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Simulation of Single Phase Unipolar Sinusoidal Pulse Width Modulation Inverter with Load Voltage Regulation

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***Abstract*—This paper presents the PSIM simulation of single phase unipolar sinusoidal pulse width modulation (SPWM) inverter with load voltage regulation. From the point of view of minimization of current distortion, inverter switching strategies can be classified in to two categories; one is unipolar current controlled inverter and another is the bipolar current controlled inverter. Unipolar switched inverter offers reduced switching losses and generates less electromagnetic interference (EMI). The SPWM technique is used to produce pure sinusoidal wave of output voltage and current. The control circuit itself generates the required pulse according to the load demand, to get variable output voltage from the inverter by changing the modulation index of unipolar SPWM scheme.**

Keywords*— Bipolar, EMI, Modulation Index, PSIM, SPWM, Unipolar.

I. INTRODUCTION

Sinusoidal pulse width modulation (SPWM) is widely used in power electronics to digitize the power so that a sequence of voltage pulses can be generated by the switching of the power switches [1]. From the point of view of minimization of distortion in current wave, two inverter switching strategies can be classified in to two types, one is unipolar current controlled inverter and another is the bipolar current controlled inverter. Unipolar switched inverter offers reduced switching losses and generates less EMI as compare to bipolar switched inverter [2]. In case of bipolar switching scheme the output voltage changes between $+V_{dc}$ and $-V_{dc}$ whereas in case of unipolar switching scheme, the output voltage changes between $+V_{dc}$ and 0 or between 0 and $-V_{dc}$ [3]. A unipolar SPWM voltage modulation type [4]-[5] is used because this method offers the advantage of effectively doubling the switching frequency of the inverter voltage, thus making the output filter smaller, cheaper and easier to implement. In unipolar SPWM technique, for half period of the cycle, series of constant amplitude rectangular pulses with different duty cycle is generated and for remaining half period it will be zero. The width of this pulse is modulated to obtain inverter output voltage control and to reduce its harmonic content. To generate unipolar SPWM signal, triangle wave as a carrier signal is compared with the positive half cycle of sinusoidal wave, whose frequency is the desired frequency. So rectangular pulses of different width are generated for positive cycle of sine wave and no pulse is generated for negative cycle. This conventional method of producing unipolar SPWM is used in control circuit.

II. SYSTEM OVERVIEW

The inverter developed is intended for stand-alone domestic operation. The block diagram of the whole system is shown in Fig. 1.

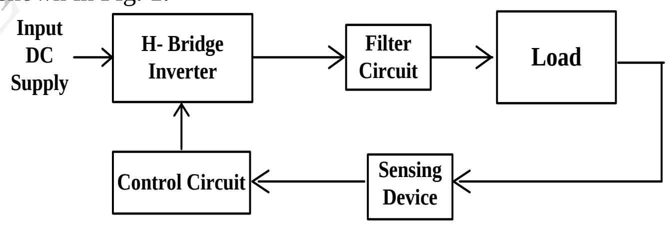

Fig. 1. Block diagram of Unipolar SPWM Inverter

The system comprises of a control curcuit, power switches in full bridge arrangement, filter circuit and load. Two unipolar SPWM signals and two square pulses generated by control circuit. The pulse signals are then fed to the IGBTs connected in full bridge configuration. The output of the inverter follows the square waveform pattern which is filtered by LC filter to get a sinusoidal wave and minimize the harmonics.

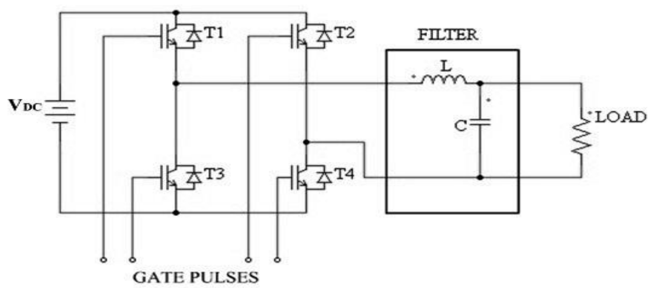

Fig. 2. Full bridge inverter topology

The power circuit topology chosen is full bridge inverter because it is capable of delivering high current at low voltage. Fig. 2 shows the full bridge inverter topology. It consists of DC voltage source, four switching elements (IGBTs), LC filter and load. The LC filter is required to reduce harmonic content and to make the signal sinusoidal in nature. The arrangement of the LC filter and load is shown in Fig. 2.

III. CONTROL CIRCUIT

The two switches T1 and T2 are triggered by unipolar sinusoidal pulse width modulated signals SPWM1 and SPWM2 respectively at 5 kHz frequency and the switches T3 and T4 are triggered by square pulses SQ1 and SQ2 respectively at 50 Hz frequency. SPWM1 and SPWM2 are generated by comparing sinusoidal wave and triangle waveform, while SQ1 and SQ2 are generated by square wave generator.The simulation circuit for generating unipola SPWM is shown in Fig. 3. In this simulation a carrier triangular wave of frequency 5000 Hz is compared with the sinusoidal modulating wave of fundamental frequency of 50 Hz. Rectangular pulses of different width are generated for positive cycle of sine wave and no pulse is generated for negative cycle. The pulse widths of the pulses are varying in a sinusoidal manner so that the average or the fundamental component of frequency is the same as the fundamental frequency and its amplitude is proportional to the amplitude of carrier wave. The generated unipolar SPWM signals is shown in Fig. 4.

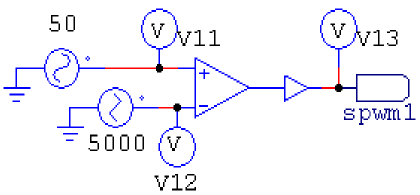

Fig. 3.1 Simulation circuit for generation of Unipolar SPWM

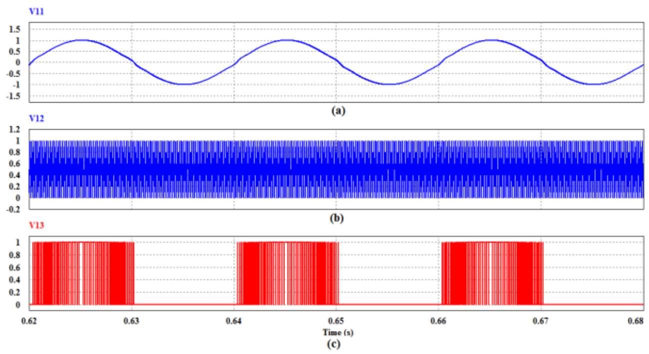

Fig. 4. (a) Modulating sinusoidal wave, (b) Carrier triangular wave,(c) Unipolar SPWM signal

Fig. 4 shown the waveform of (a) sinusoidal modulating wave of 1 V peak and 50 Hz frequency, (b) carrier triangular wave of 1 V peak to peak and frequency of 5000 Hz and (c) unipolar sinusoidal Pulse width modulated wave of fundamental frequency 50 Hz, switching frequency of 5000 Hz and its peak value is 1 V. For the positive half cycle of sinusoidal wave it comparing with triangular wave and it generate the SPWM. and for remaining negative half cycle SPWM signal is not generated. So only for 10 msec. the pulses are generated according to the value of modulating sinusoidal wave and triangular wave.

The SPWM1 and SQ1 are maintained in phase with each other and similarly SPWM2 and SQ2 are maintained in phase with each other. However, 180 degree phase shift is maintained in the pair of SPWM1, SQ1 and the pair of SPWM2, SQ2. One of the most important considerations is the dead time control. If the dead time is too less, it will damage the switch and if it is more, it will result in increased total harmonic distortion.

IV. SIMULATION OF SINGLE PHASE UNIPOLAR SPWM INVERTER

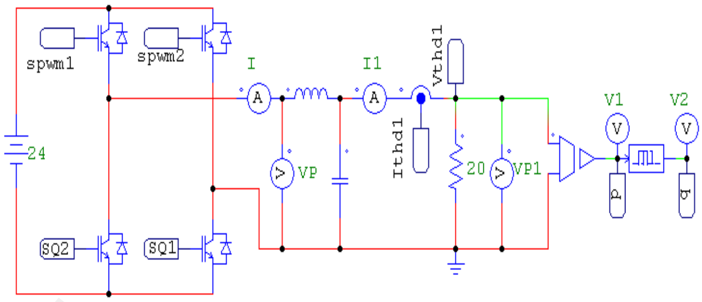

Fig. 5. simulation circuit of single phase H-bridge inverter

Fig. 5 is shown the simulation circuit of single phase inverter. In this simulation the switches T1, T2, T3 and T4 is connected in H-bridge configuration. T filter is connected between load and output of H-bridge. The switching pulse given to the switch is depending upon the load condition. Output of the inverter is sensed by sensor and given to the control circuit. The unipolar SPWM pulses spwm1 is generating according to "p" and spwm2 is generating according to "q".

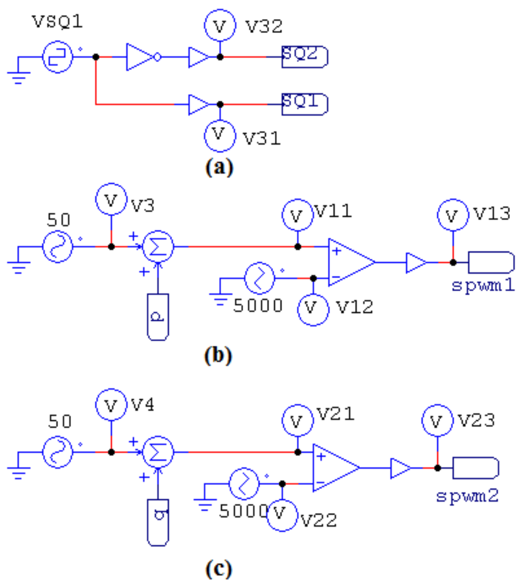

Fig. 6. Simulation of control circuit of inverter

Fig. 6 shows the control circuit for this inverter. Unipolar SPWM pulses are generated according to the output by control circuit. Control circuit is generating two unipolar SPWM pulses and two square pulses. Fig. 6 (a) shows the circuit for generating two square pulses (SQ1 and SQ2) of 50 Hz which is 180 degree phase shifted to each other. Fig. 6 (b) shows the circuit to generate unipolar SPWM pulse (spwm1) which has switching frequency of 5000 Hz and modulation index is depending upon the load condition. Fig. 6 (c) shows the circuit to generating unipolar SPWM pulse (spwm2) which is 180 degree phase shifted to spwm1.

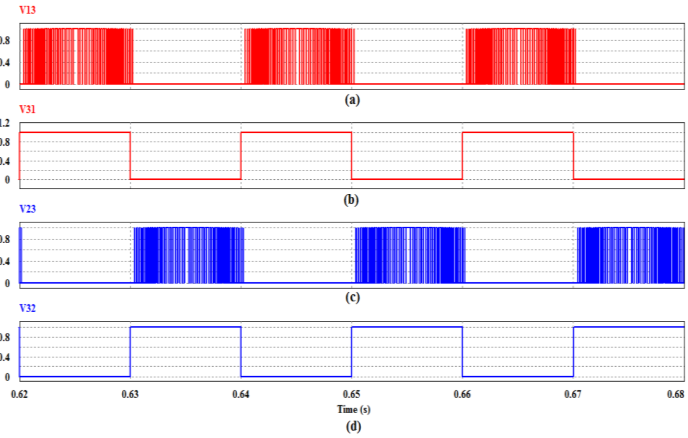

Fig. 7. Gate pulses for inverter

The gate pulses generated for inverter are shown in Fig. 7. In this figure; (a) shows the gate pulse for switch T1 which is unipolar SPWM, (b) shows the square pulse which is given to switch T4 (c) gate pulse for switch T2 which is unipolar SPWM and (d) shows the square pulse which is given to switch T3.

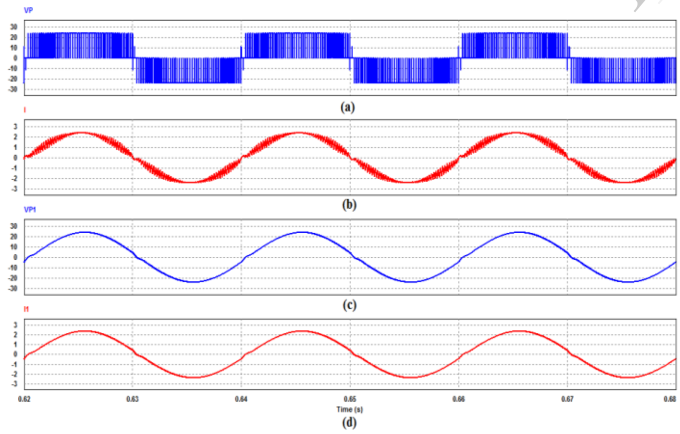

Fig. 8. Inverter output waveform for resistive load (a) Voltage before filter (b) Current before filter (c) Voltage after filter (d) Current after filter

For resistive load of 10Ω, the waveforms of inverter outputs are as shown in Fig. 8. In this figure; (a) shows the output voltage before filter which has SPWM pulses for fundamental frequency 50 Hz. The peak value of each SPWM pulse is 24 V; (b) shows the current before filter. The value of current is 2.4 A and it has harmonic components, (c) shows the output voltage of inverter after filter which is sinusoidal for fundamental frequency is 50 Hz and the value is 24 V and (d) shows the output current of inverter after filter and its value is 2.4 A.

V. LOAD VOLTAGE REGULATION OF INVERTER

For different value of resistive load like 5Ω, 10 Ω, 15 Ω and 20 Ω, output waveform of inverter is shown in Fig. 9 (a), (b), (c) and (d) respectively. In Fig 9 first waveform shows the unipolar SPWM, gate pulses of the inverter. Second waveform shows the peak value of output voltage of the inverter which is same (24 V) for all load condition, but the modulation index decreases as decrease in the load. Third waveform shows the output current and its value which is directly dependent on load condition. The last waveform shows the THD value of output voltage of inverter after using filter. The value of output current is changing according to load condition but value of output voltage is same for all load condition. The value of output voltage is regulated for all load condition and its value is 24 V.

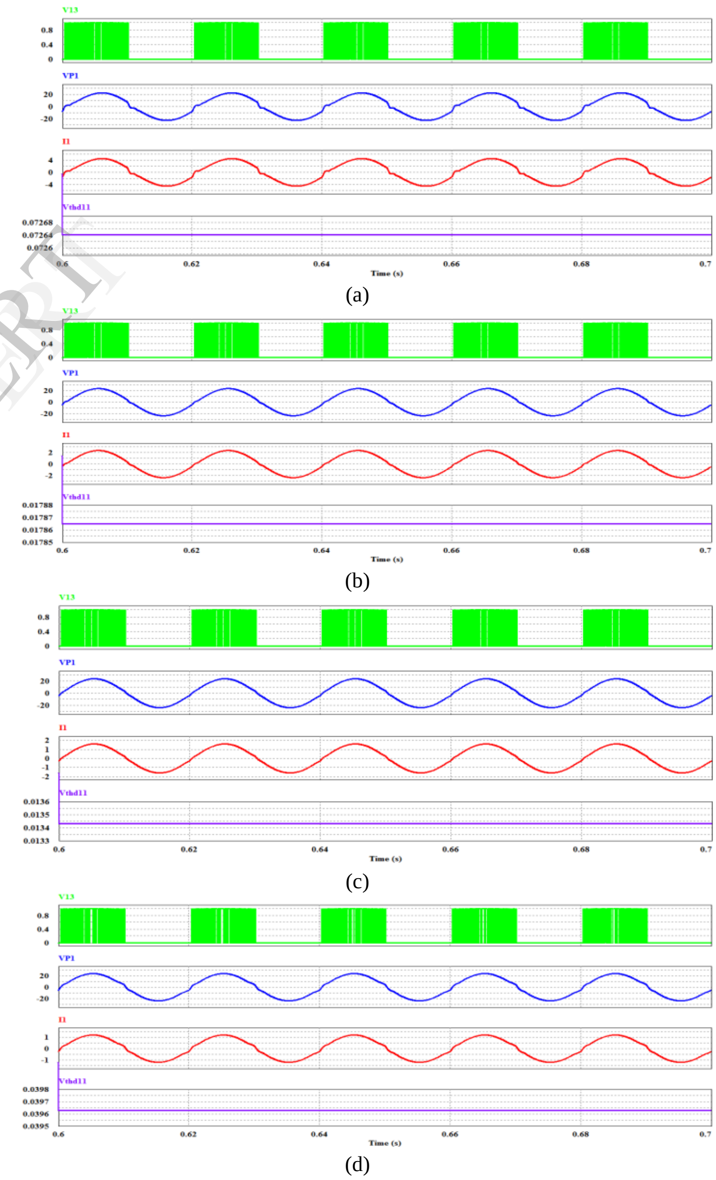

Fig. 9. Inverter output for different load conditions (a) 5 ohm, (b) 10 ohm, (c) 15 ohm, (d) 20 ohm

The results for different value of resistive load of unipolar SPWM inverter are tabulated in TABLE I. The value of output current is changing according to load condition but value of output voltage is same for all load condition. So the output voltage is regulated for all load condition. The value of output current is increase as we decrease the resistance. The value of voltage THD is decrease after filter.

TABLE I. VALUE OF OUTPUT VOLTAGE, CURRENT AND VOLTAGE THD FOR DIFFERENT LOAD CONDITION

Load (Ω)	Voltage (V)	Current (A)	% Voltage THD	
			without filter	with filter
20	17.20	0.86	54.18	3.96
15	17.14	1.14	54.45	1.34
10	16.99	1.70	55.31	1.78
5	16.30	3.26	58.92	7.27

VI. CONCLUSION

The unipolar SPWM pulses are generated for fundamental frequency of 50 Hz and its switching frequency of 5000 Hz are simulated in PSIM simolator. The output voltage of inverter is regulated by changing the modulation index of the unipolar SPWM pulses according to the load condition which is given as the gate pulses to inverter switches. The simulation has been performed for output voltage regulation of inverter for different values of load.From result the output voltage remain almost constant and THD of output voltage waveform remaining in its certain limit for different load conditions.

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