary circuit. Also inverter stage switches perform ZVS when the dc-link voltage is zero. Therefore all switches perform soft-switching when the switches are turned on and off. Thus the proposed system reduces switching loss and voltage stress.

Keywords: - soft-switching, zero voltage state, zero current state, single phase inverter, boost converter

I. INTRODUCTION

Present days, the power electronics are required to develop smaller, lighter, less expensive and reliable system. In order to operate these systems, a switching frequency has to be increased. But, increasing the inverter switching frequencies is dependent on the advances in device technology and makes higher switching losses. To solve this problem, the soft switching techniques have been adopted in the inverter circuit. By the soft-switching techniques, the switching losses are ideally zero and the switching frequencies can be increased to above the audible range. In this paper, a novel DC-AC single phase resonant inverter using soft switching boost converter is proposed. This proposed inverter consists of soft-switching boost converter and H-bridge inverter.

In the 1970's, conventional PWM power converters were operated in a switched mode operation. Power switches have to cut off the load current within the turn-on and turn-off times under the hard switching conditions. Hard switching refers to the stressful switching behavior of the power electronic devices. During the turn-on and turn-off processes, the power device has to withstand high voltage and current simultaneously, resulting in high switching losses and stress. Dissipative passive snubbers are usually added to the power circuits so that the dv/dt and di/dt of the power devices could be reduced, and the switching loss and stress diverted to the passive snubber circuits. However, the switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converters. Typical converter switching frequency was limited to a few tens of kilo-Hertz (typically 20kHz to 50kHz) in early 1980's. The stray inductive and capacitive components in the power circuits and power devices still cause considerable transient effects, which in turn give rise to electromagnetic interference (EMI) problems.

In the 1980's, lots of research efforts were diverted towards the use of resonant converters. The concept was to incorporate resonant tanks in the converters to create oscillatory (usually sinusoidal) voltage and/or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. The reduction of switching loss and the continual improvement of power switches allow the switching frequency of the resonant converters to reach hundreds of kilo-Hertz (typically 100 kHz to 500 kHz). Consequently, magnetic sizes can be reduced and the power density of the converters increased. Various forms of resonant converters have been proposed and developed. However, most of the resonant converters suffer several problems. When compared with the conventional PWM converters, the resonant current and voltage of resonant converters have high peak values, leading to higher conduction loss and higher V and I ratings requirements for the power devices. Also, many resonant converters require frequency modulation (FM) for output regulation. Variable switching frequency operation makes the filter design and control more complicated.

In late 1980's and throughout 1990's, further improvements have been made in converter technology. New generations of **soft-switched converters** that combine the advantages of conventional PWM converters and resonant converters have been developed. These soft-switched converters have switching waveforms similar to those of conventional PWM converters except that the rising and falling edges of the waveforms are 'smoothed' with no transient spikes. Unlike the resonant converters, new soft-switched converters usually utilize the resonance in a controlled manner. Resonance is allowed to occur just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. Other than that, they behave just like conventional PWM converters. With simple modifications, many customized control integrated control (IC) circuits designed for conventional converters can be employed for soft-switched converters. Because the switching loss and stress have been reduced, soft-switched converter can be operated at the very high frequency (typically 500 kHz to a few Mega-Hertz). Soft-switching converters also provide an effective solution to suppress EMI and have been applied to DC-DC, AC-DC and DC-AC converters. This paper covers the basic technology of resonant and soft-switching converter.

The soft-switching boost converter in proposed inverter additionally has resonant inductor Lr, resonant capacitor Cr, bridge diode and auxiliary switch Q2. When the resonance between resonant inductor and capacitor is generated, the converter switches are turned on and off with soft-switching.

II. PROPOSED INVERTER

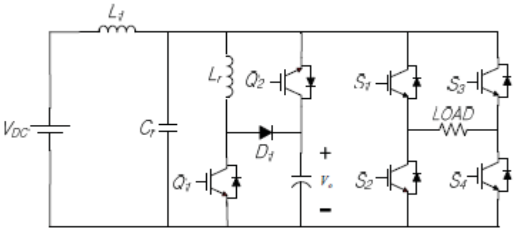

Fig. 1 Proposed novel DC-AC single phase resonant inverter using soft switching boost converter

Fig. 1 shows the proposed a novel DC-AC single phase resonant inverter using soft-switching boost converter. The auxiliary circuit in proposed inverter consists of an auxiliary switch, resonant inductor, resonant capacitor, and bridge diode. So, the main switch is turned on with ZCS and turned off with ZVS. Also the auxiliary switch is turned on and off with ZVS. Therefore, the converter stage switches perform the soft-switching.

SIMULATION MODEL

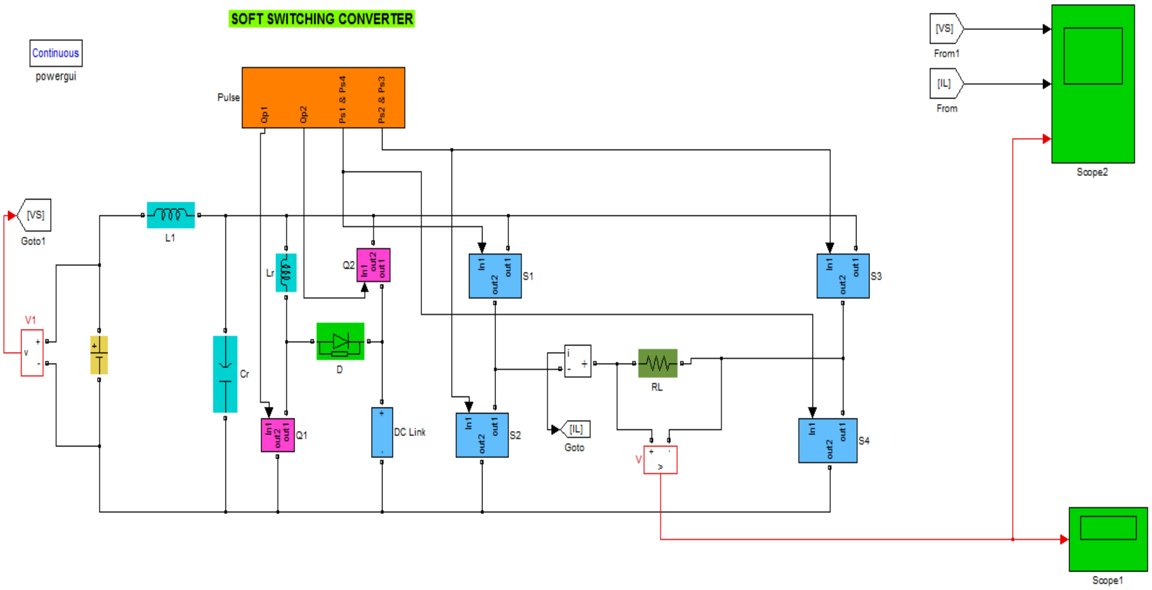

Fig.2 simulation model for the novel DC-AC single phase resonant inverter

The H-bridge inverter performs the soft-switching under the influence of the dc-link voltage. When the auxiliary switch is turned off with ZVS, the dc-link voltage is zero. The inverter switches are turned on and off with ZVS while the dc-link voltage becomes zero. So all of switches in proposed inverter are turned on and off with soft-switching.

Therefore, the proposed soft-switching inverter has many advantages like as improved efficiency, low switching losses, low voltage stress, reduced acoustic noise and EMI. Another significant advantage of the proposed topology is an excellent PWM capability due to not only variable link pulse but also variable pulse position.

The proposed inverter operation mode analysis can be divided into six modes, as shown in Fig 2. Fig 3 shows the proposed waveforms for the novel DC-AC single phase resonant inverter using soft-switching boost converter.

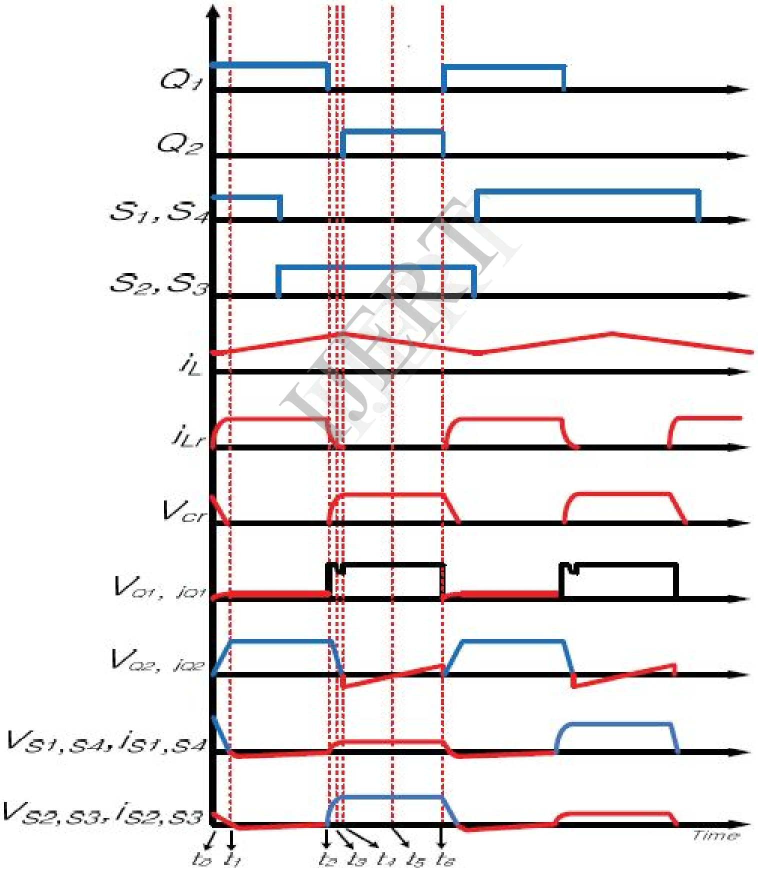

Fig.3 Operation waveforms for the novel DC-AC single phase resonant inverter using soft-switching boost converter

III. EQUIVALENT CIRCUIT ANALYSIS

Mode 1 (t0_t<t1): The resonant capacitor is discharged through resonant path Cr and Lr. The resonant inductor current begins to increase linearly from zero. Therefore, the main switch is turned on with ZCS influenced by resonant inductor. The energy of the main inductor is delivered to the load through the switches (S1, S4). The next mode is started as soon as the resonant capacitor has ully discharged. In this mode, the main inductor current is given by

$$i_{L_1}(t) = i_{L1}(t_0) + \frac{V_{in}}{L}(t_1 - t_0) \quad (1)$$

$$i_{L1}(t_0) \equiv I_{\min} \equiv i_{Lr}(t_0) \quad (2)$$

Initial resonant inductor current and capacitor voltage given by

$$i_{Lr}(t_0) \equiv 0 \quad (3)$$

$$v_{cr}(t_0) \equiv V_{out} \quad (4)$$

The resonant period is

$$t_r = \frac{\pi}{2}\sqrt{L_r C_r} \quad (5)$$

The resonant impedance is

$$Z_r = \sqrt{\frac{L_r}{C_r}} \quad (6)$$

The inductor current and resonant capacitor voltage in resonant period are given by,

$$i_{Lr}(t) = (I_{L1\min} - I_o) + I_o \cos\omega_r(t_1 - t_0) + \frac{V_o}{Z_r} \cdot \sin\omega_r(t_1 - t_0) \quad (7)$$

$$v_{cr}(t) = v_o \cos\omega_r(t_1 - t_0) - \frac{V_o}{Z_r} \cdot I_o Z_r \cdot \sin\omega_r(t_1 - t_0) \quad (8)$$

Mode 2 (t_1_$t<t_2$): When the resonant capacitor is fully discharged to Mode1, the anti-parallel diodes in inverter switches constitute current path. At this time, the inverter stage is zero. When the inverter stage is in the zero voltage condition, the inverter switches are given to PWM signal (S_1, S_4). So, inverter switches are turned on and off with ZVS. This mode is maintained when the main switch is turned-off. The main inductor current is given by

$$I_{L_1}(t) = I_{L1}(t_1) + \frac{V_{in}}{L}(t_2 - t_1) \quad (9)$$

The resonant inductor current and resonant capacitor voltage are given by

$$i_{Lr}(t) \equiv i_{Lr}(t_1) \equiv i_{Lr}(t_2) \quad (10)$$

$$v_{cr}(t_1) \equiv v_{cr}(t_2) \equiv 0V \quad (11)$$

Mode 3 ($t2< t<t3$): When the switch is turned off with ZVS, the resonant inductor releases energy. Thus, the bridge diode is turned on. The dc-link capacitor is transferred to main inductor and resonant inductor energy through the bridge diode. The resonant capacitor starts to charge main inductor energy. At that time, the resonant inductor current and resonant capacitor voltage are given by

$$i_{Lr}(t) = v_o + \left(\frac{I_{in}}{C} - v_o\right)\cos\omega_r(t_3 - t_2) - \frac{I_{L(o)}}{Z_r}\sin\omega_r(t_3 - t_2) \quad (12)$$

$$v_{cr}(t) = v_o - v_o \cos\omega_r(t_3 - t_2) + Z_r(I_{in} - I_o - I_{L(o)})\sin\omega_r(t_3 - t_2) \quad (13)$$

$$i_{Lr}(t_3) \equiv 0 \quad (14)$$

In this mode, the main inductor current is given by

$$I_{L_1}(t) = I_{L1}(t_2) - \frac{v_o - v_{in}}{L}(t_3 - t_2) \quad (15)$$

$$I_{L_1}(t_2) \equiv I_{\max} \quad (16)$$

Mode 4 ($t3< t<t4$): When the resonant inductor energy is fully released, the bridge diode is turned-off. This mode is maintained until the resonant capacitor voltage becomes 400[V]. The main inductor current flows continuously through the inverter switches (S1, S4). In this mode, resonant capacitor voltage is given by

$$v_{cr}(t) = \frac{I_{L1} - I_o}{C}(t_4 - t_3) + V_C(t_3) \quad (17)$$

$$v_{cr}(t_4) \equiv V_{out} \quad (18)$$

Resonant inductor current is given by

$$i_{Lr}(t_3) \equiv i_{Lr}(t_4) \equiv 0 \quad (19)$$

Mode 5 (t_4 $t<t_5$): This mode is started when the resonant capacitor is fully charged. After that, the auxiliary switch is turned on with ZVS because the switch voltage is zero. When the main inductor current decreases linearly, the dc-link capacitor is charged from the main inductor energy. Because the main inductor current flows through the anti-parallel diode, the auxiliary switch voltage is zero voltage. When the auxiliary switch current path is changed, the next mode starts. In this mode, the main inductor current can be expressed as

$$I_{L_1}(t) = I_{L1}(t_4) - \frac{v_o - v_{in}}{L}(t_5 - t_4) \quad (20)$$

Mode 6 (t_5 $t<t_6$): In this mode, the auxiliary switch current path is changed because the dc-link capacitor starts to discharge. Therefore, the load is supplied the energy by the dc-link capacitor and main inductor. This mode maintains that the main inductor current equal to the resonant current. The main inductor current in this mode is expressed as

$$I_{L_1}(t) = I_{L1}(t_5) - \frac{v_o - v_{in}}{L}(t_6 - t_5) \qquad (21)$$

$$i_{L1}(t_6) \cong I_{\min} \qquad (22)$$

$$i_{Lr}(t_5) \cong i_{Lr}(t_6) \cong 0 \qquad (23)$$

$$v_{cr}(t_4) \cong V_{out} \qquad (24)$$

After this mode ends, returning the mode 1.

IV. SIMULATION RESULT

This proposed resonant inverter is simulated to demonstrate the features and theoretical analysis. A 3kW prototype resonant inverter is built and simulated using the PSIM tool. The parameters used for simulations are as follow TABLE1

TABLE1. Simulation parameters

V_{dc}	200[V]
$V_{dc\text{-}link}$	400[V]
Main inductor	1000[μ H]
Resonant inductor	10[μ H]
Resonant capacitor	10[nF]
DC-Link-Cap	1000[μ F]
Con. Switching Freq.	30[kHz]
Inv. Switching Freq.	15[kHz]

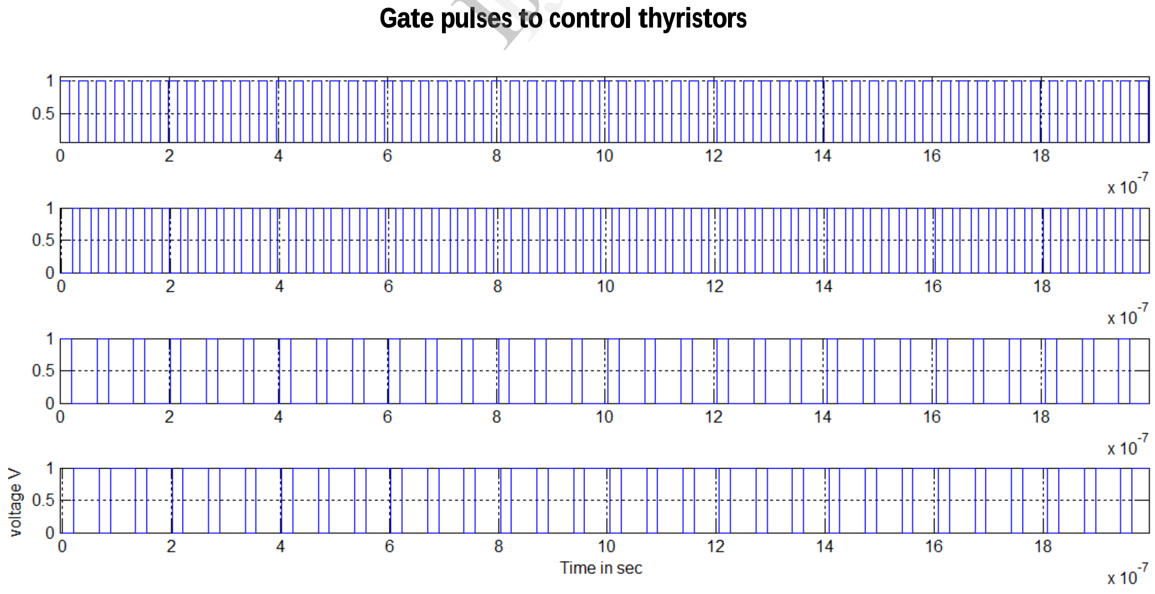

Fig.4 GATE pulses in resonant DC-AC single phase inverter

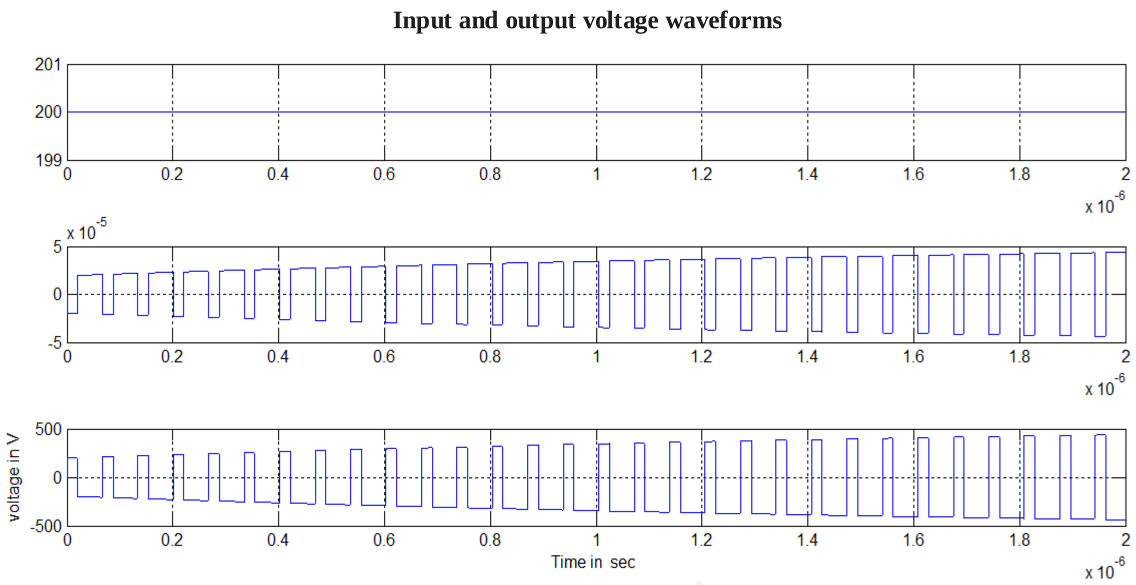
Input and output voltage waveforms

Fig.5 source voltage, line current, load voltage wave forms of resonant DC-AC single phase inverter

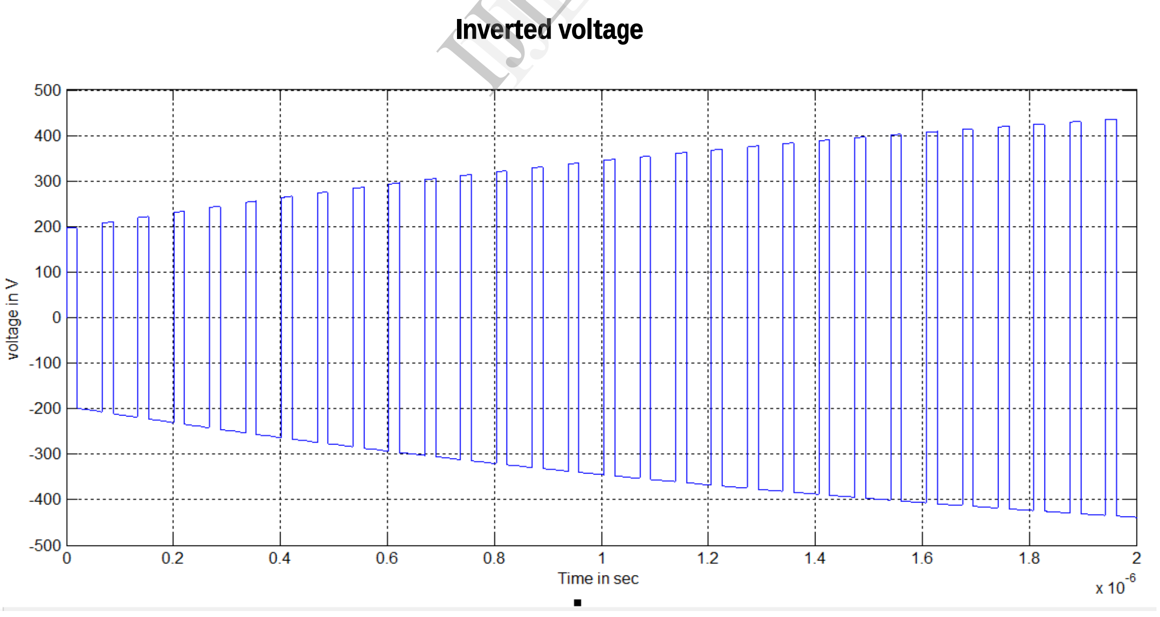
Inverted voltage

Fig.6 inverted voltage wave forms of resonant DC-AC single phase inverter

V. CONCLUSION

In this paper, we proposed a novel DC-AC single phase resonant inverter using soft-switching boost converter. In this topology, all switches perform a soft switching by resonance between the resonant inductor and capacitor. So, the proposed topology can reduce the switching loss and voltage stress. The proposed inverter is analyzed through the operation mode, and its validity is proven through simulation.

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