Simulation and Implementation of Current-Fed Full-Bridge Boost Converter with Zero Current Switching for High Voltage Applications

P.Parvathy[1] and Dr.N.Devarajan[2]

**[1] Research scholar, Anna University
Coimbatore, Tamilnadu, India**

**[2]Professor of Electrical Engineering, Government College of Technology
Coimbatore, Tamilnadu, India**

Abstract

This paper presents a current-fed full-bridge boost converter with zero current switching (ZCS) based on constant on-time control for high voltage applications. The proposed converter utilizes the leakage inductor and the winding parasitic capacitor resonant tank to achieve ZCS. In order to achieve ZCS under wide load range, the turn-on time of the full-bridge boost converter is kept constant and the output voltage is regulated via frequency modulation. The circuit is simulated using MATLAB and implemented using micro controller. Both simulation and hardware results are compared.

Keywords: Phase - shift resonant converter, Zero current control, Pulse width modulation control, soft switching.

1. Introduction

High voltage converters are widely used in industrial applications, such as medical X-ray imaging, RF generation, traveling wave tube, lasers, and aerospace, etc. In high voltage dc-dc converters, (Sable, and Lee, 1989; Forsyth, et al.,1991a,b; Chan et al., 2001)[9],[3],[4],[1]. the output filter inductor becomes a bulky and expensive component due to the high voltage stress on this inductor. Therefore, the output filter inductor is not preferred in high voltage dc-dc converters. Current-fed converters are widely applied in high voltage applications due to their excellent operating characteristics, such as no possibility of flux unbalance and no output inductor. Usually, a very high turns-ratio transformer results in large leakage inductance and parasitic capacitance in high voltage applications. These parasitic components would cause high voltage and high current spikes on the power devices and will increase the switching losses. Thus, the efficiency and the reliability of the converter is reduced. So, the circuit topologies applied for high voltage applications are highly constrained by the high voltage transformer. The full bridge ZCS PWM converters shown in Fig. 1 provide a solution for high voltage applications. The block diagram of current-fed full-bridge boost converter is shown in Fig. 2.The full bridge (Chan et al., 2001) [1].ZCS PWM (Chan et al., 2003) [2] converter utilizes leakage inductor and parasitic capacitor of the high-voltage transformer to achieve ZCS operation. So that, the voltage and current spikes on the power devices and the switching losses of the converter will be reduced and the rectifier diodes on high voltage side are operated with ZCS. The full bridge PWM converter utilizes phase-shift control (Xu et al., 2004) [13] technique to achieve voltage regulation and ZCS with constant-frequency operation. In order to use phase-shift control scheme, the switches of full-bridge converter must provide reverse-voltage blocking capability. Thus, these switches can be constructed by IGBT or MOSFET in series with a reverse-voltage blocking diode. However, the series-connected diodes will increase component count and cost and also cause higher conduction losses.
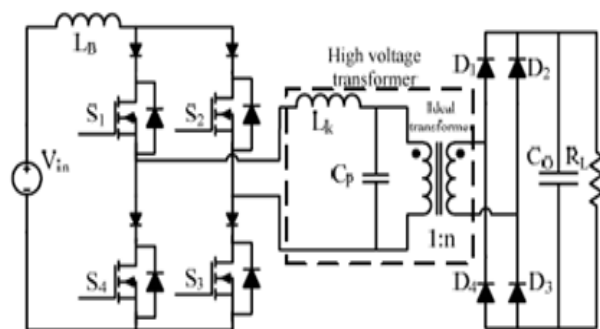

Fig. 1 Conventional full bridge ZCS PWM Converter circuit.

In this paper, a full-bridge ZCS converter without series-connected diodes is proposed. The overlapping conduction time of four switches is kept constant and the output voltage is regulated by varying the switching frequency.

The conduction time of the full bridge boost converter is specially designed to ensure ZCS operation under wide load range. The conduction time of the full bridge boost converter is specially designed to ensure ZCS operation under wide load range. In the conventional switched mode operation of PWM power converters, power switches have to cut off the load current within the turn-on and turn-off times under the hard switching conditions. During the turn-on and turn-off processes, the power device has to withstand high voltage and current simultaneously, resulting in high switching losses and stress. Dissipative passive snubbers are usually added to the power circuits so that the dv/dt and di/dt of the power devices could be reduced, and the switching loss and stress are diverted to the passive snubber circuits. However, the switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converters. Typical converter switching frequency was limited to a few tens of kilo-Hertz (typically 20kHz to 50kHz). The stray inductive and capacitive components in the power circuits and power devices still cause considerable transient effects, which in turn give rise to electromagnetic interference (EMI) problems. The transient ringing effects are major causes of EMI.

In resonant converters (Steigerwald,1988)[12]using resonant tanks to create oscillatory voltage and/or current waveforms(Soto-Sanchez, and Green,2001) [11] so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. The reduction of switching loss and the continual improvement of power switches allow the switching frequency of the resonant converters to reach hundreds of kilo-Hertz (typically 100 kHz to 500kHz). Consequently, magnetic sizes can be reduced , the power density of the converters increased the resonant current and voltage of resonant converters have high peak values leading to higher conduction loss and higher V and I ratings requirements for the power devices. Also, many resonant converters require frequency modulation (FM) for output regulation. Variable switching frequency operation makes the filter design and control more complicated.

The soft-switched converters combine the advantages of conventional PWM converters and resonant converters .These soft-switched converters have switching waveforms similar to those of conventional PWM converters except that the rising and falling edges of the waveforms are smoothed with no transient spikes. Unlike the resonant converters, the soft-switched converters usually utilize the resonance in a controlled (Sira-Ramirez, et al .,1998; Han, et al.,2002;Jacobson, et al., 1995)[10],[5],[6], manner. Resonance is allowed to occur just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. Other than that, they behave just like conventional PWM converters. With simple modifications, many customized control integrated control (IC) circuits designed for conventional converters can be employed for soft-switched converters, because the switching loss and stress have been reduced. Soft-switched converter can be operated at the very high frequency (typically 500 kHz to a few Mega-Hertz). Soft-switching converters also provide an effective solution to suppress EMI and have been applied to DC-DC converters. The draw backs of these conventional converters are more switching losses, more conduction losses due to series diode, high voltage stress ,less efficiency and reliability requires bulky output filter inductor.
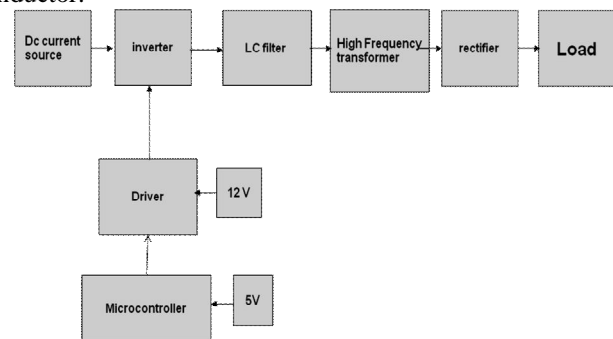

Fig. 2   Block diagram of current-fed full-bridge boost converter.

2. Features of the Proposed Converter

The proposed current-fed full-bridge boost converter circuit is shown in Fig. 3 where L_K is the leakage inductor of the transformer and C_P is the parasitic capacitance which is used as the resonant tank. In order to simplify the analysis, the input inductance L_B is assumed sufficiently large such that the input inductor current can be treated as a dc current source I_{LB}. Equivalent circuit of the proposed converter is shown in Fig. 4. The magnetizing inductor of the transformer is very large and thus the magnetizing current is negligible. The simplified equivalent circuit with the constant current   waveforms is shown in Fig. 5. The turn-on time Ton of the full-bridge boost converter is defined as the overlapping conduction time of four switches. The turn-on time Ton is designed as constant to achieve ZCS and the output voltage is regulated via frequency modulation. The   proposed converter has less voltage stress, less switching losses due to ZVS, high efficiency and reliability, less conduction losses due to absence of series diode, no need bulky output filter inductor source I_{LB} and the key analytical waveforms are shown in Fig. 5.
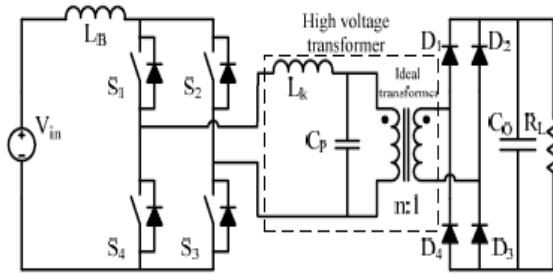
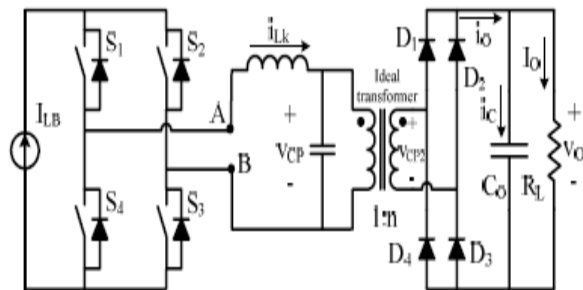Fig. 3   The circuit diagram of proposed current-fed full-bridge boost converter.

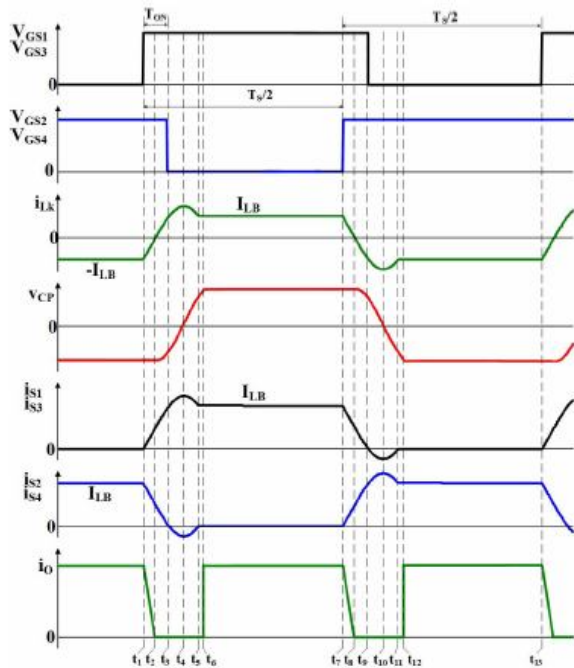Fig. 4   Equivalent circuit of the proposed converter.

Fig. 5   Key waveforms of the proposed converter.

3. Simulation results

Digital simulation is done using Matlab and the results are presented here. Resonant converter is shown in Fig.5.1 DC input voltage is shown in Fig.5.2 Vgs and Vds across switch 1 is shown in Fig.5.3 The primary side voltage of the transformer is shown in Fig.5.4 The secondary side voltage of the transformer is shown in Fig.5.5 The simulink model of current-fed full-bridge boost converter is shown in Fig.5.6. Transformer secondary side voltage of the current-fed full-bridge boost converter is shown in Fig.5.7. Output voltage is shown in Fig.5.8. Output current is shown in Fig.5.9.
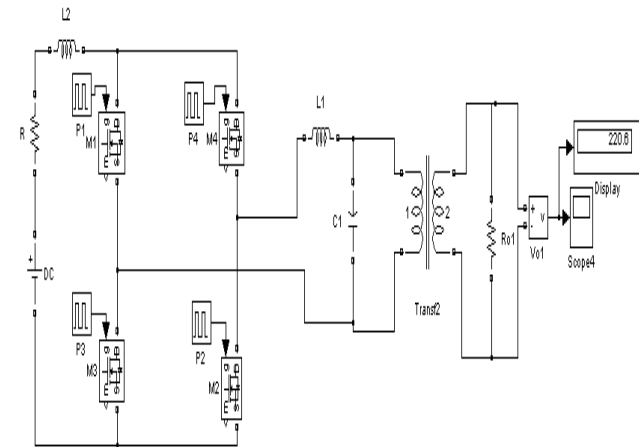

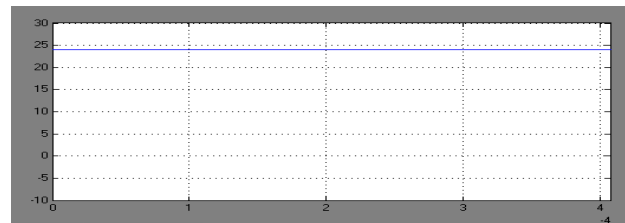Fig. 5.1 Simulation diagram of resonant inverter.
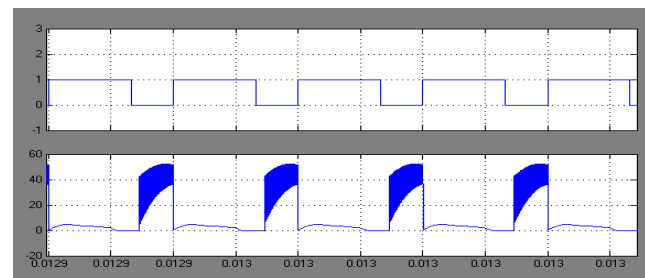

Fig. 5.2   DC input voltage.
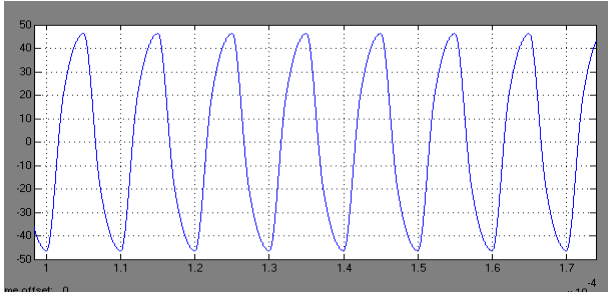

Fig. 5..3 Vgs and Vds across switch 1.

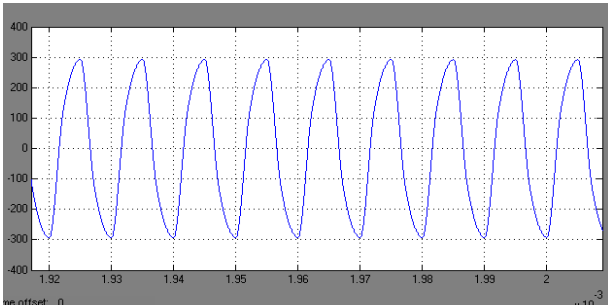Fig. 5..4 Transformer primary side voltage.

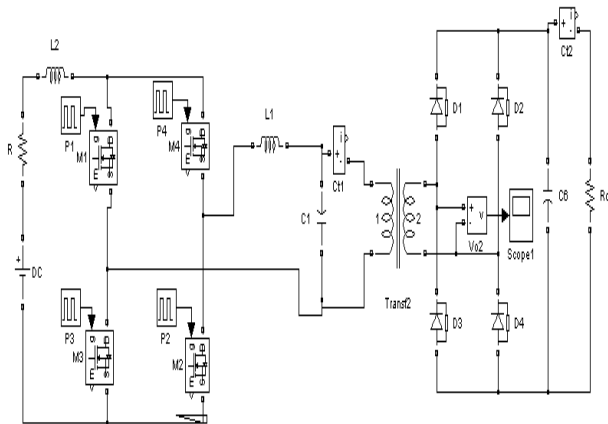Fig. 5.5 Transformer secondary side voltage.

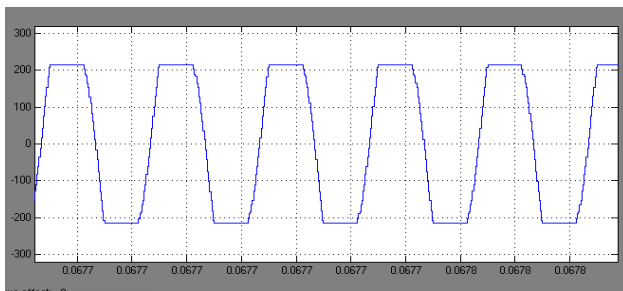Fig. 5.6 Simulation diagram of current-fed full-bridge boost converter.

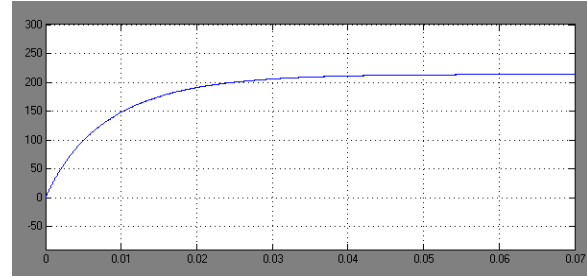

Fig. 5.7 Transformer secondary side voltage
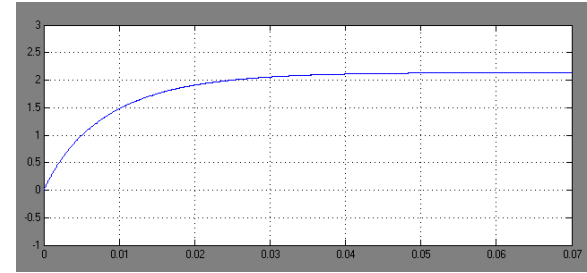

Fig. 5.8 Output voltage.

Fig. 5.9 Output current.

4. Experimental results

I   In order to verify the effectiveness of the proposed converter configuration and its control strategy, a cost effective current-fed full-bridge boost converter has been developed, simulated and implemented in real time in open loop using Atmel 89c2051 micro controller for a prototype. The hardware of current-fed full-bridge boost converter is fabricated using the following components: Atmel 89c2051, IR2110, IRF840, 2200f capacitor, 7805 and 7812. The overview of hardware module is shown in Fig. 6.1 DC input voltage is shown in Fig. 6.2. Driving pulses are shown in Fig. 6.3. DC output voltage across the capacitor is shown in Fig. 6.4. The control circuit is shown in Fig. 6.5.

A step-down transformer (230/15) V is used to give input supply to the power circuit. The 15V AC input is rectified into 15V pulsating DC with the help of full bridge rectifier circuit. The ripples in the pulsating DC are removed and pure DC is obtained by using a capacitor filter. The positive terminal of the capacitor is connected to the input pin of the 7812 regulator for voltage regulation. An output voltage of 12V is obtained from the output pin of 7812 is fed as the supply to the pulse amplifier. An output voltage of 5V obtained from the output pin of 7805 is fed as the supply to the micro controller .From the same output pin of the 7805, a LED is connected in series with the resistor to indicate that the power is ON. Phase shift pulse method is used to control the inverter to achieve ZCS . The transformer's size is small due to high frequency. It is also

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used for isolation purpose. Rectifier converts AC supply to DC supply. DC supply is filtered with the help of capacitor filter. Micro controller is used to generate triggering pulse for Mosfets.Driver called as power amplifier because it is used to amplify the pulse output from micro controller. It is an opto coupler IC. It provides isolation between microcontroller and power circuits.The proposed converter has less voltage stress, less switching losses due to ZVS, high efficiency , high reliability, less conduction losses due to absence of series diode and no need for bulky output filter inductor.
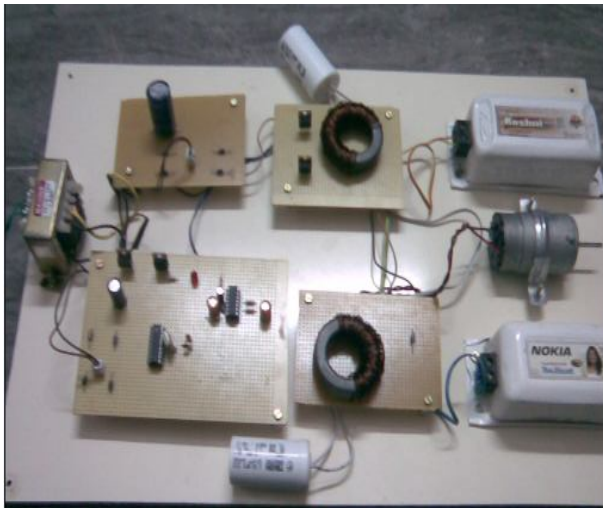

Fig. 6.1 Overview of hardware kit.
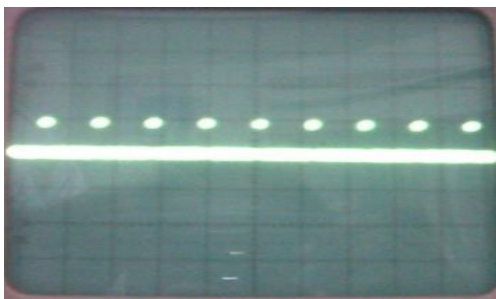

Fig. 6.2 DC input voltage.

Scale: 1 unit=5v

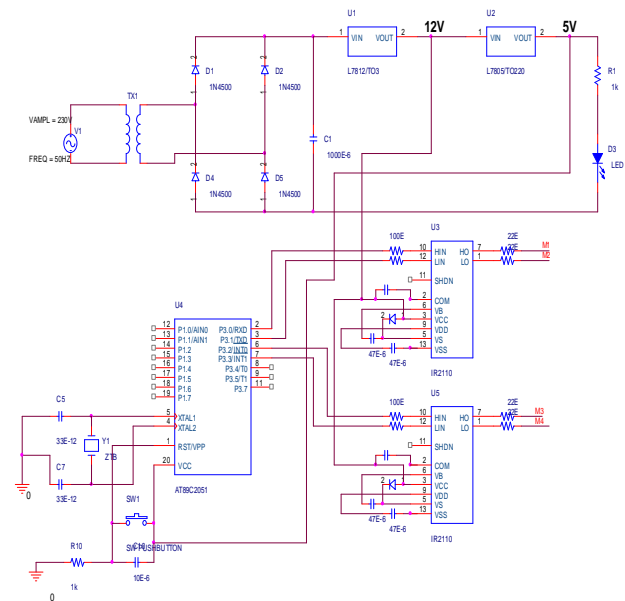Fig. 6.3 Driving pulses.

Fig. 6.4 Voltage across capacitor.

Fig. 6.5 Control circuit.

5. Conclusion

The current-fed full-bridge boost converter with zero current switching is simulated using matlab simulink and implemented using Atmel 89c2051microcontroller. This converter has the advantages like less voltage stress, less switching losses due to ZCS, high efficiency and reliability, less conduction losses due to absence of series diode, no need for bulky output filter inductor, reduces number of switches, reduces transformer and filter size , reduces ripple, reduces switching losses, reduces switching stresses and increases power density. The scope of this paper is the simulation and implementation of current-fed full-bridge boost converter with zero current switching using microcontroller. The experimental results closely agree with the simulation results.

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BIOGRAPHY

P.Parvathy obtained her B.E (ICE) from University of Madras and M.E (E&C) from Sathyabama University in the year 1997 and 2007 respectively. She is presently a research scholar at Anna University, Coimbatore.

Dr.N.Devarajan received his B.E (EEE) and M.E (Power Systems) from Government college of technology, Coimbatore in the year 1982 and1989 respectively. He received PhD in the area of control systems in the year 2000. He has published 41 papers in the national and international conferences. He has published 122 papers in international journals and one national journal. His areas of interests are control systems, electrical machines and power systems. He is a member of system society of India, ISTE and Fellow of Institution of Engineers. He is now the assistant professor of electrical engineering department at GCT, Coimbatore.