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ANALYSIS OF CURRENT FED ISOLATED FULL BRIDGE DC-DC WITH VOLTAGE MULTIPLIER

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ABSTRACT

Active clamp concept introduced on the primary side of isolation transformer to reduce the turn-off voltage spikes of full bridge active devices. Innate soft-switching with elongated range can be achieved in the recommended converter by using the parasitic capacitance of MOSFET switches and leakage inductance of the high frequency transformer. Zero Voltage Switching(ZVS) is achieved for all the primary devices which allow greater switching frequency operation and improvement in over-all efficiency of the converter for utility interface. Cost, size and weight of the converter minimizes for the higher switching operation of the converter. Half-wave Cockcroft-Walton Voltage Multiplier (H-W C-W VM) having minimum number of multiplying stages is used on the secondary side of the designed converter in order toget the required DC-link voltage for three phase utility grid connection. The converter's switching frequency is maintained at 100 KHz. This paper is organized as introduction, steady state operation, simulation results with two different cases i.e. full load and half load conditions and finally, test result validation of a 250 Watt experimental setup with the proposed converter. High-boost dc-ac inverters are used in solar photovoltaic (PV), fuel cell, wind energy, and uninterruptible power supply systems. High step-up and step-down capabilities and shoot-through immunity are some of the desired properties of an inverter for a reliable, versatile, and low-distortion ac inversion. The recently developed Z-source inverter (ZSI) possesses these qualities. However, the realization of ZSI comes at a cost of higher passive component count as it needs two sets of passive filters. A switched boost inverter (SBI) has similar properties as ZSI, and it has one *L*-*C* pair less compared to ZSI, but its gain is less than ZSI. This paper proposes the current-fed switched inverter (CFSI) which combines the high-gain property of ZSI and low passive component count of SBI. The proposed inverter uses only one *L*-*C* filter and three switches apart from the inverter structure.

1. INTRODUCTION

Today's technology is mainly looking at sustainable energy. Though we have several renewable technologies available for different power applications, some constraints on existing topologies are not able to give promising solutions. Out of all the available renewable sources, fuel Cells are considered to be more capable and standard power generating units as fuel cells supply power as long as fuel supply is there. Lesser voltage at the output of stack, dull response to load variations, presence of ripple current which slashes down the efficiency and permitting reverse current flow are the disadvantages associated with fuel cell, inspire of it being a promising power solution. To overcome the above technical challenges very strong power conditioning unit should be present. To connect fuel cell with utility grid we need to develop a power converter with high voltage gain.

More-over fuel cell characteristics differ from other renewable sources characteristics. This characteristic has three regions of operation as shown in Fig.1. These regions are very important in deciding converter operating set point for maximum power extraction from the fuel cell[1]. Current fed converters are best suitable for fuel cells. Current fed topologies either full bridge or half bridge isolated DC-DC converters have given appropriate solutions for most of the technical challenges faced by fuel cells [2]. Full bridge current fed isolated DC-DC converters were analyzed in [3, 4]. These converters and their complete analysis were given in [5, 6]. Active clamp concept was introduced in current fed converter topologies to reduce the turn-off spikes of active switches to greater extent in [7, 8].

VOLTAGE SOURCE INVERTERS (VSIs) find wide application in uninterruptible power supplies, solar photovoltaic (PV) and fuel-cell applications, wind power systems, hybrid electric vehicles, industrial motor drives, etc. [1], [2]. The limitation of traditional VSI is that its peak ac output voltage is always less than the input dc-link voltage [3]. Also, shoot-through in any of the inverter legs is not permitted as it results in flowing of high short-circuit current. Therefore, a dead-band is introduced between the switching signals of complementary switches of the inverter legs, which, in turn, causes ac output distortion. High-boost inversion is essential in small rooftop solar PV/fuel-cell applications when it is connected to 110–240-V ac systems. For such applications, either a step-up transformer at the inverter output or a two-stage boost-inverter structure is used. Inverter systems with step-up transformers having a high turns ratio are generally bulky and noisy. Therefore, the alternate option is to go for a transformer-less design [4]–[6]. The maximum gain of conventional boost converter is achieved at duty ratio (*D*) near unity, where the diode and the output capacitor have to sustain a high current with very small pulsewidth. This results in severe reverse recovery of the diode, which increases the conduction loss and produces electromagnetic interference (EMI). This problem is aggravated at high switching frequencies as the reverserecovery time (*t*rr) of the device may be larger than the time available during (1-*D*) interval [7]. Moreover, a boost converter has a maximum output to input voltage conversion ratio of 4–5 [8]. Cascaded boost converter or quadratic boost converter can provide higher gain, but they need more passive components and passive switches [7]. Converter with coupled inductor can deliver high gain without extreme duty cycle operation [9], [10].

Single-switch high-gain dc/dc converters using four terminal switched cells and switched-capacitor cells possess high gain at reduced switch stress

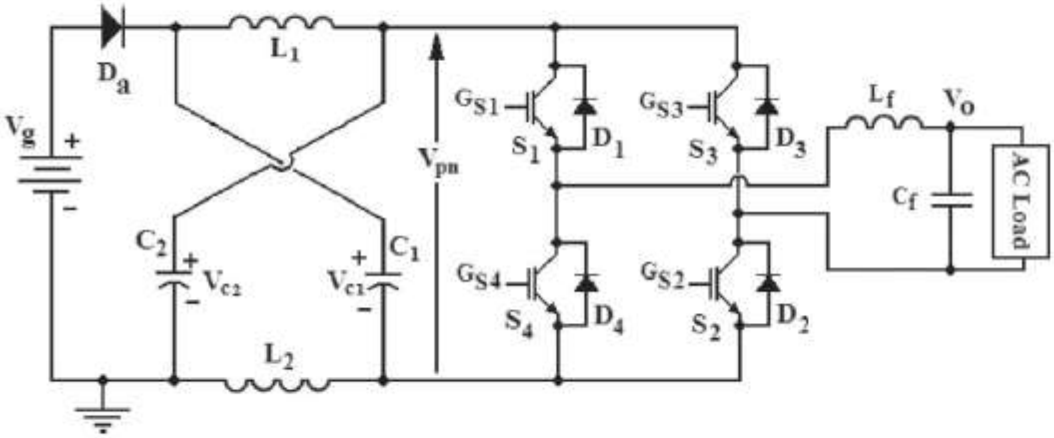

Fig. 1. Schematic of a ZSI.

2. REVIEW OF THE CURRENT-FED DC/DC TOPOLOGY

Current-fed dc/dc converter can provide high boost without operating at extreme duty cycle condition [8]. In the boost converter, the inductor charges the output capacitor only during (1-*D*) interval in a switching cycle. However, the current-fed dc/dc converter utilizes both *D* and (1-*D*) intervals to boost up the output voltage to a high value. The circuit diagram of the current-fed dc/dc topology (CFT) is shown in Fig. 2(a). Under continuous conduction mode (CCM) operation, in *D* interval (position 1 of the switch), the output terminals are connected across the inductor and ground. In *D_* (position 0 of the switch) interval, the output terminal connections are reversed. From the volt-second balance of the inductor *L* [8], the conversion ratio of CFT can be obtained as in the following and as shown in Fig. 2(b)

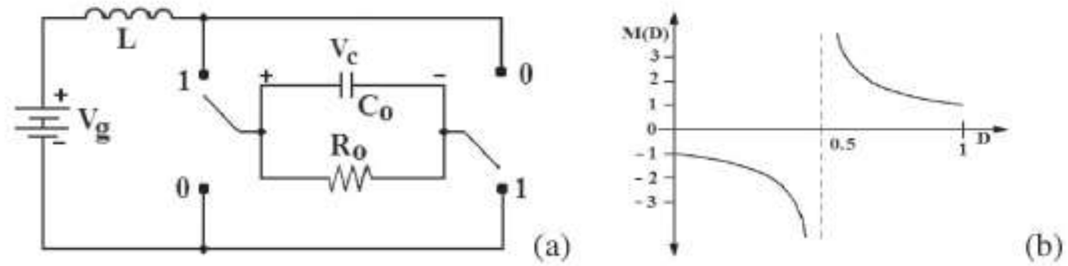

Fig. 2. (a) Circuit diagram of the current-fed dc/dc topology (CFT). (b) Conversion ratio of the CFT.

$$B_{\mathrm{CFT}}(D) = \frac{V_c}{V_g} = \frac{1}{2D-1}.$$

From the transfer characteristic of Fig. 3(b), it is noted that the converter gain is negative when the duty ratio (*D*) of the converter is between 0 and 0.5, and the gain is positive when *D* is beyond 0.5. Fig. 4(a) shows the complementary current-fed topology (CCFT) structure which is obtained by interchanging the *D* and *D_* intervals of the CFT structure. In this case, the controlled switches and the passive switches are interchanged in order to get the CCFT structure from the CFT structure. The equivalent circuits of the CCFT converter in the *D* and *D_* intervals are shown in Fig. 4(c) and (d), respectively. Using inductor volt-second balance [8], the steady-state output to input conversion ratio can be derived as

$$B_{\mathrm{CCFT}}(D) = \frac{V_c}{V_g} = \frac{1}{1-2D}.$$

3. STEADY STATE OPERATION AND ANALYSIS

In this section, complete analysis and steady state operation of the converter with design equations is presented. Main focus is given to the proposed converter with active clamp circuit and voltage multiplier. Mode by mode analysis with Active-Clamped ZVS operation was explained for one complete half cycle. Analysis is done on the primary side alone, due to the presence of voltage multiplier on the secondary of the high frequency transformer which just behaves as a multiplying stage. Fig.3 shows the Theoretical steady state operating waveforms of the proposed converter.

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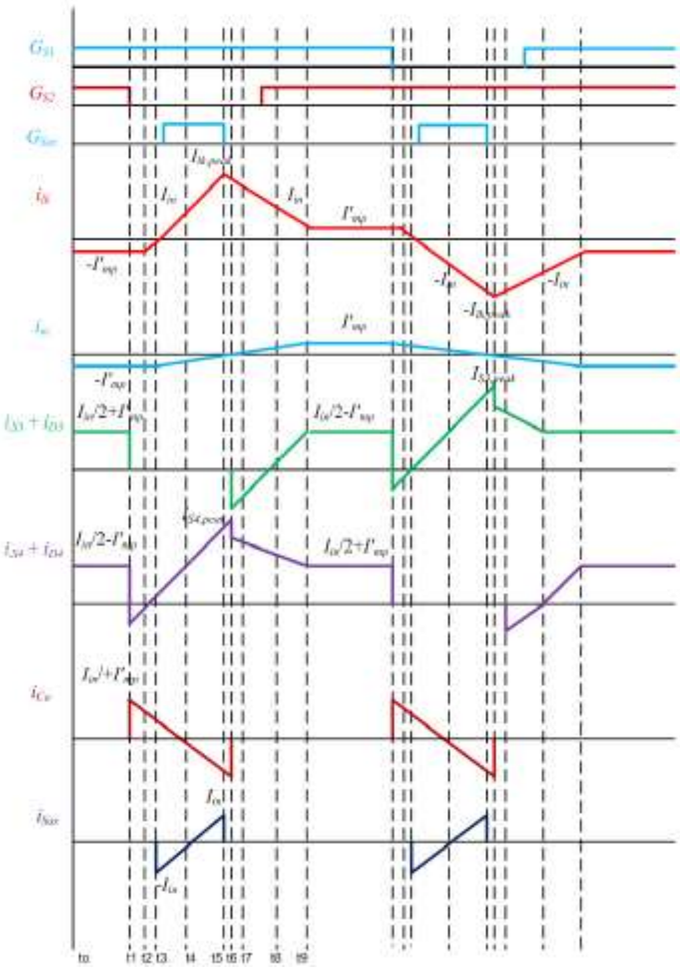

Fig.3. Theoretical Steady State operating Waveforms of the proposed converter

3.1.Interval 1(t0< t < t1)

In this interval, all the four switches on primary side S1 to S4 are turned ON and the Clamping Switch Sax is turned OFF. Boost inductor starts storing energy. The transformer leakage inductance current flows through all the switches so that increment in currents of switches S1 and S4 occurs. Other two switch currents through S2 and S3 decreases. Fig.4(a) shows circuit equivalent of this interval.

$$i_{lk} = i_m = -i'_{mp}$$

$$i'_{mp} = \frac{V_{in}}{2 * f * (L_{lk} + L_m)}$$

$$V_{sax} = \frac{V_{in}}{2 * (1 - D)}$$

$$V_{cau} = \frac{V_{in}}{2 * (1 - D)}$$

3.2.Interval 2(t1< t < t2)

In this interval at t=t1 primary switches S2 and S3 are made to turn OFF by removing the pulse. Boost inductor current changes the path through the clamping switch which causes zero current through all the switches. Leakage current flows through the body diodes of D1 and D4 of primary MOSFET devices S1 and S4 respectively. Hence the current through switches S1 and S4 immediately dips to negative value. Parasitic capacitance of device C2 and C3 of primary MOSFET devices S2 and S3 gets charged and clamping switch capacitor Cax gets discharged. Fig.4(b) shows the circuit equivalent of this interval.

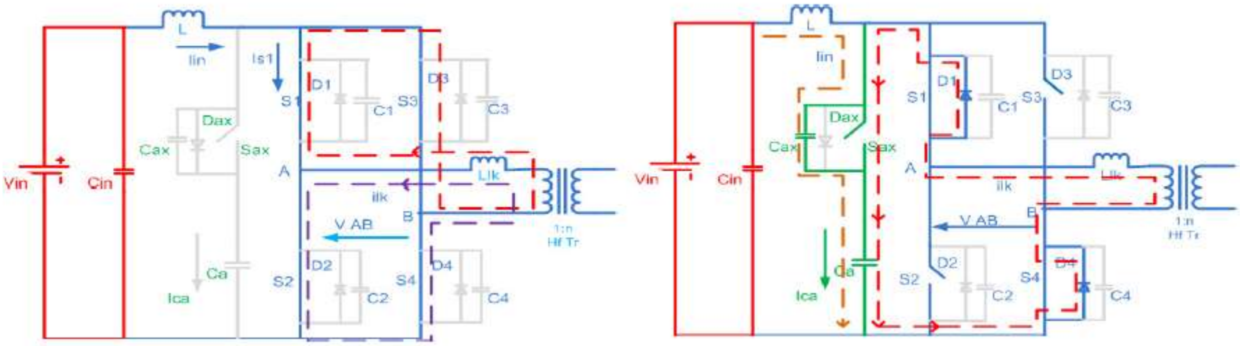

Fig. 4(a) Interval 1; (b) Interval 2

CONCLUSION

This paper has proposed a high-boost inverter structure based on the current-fed dc/dc converter topology. The proposed converter (CFSI) can work in both buck mode and boost mode and exhibits improved EMI noise immunity. The high gain of the converter is obtained due to insertion of shoot-through interval. In this paper, the development of the CFSI circuit has been described in detail along with its steady-state characteristics. The PWM switching scheme and the restriction on modulation index have also been described. The proposed inverter has been compared with traditional boost-VSI topology, SBI, and ZSI to present the advantages and disadvantages of CFSI. This paper has also presented a DSP-based closed-loop control scheme meant to regulate the ac and dc bus voltages. The proposed converter is tested on a laboratory prototype and verified.

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