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Single-ended resonant inverter for photovoltaic applications

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The Single-Ended (SE) resonant microinverter is a type of class E parallel resonant inverter and popularly used in many applications due to its lower cost structure and relatively high efficiency. However, its maximum power rating should be limited because the resonant voltage of SE resonant inverter increases as its power increases. Consequently, the maximum power rating of SE resonant inverter should be limited up to around 2 kW. This paper proposes an interleaved single-ended resonant inverter for the photovoltaic applications. The proposed inverter can provide two times higher output power than the conventional single-ended resonant inverter. A burst mode control enhances the power control range from very light load to full load and can improve efficiency.

Keywords: *Burst mode, Single-Ended(SE), interleaved, class E, resonant converter*

1.0 INTRODUCTION

For solar PV, a high-frequency resonant micro inverter is required that converts the DC into AC on a panel itself. Basically, two types of resonant inverters, a Half-Bridge (HB) inverter and a Single-Ended (SE) inverter can be considered. Of these two inverter types, the SE resonant inverter is generally more popular in PV due to its lower cost structure as well as its relatively high efficiency. However, the SE resonant inverter has the acritical drawback that its application should be having lower power rating than 2 kW. In the SE resonant inverter,the peak working voltage of IGBT is normally around 1100 V under the condition with the input voltage is 220 V, the switching frequency is around 20 kHz, and the power rating is 2 kW[1]. Meanwhile, the breakdown voltage of IGBT in the SE resonant inverter is normally limited to around 1200 V~1500 V due to the trade-off between the breakdown voltage and the current rating; As the higher breakdown voltage of IGBT gets higher, its $V_{CE\,(sat)}$ also gets higher exponentially. In this paper, a inter leaved SE resonant micro inverter for PV application is proposed and discussed with experimental results. The proposed inverter can provide twice of output power than conventional one by means of the alternative switching operation of two inverters. Besides, a burst mode control allows wide power control range and better thermal performance thereby the proposed inverter will also be more reliable. To verify the validity of the proposed inverter.

2.0 PROPOSED INTERLEAVED SE RESONANT INVERTER FOR IH APPLICATIONS

2.1 Single-ended Resonant Inverter for IH applications

The rectifier, choke coil, and input capacitor, Cin shown in Figure 1 comprises a Low-Pass Filter (LPF). Meanwhile, the working coil can be

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represented as a series combination of inductance, Lr, and Resistance [2-3], Req, which combine with a capacitor (Cr) to form are sonant tank circuit. The operation of the inverter is simply divided into 4 modes. During the mode I, the resonant current flows through the anti-parallel diode, thus the collector-

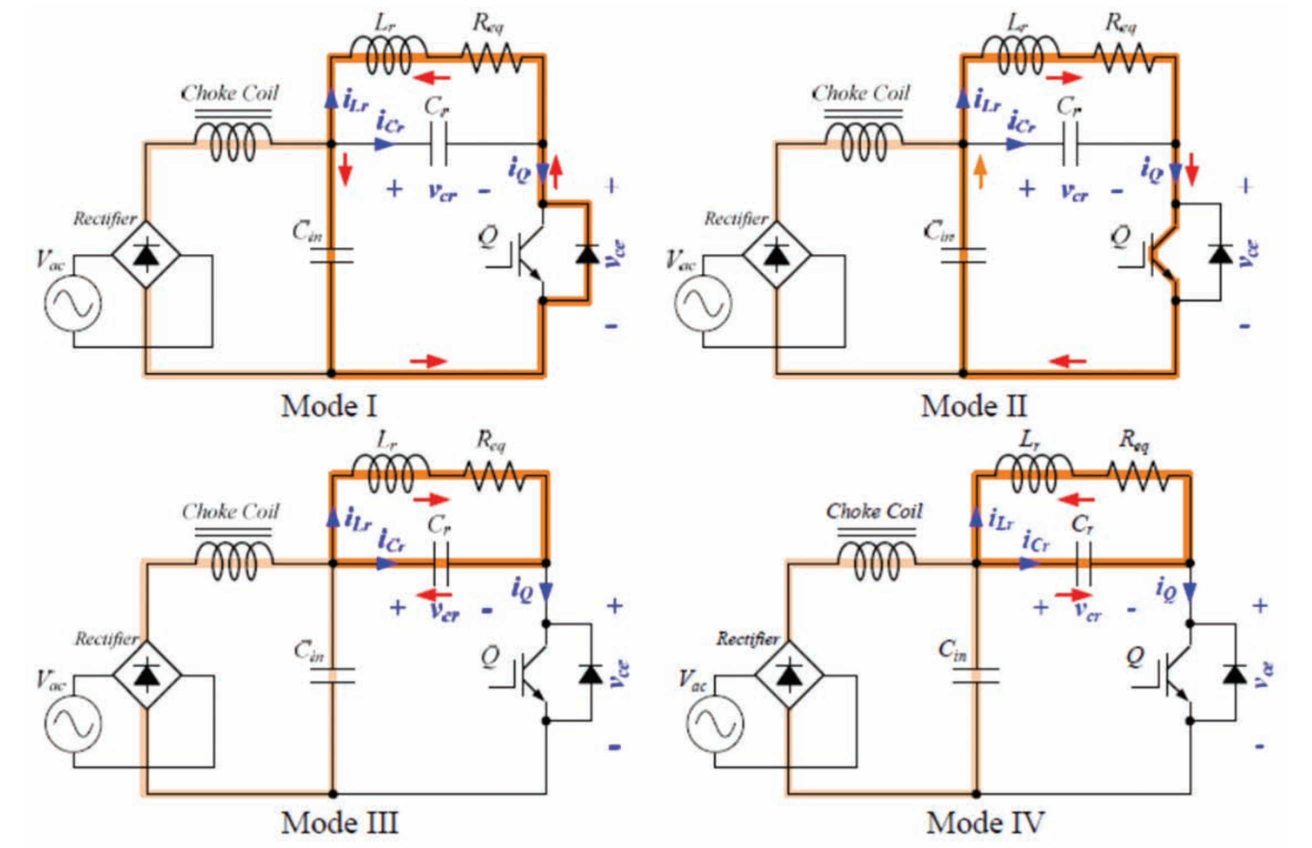

FIG. 1. THE CIRCUIT DIAGRAM AND OPERATION MODES OF SE RESONANT INVERTER

The switch should be turned on within this mode to achieve Zero Voltage Switching (ZVS) turn-on. When the switch is turned-off, a quasi-resonance between Lr and Cr is begun. Since the switching voltage gradually rises due to this resonance (slower dV_{CE}/dt condition), the ZVS turn-off is also achieved. In order to achieve ZVS turn-on and turn-off, the off-time has to be fixed. Through the zero voltage switching (ZVS) by voltage resonance, this inverter system provides the better efficiency [5]. However, it needs high voltage IGBT as a switching device. Because the inverter is operated by only single IGBT and a very high resonant voltage is applied to the IGBT [6].

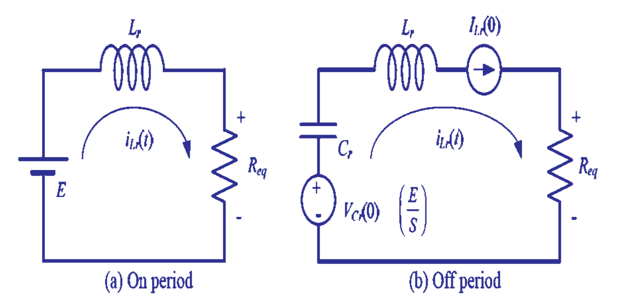

FIG. 2. EQUIVALENT CIRCUITS OF SE RESONANT INVERTER DURING IGBT ON AND OFF PERIOD

The equivalent circuits during the IGBT on and off period are illustrated in Figure 2. In the SE resonant inverter in Figure 3, i_{Leq} flows through $L_{eq}, R_{eq,} Q$ and C_{in} and the energy is transferred to the load during the switch-on period [7] as shown in Figure 4 Thereby the voltage equation is:

$$V_{in} - L_{eq}\frac{di_{Leq}}{dt} - R_{eq}i_{Leq} = 0 \quad ...(1)$$

The inductor current

$$i_{Leq(on)}(t) = \frac{E}{R}(1 - e^{\frac{R}{L}t}) \quad ...(2)$$

When switch, Q, is turned off at t_2 in Figure 1, the resonance between L_r and C_r is begun and the circuit can be considered as shown in Figure 3 [9]. Therefore, the voltage and current equations are derived as below

$$\frac{V_{in}}{s} - \frac{1}{sC}I_{off}(s) + L\{sI_{off}(s) - I_0\} + RI_{off}(s) = 0 \quad ...(3)$$

$$i_{Leq(off)}(t) = e^{-at}A\cos(\omega t + \theta) \quad ...(4)$$

Where,

$$A = \sqrt{\left(\frac{E}{\omega L} - \frac{aI_0}{\omega}\right)^2 + I_0^2} \quad ...(5)$$

$$\theta = \tan^{-1}\left(\frac{\alpha LI_0 - E}{\omega LI_0}\right) \quad ...(6)$$

$$\propto = \frac{R_{eq}}{2L} \quad ...(7)$$

$$\omega = \sqrt{\frac{1}{LC} - \left(\frac{E_{eq}}{2L}\right)^2} \quad ...(8)$$

3.0 INTERLEAVED OPERATION WITH TWO SINGLE-ENDED RESONANT INVERTERS

The breakdown voltage of IGBT should be limited because both $V_{CE(sat)}$ and the tail current will be exponentially increased in accordance with increasing the breakdown voltage of IGBT. Consequently, 1200 V-1500 V IGBTs are generally used in SE resonant inverters and the maximum power rating of SE resonant inverter is inevitably limited.

As the output power of SE inverter shown Figure 5 and 6 increases, the resonant voltage of inverter also increases and the higher breakdown voltage of IGBT is required. However, the performance of the IGBT in terms of conduction and switching performances get worse as its breakdown voltage increases. Therefore, the output power of SE resonant inverter has to be limited. Generally, the maximum power rating of SE inverter is limited up to around 2 kW. The proposed inverter composes two SE inverters working alternately as shown in Figure 7. Thereby it can provide two times of output power compare to conventional SE resonant inverter [10].

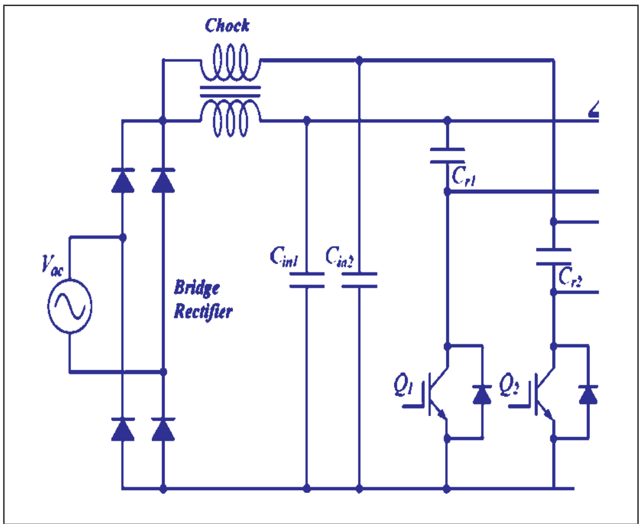

FIG. 3. CIRCUIT DIAGRAM

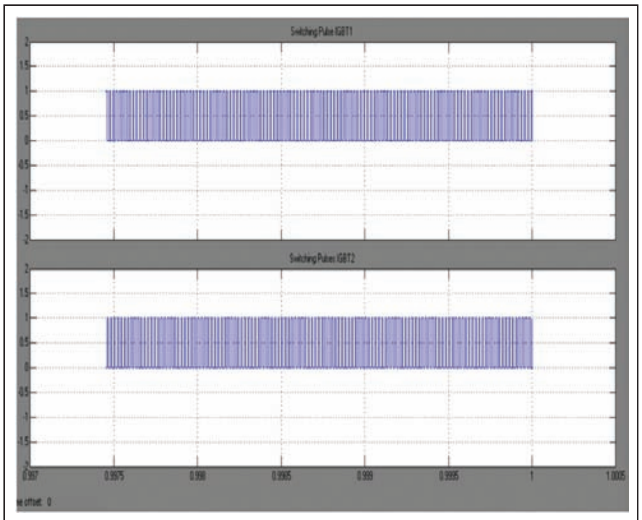

FIG. 4. SWITCHING PULSES

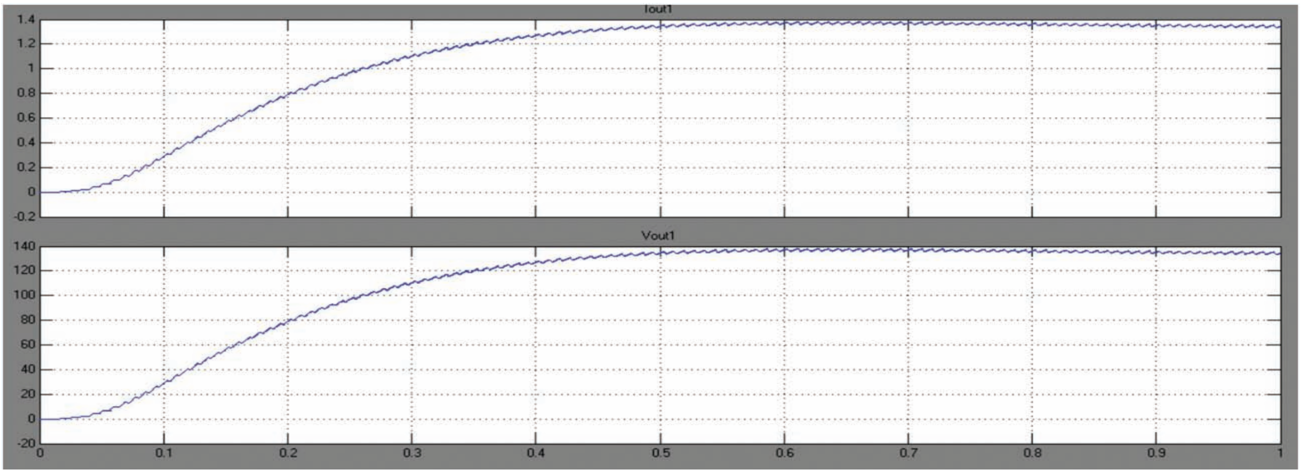

FIG. 5. OUTPUT VOLTAGE1 AND CURRENT 1

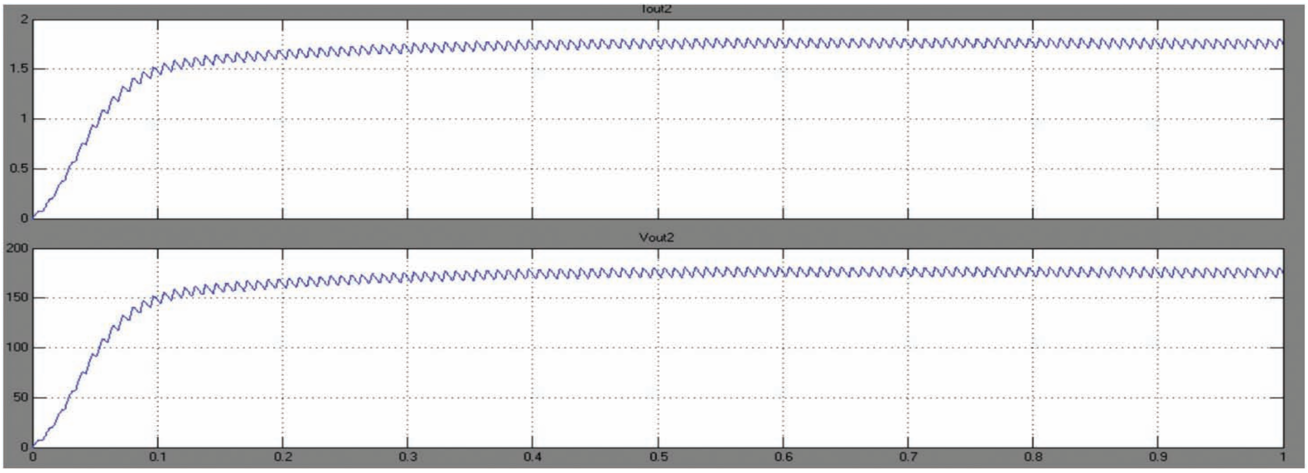

FIG. 6. OUTPUT VOLTAGE2 CURRENT2

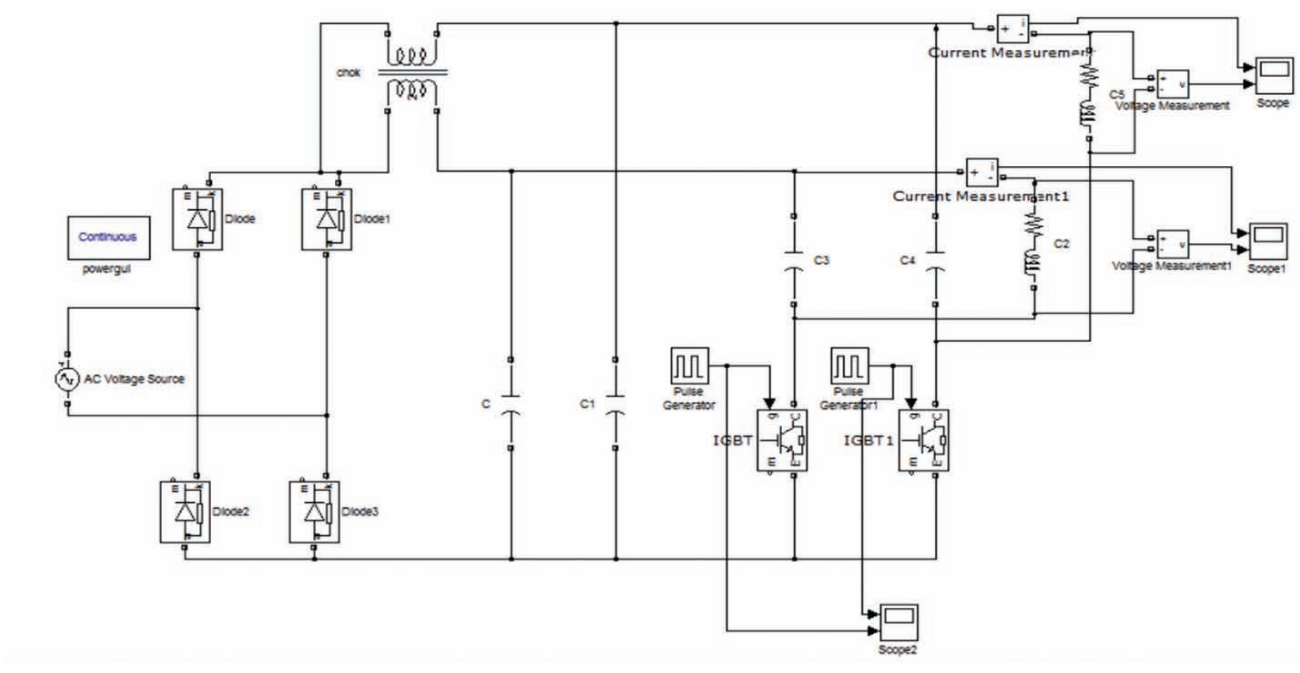

FIG. 7. SIMULATION OF TWO SINGLE-ENDED RESONANT INVERTERS

4.0 CONCLUSION

In this paper an interleaved single-ended resonant inverter for the PV applications was presented. The maximum power rating of the conventional SE resonant inverter should be limited by the resonant voltage because the resonant voltage of SE resonant inverter increases as its power increases. The proposed inverter can however provide twice of the power than conventional inverter by interleaving operation. Additionally, the burst mode control provides wider power control range and interleaved operation is more beneficial to get higher power facto

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