

Performance Comparison of Conventional and Modified Current-Fed Switched Inverter

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ABSTRACT: Conventional voltage source inverters are widely used in solar PV, fuel cell, wind energy, and uninterruptible power supply systems. High buck-boost capability, better EMI immunity, full range of operation etc. are some of the desired qualities of an inverter for its reliable operation. Impedance source inverters like Z-source inverter (ZSI) and switched boost inverter (SBI) possess low distortion ac inversion owing to their shoot-through capability. This paper discusses about a high-boost inverter, which combines the high gain property of ZSI and low passive component count of SBI. The inverter is named current-fed switched inverter. The modes of operation of the inverter are described and the relation between input and output parameters is derived. A modified version of the inverter is discussed and the performances are compared. The results are validated using MATLAB/Simulink.

KEYWORDS: Electromagnetic interference (EMI) immunity, Z-source inverter (ZSI), switched boost inverter (SBI), current-fed dc/dc topology (CFT), pulse width modulation (PWM) control.

I. INTRODUCTION

Voltage source inverters (VSI) play major roles in various fields of applications like solar photovoltaic, uninterruptible power supplies, hybrid electric vehicles etc [1]. In traditional VSI, the peak ac output voltage is always less than the input dc-link voltage [2]. Shoot-through of the inverter legs is not permitted due to the flow of high short circuit current. Dead band is introduced to prevent the shoot-through state which eventually results in ac output distortion.

For high-boost applications, either a step-up transformer at the inverter output or a two-step boost inverter structure is used. This makes the system bulky and noisy [3]. EMI is the major problem associated with a two-stage dc-ac inversion. It may cause malfunction of the inverter and damage of inverter switches [6].

Z-source inverter (ZSI) uses a diode and an "X"-shaped impedance network between the dc source and inverter [2]. Buck and boost operations are possible with ZSI [6]. It allows shoot-through of the inverter switches. The boost factor (B_{ZSI}) of ZSI is given by,

$$B_{ZSI} = \frac{V_{gN}}{V_g} = \frac{1}{1 - 2D}$$

where D denotes the shoot-through duty ratio. However, two sets of passive filters in ZSI make its realization costlier. Switched boost inverter (SBI) has one L-C pair less compared to ZSI by replacing the "X"-shaped network with an active network [7]. SBI also allows shoot-through of the inverter legs and thus possesses better EMI noise immunity [4]. However, its boost factor is only (1-D) times that of ZSI and hence not suitable for high-boost inversion.

This paper discusses about a high boost inverter named current-fed switched inverter which is derived from current-fed dc/dc topology. Similar to ZSI and SBI, it permits shoot-through of the inverter legs and thereby provides better EMI immunity. It draws continuous input current making it suitable for renewable energy source applications. Paper is organized as follows. Section II describes the basic current-fed switched inverter structure and its operations. A modified circuit of CFSI for better performance is being discussed in Section III. Section IV provides the simulation results. Performance comparison of the conventional and modified circuits is done in Section V. Concluding remarks of this paper are presented in Section VI.

II. BASIC CURRENT-FED SWITCHED INVERTER

The structure of the basic current-fed switched inverter [1] is shown in Fig. 1. It is derived from complementary current-fed dc/dc topology which is obtained by interchanging the passive and controlled switches in CFT. The main components of CFSI are one active switch (S), two diodes (D_a, D_b), one capacitor (C₀) and one inductor (L) which are connected between the voltage source V_g and the inverter bridge. In order to filter the switching frequency components in the output voltage, a low pass LC filter is employed at the output of the inverter bridge.

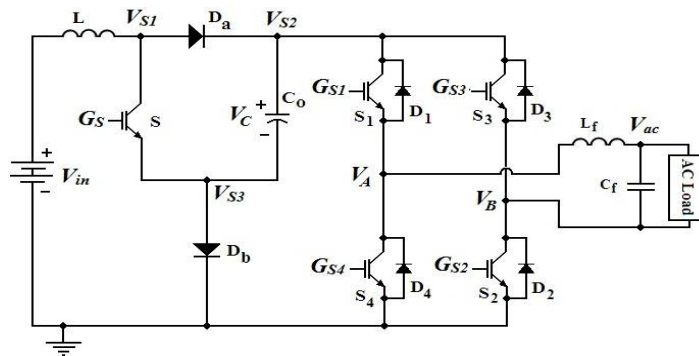


Fig. 1: Schematic of current-fed switched inverter

Operating principle

The CFSI topology inserts shoot-through state (conduction of upper and lower switches of a phase leg) in its operation to boost the input voltage from V_g to V_c. Thus, the inverter is able to buck and boost the input voltage to a desired output voltage. Hence the inverter provides efficient single stage dc-ac inversion as well as buck-boost power conversion.

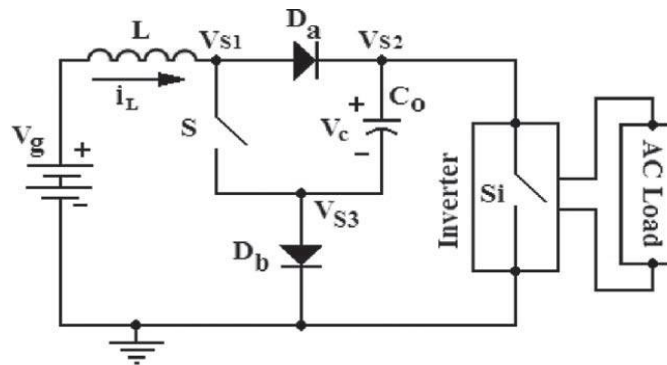


Fig. 2: Simplified structure of CFSI

Modes of operation

Simplified structure of the CFSI is shown in Fig. 2. The switch S_i represents the inverter and the inverter shoot-through action is represented by turning on the switch S_i. Initially the capacitor C₀ is charged to the voltage V_g and the initial inductor current is zero before switching signals are generated. The two operating intervals of CFSI are:

- i. Shoot-through interval (D interval)
- ii. Non-shoot-through interval ((1-D) interval)

In shoot-through (D) interval, switch S is turned on along with S_i thus charging the inductor L from V_g and C₀. In non-shoot-through (1-D) interval, switches S and S_i are turned off which makes D_a and D_b to turn on, and the inductor L charges the capacitor C₀ and power is delivered to the AC load through the inverter. The equivalent circuits of CFSI in both the intervals are shown in Fig. 3.

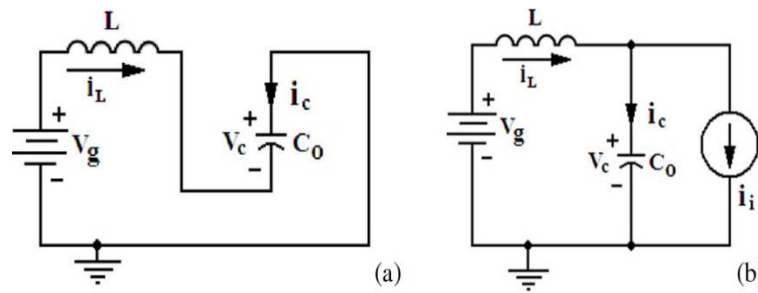


Fig. 3: Equivalent circuit of CFSI during (a) D interval (b) (1-D) interval

Assuming small ripple approximation in steady-state, the boost factor of CFSI (B_{CFSI}) is given by,

$$B_{CFSI} = \frac{V_c}{V_g} = \frac{1}{1 - 2D} \tag{1}$$

From the above equation it is evident that this topology gives a maximum gain at duty cycle close to 0.5. The peak ac output voltage of the inverter is given by,

$$V_{Acpeak} = M \times V_c = \frac{M}{1 - 2D} V_g \tag{2}$$

where M is the modulation index of the inverter.

PWM control is employed for the generation of gating pulses for the switches. The PWM technique is a modified version of the unipolar switching scheme. The control logic is different at different intervals. In order to insert shoot-through two constant voltages V_{ST} and $-V_{ST}$ are compared with the triangular carrier wave. The PWM control scheme is shown in Fig. 4.

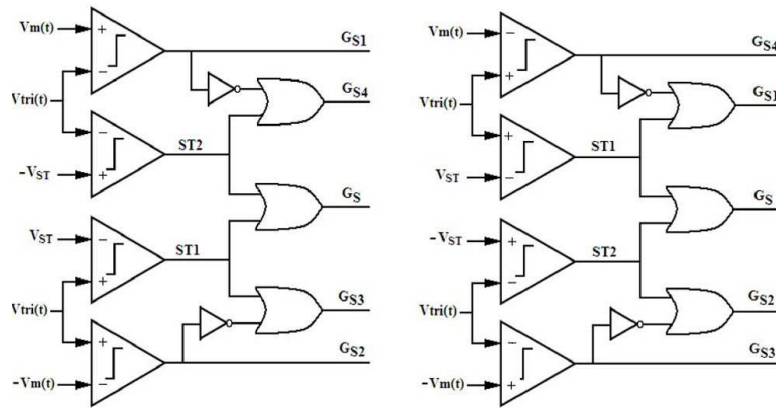


Fig. 4: PWM control scheme when $V_m(t) > 0$ (left) and $V_m(t) < 0$ (right)

The use of shoot-through state puts some restriction on the value of modulation index of the inverter given by,

$$M \leq 1 - D \tag{3}$$

Since the peak gain of CFSI is achieved at $D=0.45\sim 0.47$, the modulation index needs to be restricted to about 0.5. Hence the dc link voltage required is at least $2\sqrt{2}$ times of the desired rms AC output which imposes high stress on the inverter switches. The topological development of modified current-fed switched inverter and the way it mitigates the drawback of the CFSI is described in detail in the following section.

III. MODIFIED CURRENT-FED SWITCHED INVERTER

In the modified circuit, the restriction on the modulation index is removed by adding a switch-diode-capacitor combination in front of the H-bridge inverter. The inverter legs do not undergo shoot-through state which makes it different from the conventional CFSI. However, shoot-through action is achieved by the additional switch, ST. The modified circuit is shown in Fig. 5.

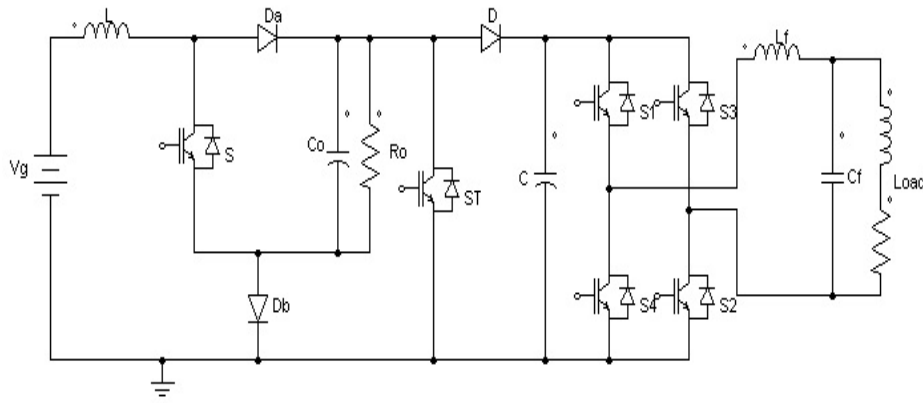


Fig. 5: Modified current-fed switched inverter topology

Initial conditions remain the same as that of the CFSI. During the shoot through interval, S and ST are turned on and source V_g and capacitor C_0 charge the inductor L. In this interval, either S_1 and S_2 or S_3 and S_4 are turned on and the load is fed by the capacitor C. In the non-shoot-through interval, S and ST are turned off, thus forcing diodes D_a and D_b to turn on. The inductor L charges C_0 and power is delivered to the ac load through the inverter. The gain of the modified topology is same as that of the CFSI. Here, the modulation index can vary over a range from 0 to 1 unlike the conventional CFSI and thus is able to achieve a higher boosting compared to it. The inductor current ripple and the capacitor voltage ripple are given by,

$$\Delta i_L = \frac{V_g + V_C}{L} DT_s \quad \Delta v_C = \frac{I_L}{C} DT_s \tag{4}$$

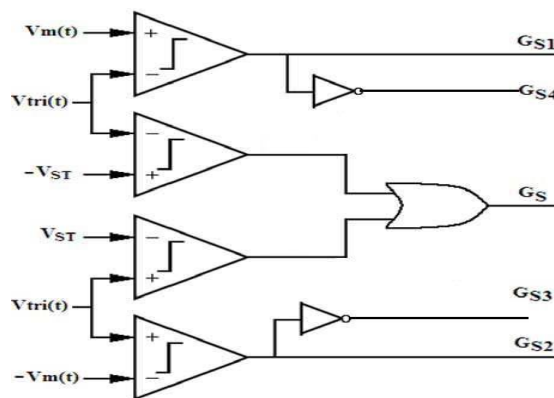


Fig. 6: Generation of PWM control signals

Pulse width modulation (PWM) technique is employed for the control of switches. Unipolar switching scheme is adopted for the inverter switches S_1, S_2, S_3 and S_4 . G_{S1} and G_{S2} are generated by comparing the sinusoidal modulation signals $V_m(t)$ and $-V_m(t)$ with high frequency carrier signal $V_{tri}(t)$. The switching signals for the switches S and ST are generated by comparing V_{ST} and $-V_{ST}$ with $V_{tri}(t)$. The control logic for the generation of PWM signals is depicted in Fig. 6. The relationship between the shoot through signal V_{ST} and D is given by,

$$D = 1 - \frac{V_{ST}}{V_{tri}} \tag{5}$$

Here, the value of M does not depend on the shoot through duty ratio D which is the major advantage of the modified topology.

IV. EXPERIMENTAL RESULTS

The modified CFSI circuit was tested using MATLAB/Simulink. The simulink model is shown in the Fig. 7. Gate pulses for the switches are generated inside the subsystem ‘Gate Pulses’. Switches S and ST share the same switching pulses.

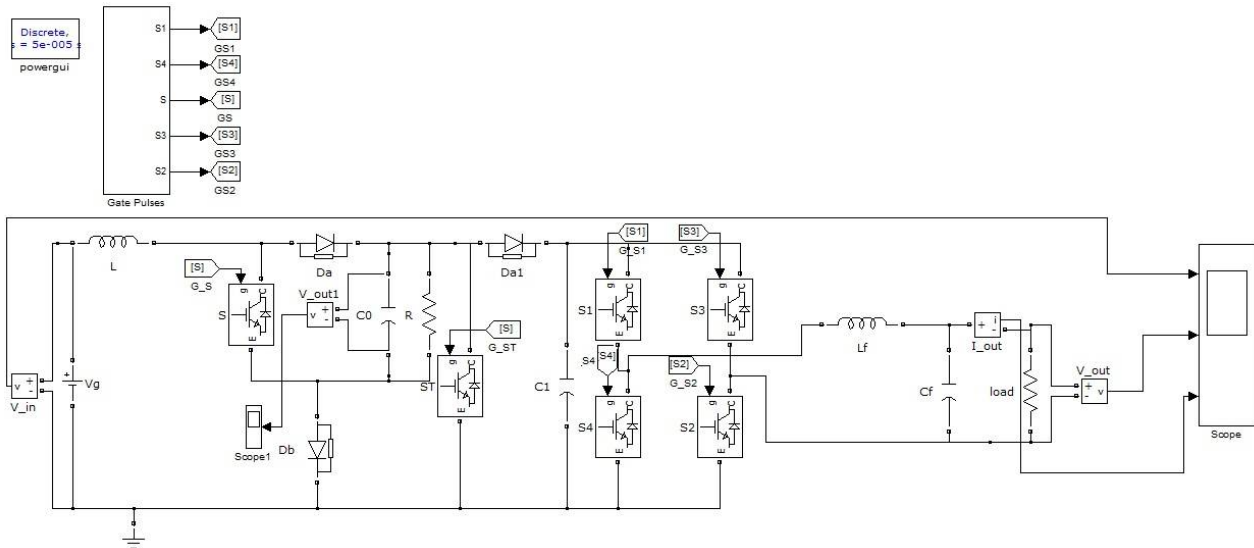


Fig. 7: Simulation diagram for the modified CFSI

The gate pulses generated for the conventional as well as modified current-fed switched inverter are shown in Fig. 8 and Fig. 9 respectively.

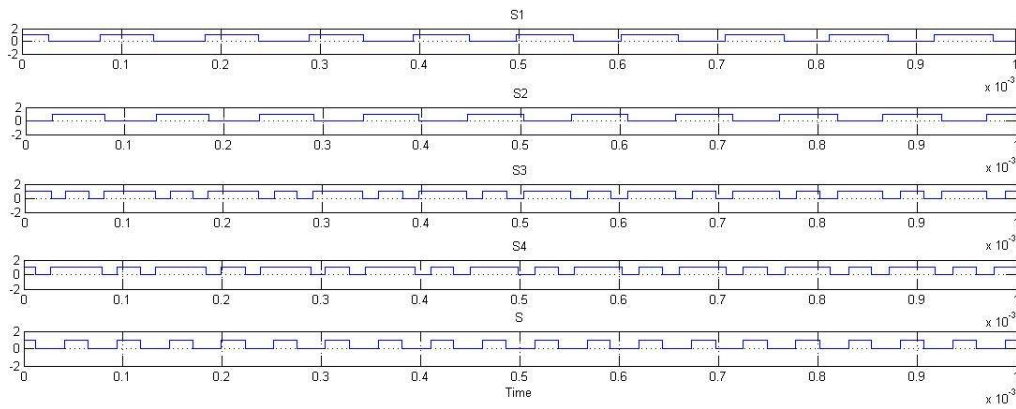


Fig. 8: Gate pulses for the conventional CFSI

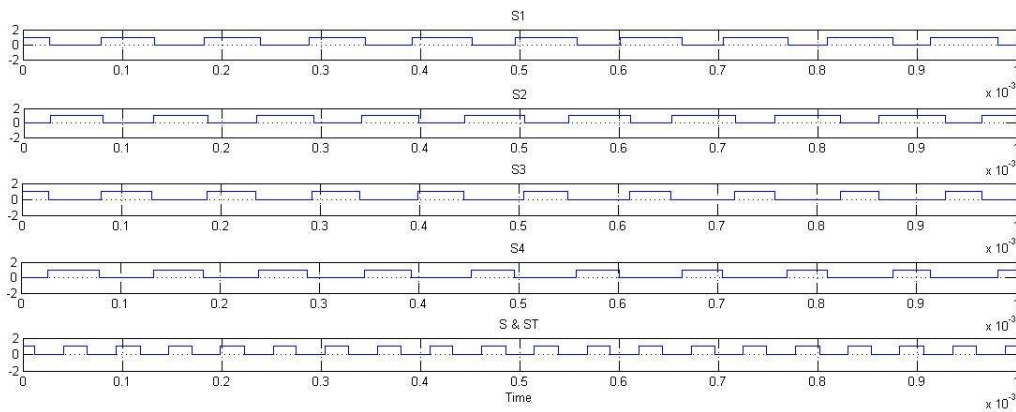


Fig. 9: Gate pulses for the modified CFSI

A carrier frequency of 9.5 kHz and modulation frequency of 50 Hz were used. Fig. 10 and Fig. 11 show the simulation results of CFSI as well as modified CFSI for the same input voltage of 12V. In the former case the modulation index is restricted to 0.5 whereas for the latter case modulation index of 0.9 is used. Shoot-through duty ratio $D=0.45$ in both the cases. The output voltage is a sinusoidal signal with rms voltage of 132 V and 206 V respectively. The output currents are 5.3 A and 8.2 A respectively.

Table 1: Technical data of modified CFSI

Parameter/Component	Attributes
Input voltage V_g	12 V
Modulation frequency f_m	50 Hz
Carrier frequency f_{tri}	9.5 kHz
Inductor L	225 μ H
Capacitor C_0	3878 μ F
Output filter inductor L_f	4.6 mH
Output filter capacitor C_f	10 μ F

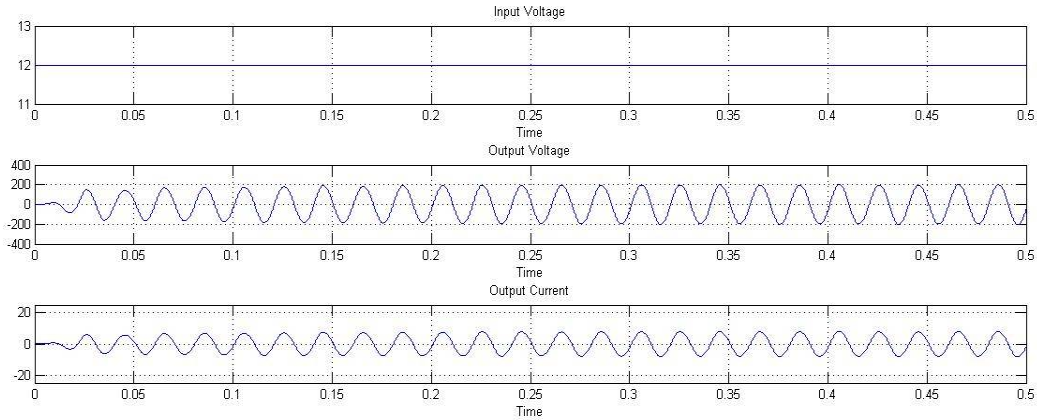


Fig. 10: Input and output waveforms of conventional CFSI

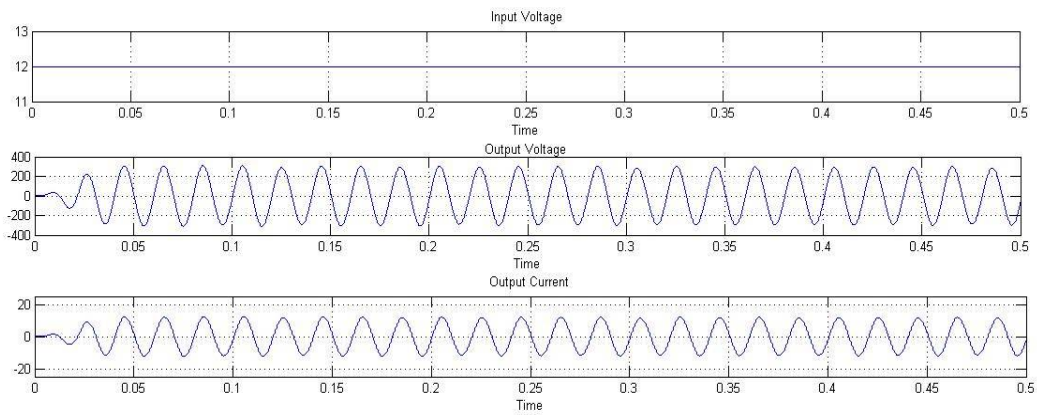


Fig. 11: Input and output waveforms of modified CFSI

V. PERFORMANCE COMPARISON

Table 2: Performance comparison of conventional and modified CFSI

Attributes	Conventional CFSI	Modified CFSI
Conversion ratio	$1/(1-2D)$	$1/(1-2D)$
Range of modulation index	0 – 0.5	0 – 1
Component Count	11	14
PWM Strategy	Complex	Simple
Input current property	Continuous	Continuous

As illustrated in Table 2, the modified CFSI gives a higher boosted output for the same input voltage and duty ratio. Although the component count is more for the modified topology, it removes the restriction on the modulation index which was the problem associated with the conventional CFSI. Thus the modulation index is no longer dependent on the shoot through duty ratio. Also, the realization of PWM logic is easier in the modified circuit since the conventional CFSI requires different control logic at different intervals.

VI. CONCLUSION

A single-stage high-boost inverter structure named current-fed switched inverter was studied and tested. The modulation index in CFSI has a restriction when operated at higher duty ratios. A modified topology that could improve the value of modulation index was discussed where it can vary over a range from 0 to 1. Thereby very high boosting of output voltage was achieved. It provides the same gain as that of CFSI. The simulation results of both the inverter topologies have been presented for better inference. Modified CFSI gives a better boost output compared to the conventional CFSI for the same input voltage and duty ratio.

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