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Simulation of PWM Control of Single Phase Switched Boost Inverter With Low Harmonics

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Abstract

Inverter converts dc-to-ac voltage, more specifically it changes a dc input voltage to a symmetric ac output voltage with intended magnitude and frequency. The output voltage can either be fixed or variable frequency. Voltage source inverter (VSI) is a traditional inverter. Z-source inverter (ZSI) exhibits better electromagnetic-interference (EMI) noise when compared to the VSI as ZSI could operate both in buck and boost mode with a wide range of obtainable output voltages from a given input voltage. However, ZSI significantly increases the size and cost as it employs an LC impedance network between the main inverter bridge and the power source and becomes unsuitable for low-power application. Any distortion in terms of output current or voltage leads to harmonic distortion with low power quality and becomes not suitable for high power applications. In this paper, we present a novel single phase switched boost inverter (SBI) and its pulse width modulation (PWM) mediated control strategy. We also show the low harmonics compared to the conventional boost inverters. The whole system is designed, modeled, and simulated in a MATLAB / Simulink software. This exhibits better electromagnetic interference compared to the traditional counter part VSI and enables compact design of power converters. This system can be very useful in both the low power and high power applications.

Keywords: MATLAB / Simulink, single phase inverter, switched boost inverter (SBI), PWM, harmonics.

Introduction

Need based development in the field of electrical engineering yielded various interdisciplinary outgrowths such as power system designs, power electronics, embedded system technologies, etc.

These technologies are highly used singly and/or in combination with others in various applications such as commercial, industrial, domestic, biomedical, etc., with no boundary [1-3]. Major growth in the industrial development increased proportionally the need of power generation and distribution. Use of various renewable energy resources such as wind turbine, photovoltaic generators power, small hydro systems and fuel cells produce a wide range of voltages due to fluctuation of energy resources and it implies to the requirement of inverter topologies and control techniques [3].

Dc-to-ac converters, generally known as inverters change a dc input voltage to a symmetric ac output voltage with intended magnitude and frequency and the output voltage could be fixed or variable at a fixed or variable frequency [4]. A variable output voltage can be obtained by varying the input dc voltage and maintaining gain of the inverter constant. Usually, when the dc input voltage is fixed and not controllable, a variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by pulse-width-modulation (PWM) control within the inverter. A typical single phase output is 120V at 60Hz [5]. Both the single phase and three phase are controlled using turn-on and turn-off devices such as bipolar junction transistors (BJTs), metal oxide semiconductor field-effect transistors (MOSFETs), insulated gate bipolar transistors (IGBTs), metal oxide semiconductor-controlled thyristors (MCTs), static induction transistors (SITs), and gate-turn-off thyristors (GTOs). The inverters generally use PWM control signals for producing an ac output voltage [5]. In this method, voltage and frequency control are achieved by using one power circuit and proper logic control. The output voltage is varied using PWM technique [6].

Voltage source inverter (VSI) is a less sensitive and traditional type of inverter [7]. Z-source inverter (ZSI) consists of an X-shaped passive network to couple the main power converter and the power source. Compared to the VSI, ZSI has the advantage of either stepping up or stepping down the input voltage by properly utilizing the shoot-through state of the inverter bridge [8]. That results the output voltage of the converter can be either higher or lower than the input voltage as per the requirement. In addition, the ZSI also possesses robust electromagnetic interference noise immunity, which is achieved by allowing the shoot-through of the inverter leg switches. These features make the ZSI suitable for various applications such as renewable power systems, adjustable speed drive systems, uninterruptible power supplies, etc [9]. However, the impedance network with two inductors and two capacitors used in the ZSI significantly increases the size and cost of the power converter. That makes the ZSI topology unsuitable for low-power applications considering significantly the size, weight, and cost are the main constraints [10]. Further, the power quality of the current or voltage is basically determined by the purity of the current wave form in its sinusoidal form. Having distortion in terms of current or voltage could lead to harmonic distortion with reflecting low power quality and becomes not very suitable for high power applications.

In this paper, we present a novel single phase switched boost inverter and its PWM mediated control strategy. We also obtain low harmonics compared to the conventional boost inverters. The whole system is designed, modeled, and simulated in a MATLAB / Simulink software. This system exhibits better electromagnetic interference compared to the traditional counter part VSI and enables compact design of power converters. This system could also be very useful in the DC nano-grid applications such as, to supply power from a solar panel or photo voltaic system at a low voltage to a grid at high voltage.

Proposed Circuit

The proposed switched boost inverter uses PWM control technique and it has various special features compared to the conventional inverter topologies (Fig. 1). SBI is a single or one stage power converter which converts dc voltage into ac and supplies both ac and dc loads simultaneously from a single dc input. It also performs the functions of both dc to dc converter and dc to ac converter in a single stage and that facilitates reducing the size and cost of overall system. The SBI could produce an ac output voltage, which is either greater or less than the available dc input and thereby it has an advantage of wide range of obtainable output voltage for a given dc input voltage.

Further, the SBI has better electro magnetic interference noise immunity as compared to the traditional voltage source inverter, because shoot-through event due to EMI noise will not damage the switches of SBI and thereby it eliminates the requirement of converter protection circuits and helps in realization of compact design of the converter circuit. As SBI allows shoot-through event, it does not required the dead time circuit and thereby it eliminates the complex dead time compensation technologies, which are required to minimize or compensate the waveform distortion caused by the dead time of VSI.

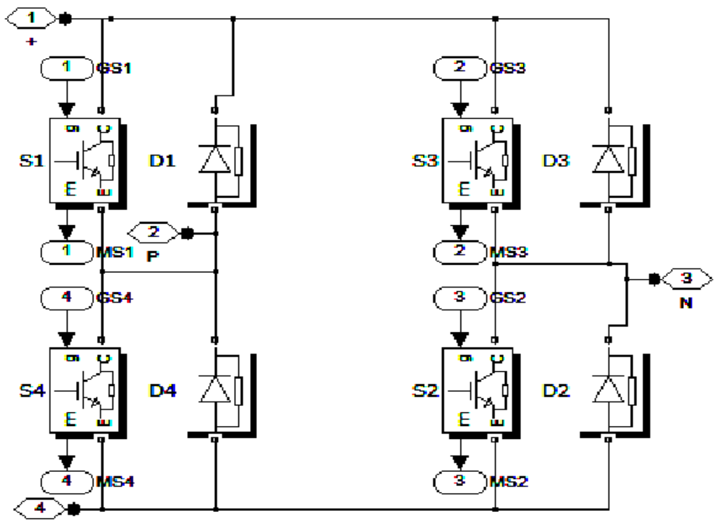

Figure 1: Circuit diagram of switched boost inverter (SBI) [S, switch; D, diodes; L, inductor; C, capacitor; LC, filter]

Steady State Operation Of Switched Boost Inverter (SBI)

The steady state operation of the switched boost inverter consists of two modes of operation. It is capable of handling both positive and negative polarities by changing the switch operation. In the first mode, the inverter is in shoot-through zero state and switch S is turned ON. The diodes D_a and D_b are reverse biased as $V_{DC} > V_g$. In this interval, capacitor C charges the inductor L through switch S and the inverter bridge. So, the inductor current equals the capacitor discharging current minus the dc load current.

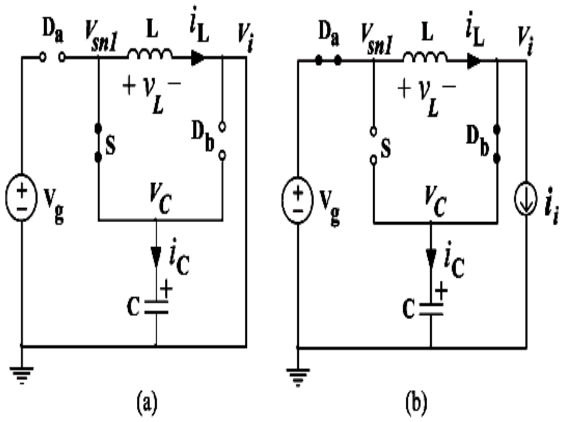

Figure 2: (a) Equivalent circuit of SBI during *D.T* interval, (b) Equivalent circuit of SBI during (1-*D*). T_S interval

In second mode of operation, the inverter is in non-shoot through state, and the switch S is turned OFF. The inverter bridge is represented by a current source in this interval as shown in the equivalent circuit (Fig . 2). Then, the voltage source V_g and inductor L together supply the power to the dc load, inverter, and the capacitor

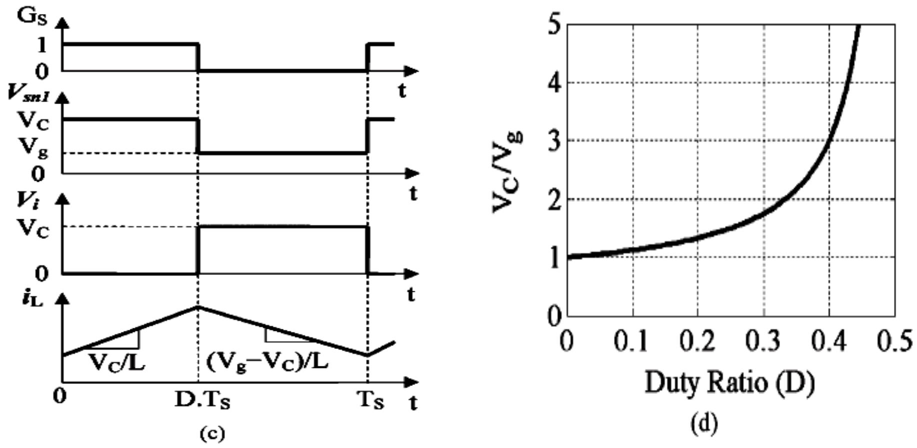

Figure 2: (c) Steady state wave forms, (d) Transfer characteristics of switched boost inverter (SBI)

through diodes D_a and D_b. Inductor-current in this interval equals the capacitor charging-current added to the inverter input-current and the dc load current. Notably, that the inductor current is assumed to be sufficient enough for the continuous conduction of the diodes D_a, D_b for the entire interval $(1 - D)$. $T_{S.}$

PWM Control of SBI

The pulse width modulation control of SBI is based on traditional sine-triangle PWM with unipolar-voltage switching. The control technique is as shown in the Fig. 3 (a). The positive and negative half cycles of sinusoidal modulating signal is as shown in Fig. 3 (b). During positive half cycle ($v_m(t) > 0$), the gate control signals G_{S1} and G_{S2} are generated by comparing the sinusoidal modulation signals $v_m(t)$, and $-v_m(t)$ with a

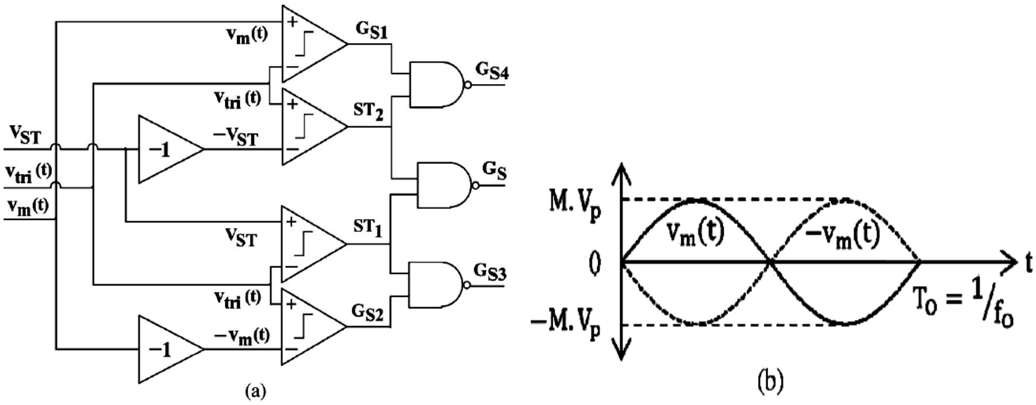

Figure 3: (a) Schematic diagram of PWM control circuit, (b) Sinusoidal modulation signals $v_m(t)$ and $-v_m(t)$

high-frequency triangular carrier $v_{\text{tri}}(t)$ of amplitude V_p. The frequency f_S of the carrier signal is chosen such that f_S □ $>f_O$. Therefore, $v_m(t)$ is assumed to be nearly constant. The signals ST_1 and ST_2 are generated by comparing $v_{\text{tri}}(t)$ with two constant voltages V_{ST} and $-V_{\text{ST}}$, respectively. The purpose of these two signals is to insert the required shoot-through interval $D{\cdot}T_S$ in the PWM signals of the inverter bridge. during negative half cycle of $v_m(t)$ ($v_m(t) < 0$), the gate control signals GS_3 and GS_4 are generated by comparing the modulation signals $-v_m(t)$, and $v_m(t)$ with the triangular carrier $v_{\text{tri}}(t)$. The shoot-through signals ST_1 and ST_2 are generated in the same manner as in the positive half cycle.

Results and Discussion

A. Steady-State Operation of SBI

A proposed block diagram (Fig. 4) used for the simulation of a laboratory prototype of the SBI, along with the PWM control circuit of Fig. 3 (a), is designed and used to verify the proposed PWM technique. Various schematic diagrams and circuit diagrams related to the simulation block diagram is shown in Fig. 1 and 5. Simulations were carried out using MATLAB / Simulink software package (MATLAB Version 2009a). The input voltage is varied from 1-64V. Simulation circuit for unidirectional switched boost single phase inverter is shown Fig. 4. Note that the switch *S* of SBI has a floating gate. This switch can be turned on using either a bootstrap gate driver circuit or a floating driver. Nevertheless, the gate-drive supply has to be floating. Here, optocoupler-based gate drivers are used to drive all seven switches of the switched boost inverter. Results are shown in Fig. 6 for V_g =1V, 16V and 64V. Obtained results show a typical sinusoidal wave with the harmonics of within the range.

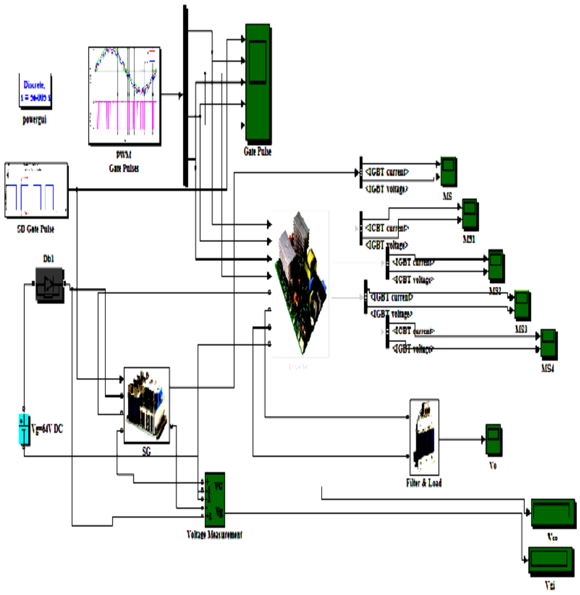

Figure 4: Simulation block diagram of single phase switched boost inverter, LC filter and a 2^{nd} order filter

B. Harmonic Analysis of Inverter's Output Voltage (v_{AB})

The harmonic spectrum of the inverter's output voltage (v_{AB}) with D = 0.4; M = 0.5 is plotted. Note that the values of D and M are satisfying the inequality.

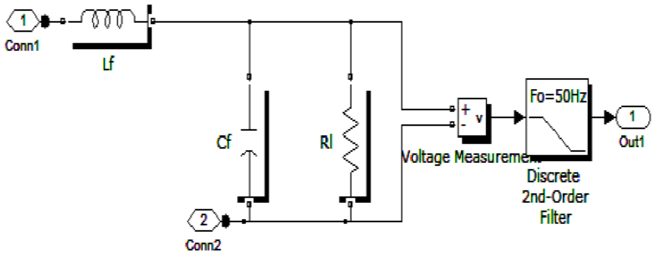

Figure 5: Schematic diagram of LC filter and 2^{nd} order filter

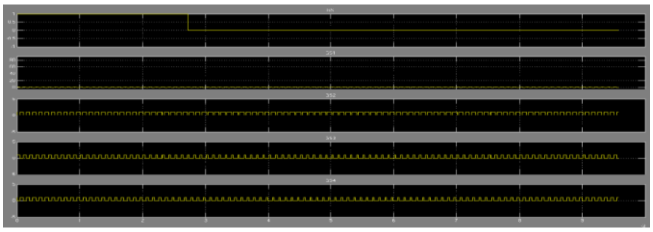

Fig. 6 (a)

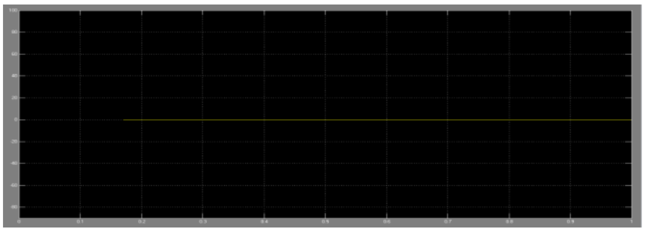

Fig. 6 (b)

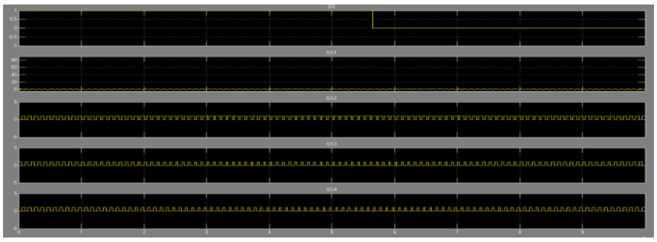

Fig. 6(c)

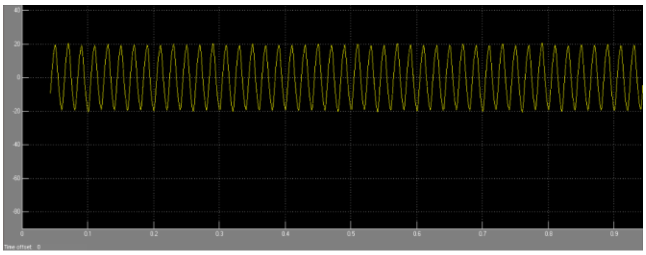

Fig. 6 (d)

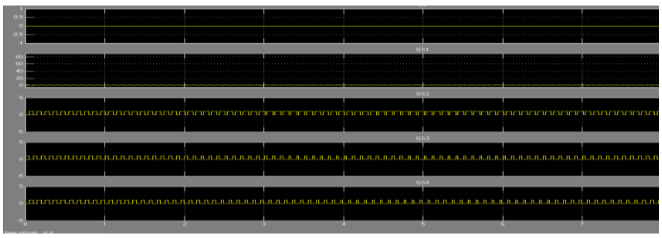

Fig. 6 (e)

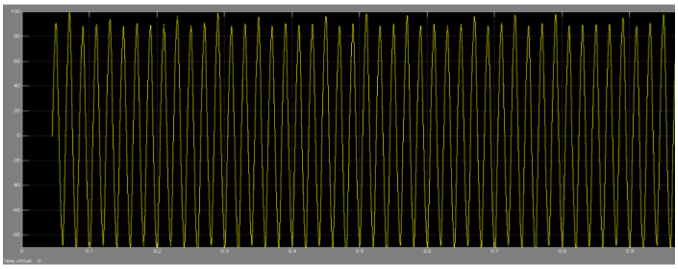

Fig. 6 (f)

Figure 6: (a) PWM signal at V_g = 1V, (b) wave form at V_g = 1V, (c) PWM signal at V_g = 16V, (d) wave form at V_g = 16V, (e) PWM signal at V_g = 64V, (f) wave form at V_g = 64V

Our simulation constitutes a 2nd order filter in addition to the typical SBI topology and LC filter. As seen in the Fig. 6, with the proposed simulation technique, we obtained 5.77% harmonics. Compared to the previous studies and higher limit, these results show at least 4 fold low (<1-10% considered relatively better harmonics). This harmonics reduction is suggesting an efficient power supply with least harmonic distortion. It can be concluded from these results that, with the proposed PWM technique, the shoot through state of the SBI will have no effect on the harmonics.

Conclusion

This proposed and simulated study presented the steady-state and harmonics analyses of a novel power converter called SBI. It shows that this topology exhibits properties similar to that of ZSI with lower number of passive components. The harmonic spectrum of the inverter's output voltage with the proposed PWM technique was simulated newly adding an additional 2nd order filter. Compared with the previous studies, we obtained relatively a lower harmonics (5.77%) at least 4 fold harmonics reduction and it shows the better quality of the current/voltage with least harmonic distortion. Particularly, use of switched boost inverter may pave the way for significant reduction in the size, weight, and cost of the power converter and makes it suitable for low-power applications. It has been proven that the shoot-through state of the SBI will have no effect on the harmonic spectrum of its output voltage, provided that the sum of the shoot-through duty ratio and modulation index is less than unity. Therefore we conclude that SBI can be used in both low and high power applications as it employs less components with cost effective and low harmonics.

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References

[1] Panneerselvam, P., "Application Of Embedded System For a Genetic Disease, Sickle Cell Anemia" Intl. Conf. on Adv. in Elec. Eng. (ICAEE), 2014. 10.1109/ICAEE.2014.6838446

[2] Panneerselvam, P., "Embedded system in biomedical application: challenges ahead" Intl. J. of Sci. Eng. & Tech., vol. 3, no.9, pp. 3422-3426. Sep. 2014.

[3] Panneerselvam, P., Subramaniam, L., Perumal, V., "Solar Energy Fed Single Phase Inverter Through Boost Converter" Intl. J. of Sci. Eng. & Tech., vol. 3, no.12, pp. 3422-3426. Dec. 2014.

[4] Bedford, B.D., and Hoft, R.G., Principle of Inverter Circuits, New York: John Wiley & Sons. 1964.

[5] Rashid, M.H., Power Electronics circuits, Devices and Applications, 3rd Ed. Pearson Prentice Hall, New Delhi, 2012.

[6] Ohnishi, T and Okitsu, H., “A novel PWM technique for three-phase inverter/converter,” Intl. Power Electro. Conf., pp. 384-395, 1983.

[7] Ravindranath, A., Mishra, S. K., and Joshi, A., “Analysis and PWM Control of Switched Boost Inverter,” Trans. Ind. Electron., vol. 60, no. 12, pp. 5593-5602, Decem. 2013.

[8] Upadhyay, S., Mishra, S., and Joshi, A., “A wide bandwidth electronic load,” IEEE Trans. Ind. Electron., vol. 59, no. 2, pp. 733–739, Feb. 2012.

[9] Zhou, Z. J., Zhang, X., Xu, P., and Shen, W. X., “Single-phase uninterruptible power supply based on Z-source inverter,” IEEE Trans. Ind. Electron., vol. 55, no. 8, pp. 2997–3004, Aug. 2008.

[10] Huang, Y., Shen, M., Peng, F. Z., and J. Wang., “Z-source inverter for residential photovoltaic systems,” IEEE Trans. Power Electron., vol. 21, no. 6, pp. 1776–1782, Nov. 2006.