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Soft-Switched High Efficiency CCM Boost Converter with High Voltage Gain

Author

Praveen Kumar Parate[1], C.S.Sharma[2], D. Tiwari[3]

[1]PG Scholar/ Dept. of EE, Samrat Ashok Technogical Institute,Vidisha, M.P, India
Email: *pparate89@gmail.com*
[2]Associate Prof./Dept of EE, Samrat Ashok Technological Institute, VidishaM.P, India
Email: *hi_css21@yahoo.co.in*
[3]Assistant Prof./Dept of EE, Samrat Ashok Technological Institute, Vidisha M.P, India
Email: *Devendra4483@gmai.com*

Abstract

This paper proposed for high efficiency converter with high voltage gain introducing a soft switch continues conduction mode (CCM) boost converter in applications such as dc back up energy system for UPS, photovoltaic, hybrid electric vehicle. In order to achieve high voltage at output terminal the rectifier diode must contain a short pulse current with high amplitude i.e. in resulting to serve the reverse recovery to high electromagnetic problems. The proposed converter shows turn on the switches in CCM by using zero voltage switching as well as to alleviate turn off switching losses owning to the switching method that utilises L_r-C_r resonance in the auxiliary circuit. Also, as a result of the proposed switching method, the switching losses produced with diode reverse recovery become very negligible even in the small duty cycle. In this type of converter has voltage conversation ratio is higher than ordinary boost converter. Resulting voltage gain of this converter is also high comparatively other converter.

Keywords - *DC-DC converter, soft-switched, high voltage gain, continuous conduction mode (CCM).*

Abbreviations and Acronyms- ZVS (Zero voltage switching), ZVC (Zero voltage current), ZVT (Zero voltage transition), CCM (*continuous conduction mode*), EMI (electromagnetic interference)

1. Introduction

DC-DC converter are required in many application in wide range industries for high efficiency and high voltage, to fulfil these requirement the conventional boost converter cannot be used as they cannot provide such a high DC voltage gain, even for an extreme duty cycle. It also may result in a serious reverse-recovery problem and increase the rating of all devices. As a result, the conversion efficiency is degraded and the electromagnetic interference (EMI) problem is severe in this situation [7]. To increase the conversion efficiency and voltage gain, many modified step-up converter topologies have been investigated. When switch is turned on in hard switched boost converter there is a large amount of current spikes in the main switch and through the diode. Therefore will be large current passing through at output coupled capacitor. In most of the switched-capacitor and coupled inductor converters hard switching is used and therefore they are not applicable for high efficiency and high power application.

These problems are overcome by soft switched like MOSFET, IGBT. The main features of these soft switched techniques are high efficiency, low switching losses and high voltage conversation ratio. Zero voltage transition (ZVT) [1]-[3] pulse width modulation proposes soft switching and reverse recovery problem can be eased by a simple auxiliary circuit construction.ZVS condition [4]-[7] can be achieved by partial resonance of shunt branch across the main switch.

2. Soft Switched Boost Converter Operation and Analysis

The proposed circuit diagram of soft switched CCM boost converter as shown in figure is described below. The converter consists of a general boost converter as the main circuit and an auxiliary circuit. In main circuit two switches are operated with asymmetrical complementary switching to regulate the output voltage. In auxiliary circuit includes capacitor C_1, C_2, and two diodes D_1,D_2. Capacitor C_1 and C_2 are mounted on top of output capacitor C_3 to form the output voltage of the converter. The auxiliary circuit, not only output voltage is raised but ZVS turn-on of active switches$S_1$and S_2 in CCM Boost Converter. Unlike PWM method in which the switches are turned OFF with high peak current, the proposed converter utilizes L_r–C_r resonance of auxiliary circuit, thereby reducing the turn-off current of switches. This paper proposes a new soft-switched CCM boost converter suitable for high-power applications such as power factor correction, hybrid electric vehicles, and fuel cell power conversion systems.

<u>The proposed converter has the following advantages</u>:

1) Zero voltage switching (ZVS) turn-on of the active switches in CCM;

2) Negligible diode reverses recovery due to zero current switching (ZCS) turn-off of the diode;

3) Voltage conversion ratio is almost doubled compared to the conventional boost converter; 4) greatly reduced components' voltage ratings and energy volumes of most passive components.

The proposed CCM boost converter operates in five modes.

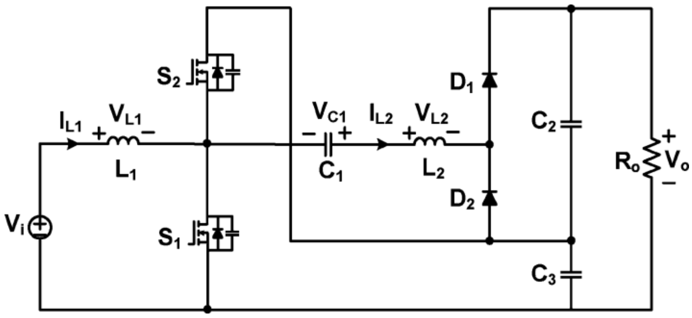

Fig.1. Proposed soft-switched CCM boost converter

3. Operating Principle

Mode I: In this mode when current iL_2goes to zero and diode$D_2$is turned on. During this mode, the lower switch S_1maintains ON state. Both input inductor current $iL_1$and auxiliary inductor current iL_2flows through lower switch $S_1$and diode of body switch S_1 conducting therefore inductor L_1 and L_2 start increasing and decreasing respectively. The slope of these currents are given by

$$\frac{diL1}{dt}=\frac{Vi}{L1} \quad (1)$$

$$\frac{diL2}{dt}=\frac{Vc1-Vc2-Vc3}{L2} \quad (2)$$

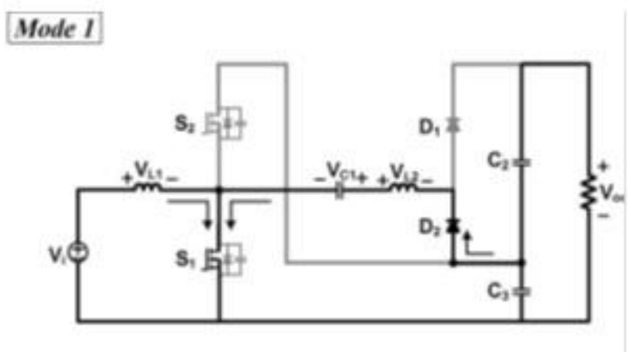

Fig. 2 Mode 1 Operating circuit

*Mode II: I*n begins of this mode switch S_1 maintain the on state and the body diode of switch $S_2$is turned on. The gating signal is applied to switch S_2during this mode, and $S_2$is turned on under ZVS conditions. Both$iL_1$and $iL_2$are flowing through the switch S_1. The slope determined bythe following equations:

$$\frac{diL1}{dt} = \frac{Vi}{L1} \qquad (3)$$

$$\frac{diL2}{dt} = \frac{Vc1-Vc3}{L2} \qquad (4)$$

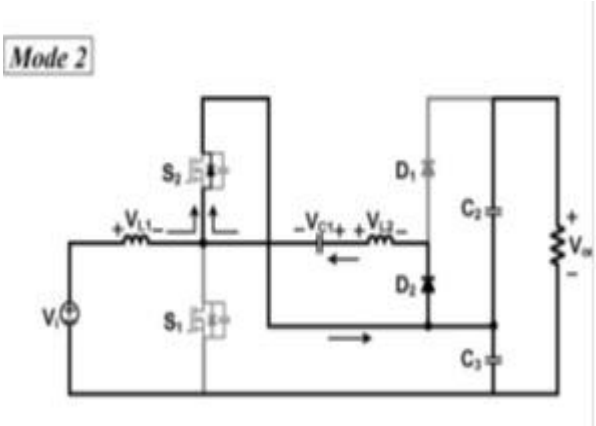

Fig 3.Mode 2 Operating circuit

Mode III: During this mode, there is no current path for auxiliary circuit. At the end of this mode turn off signal applied to switch S_1 and output capacitor C and C supply the load. The following equation given below:

$$\frac{diL1}{dt} = \frac{Vi}{L1} \qquad (5)$$

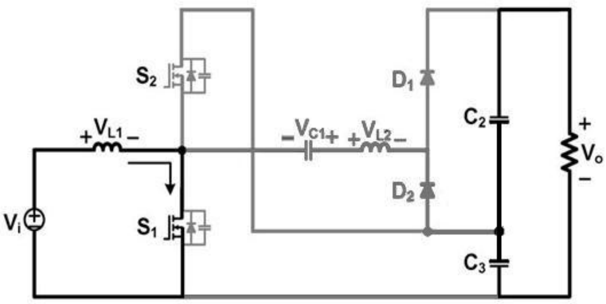

Fig 4. Mode 3 Operating circuit

Mode IV: During this mode, body diode of switch S_2 is turn on and S_1 turned off. The gate signal applied to S_2 under ZVS condition. Current of inductor iL_1 start to decrease and at the end of this mode current iL_1 and iL_2 are equal.

$$\frac{diL1}{dt} = \frac{Vi-Vc3}{L1} \qquad (6)$$

$$\frac{diL2}{dt} = \frac{Vc1-Vc2}{L2} \qquad (7)$$

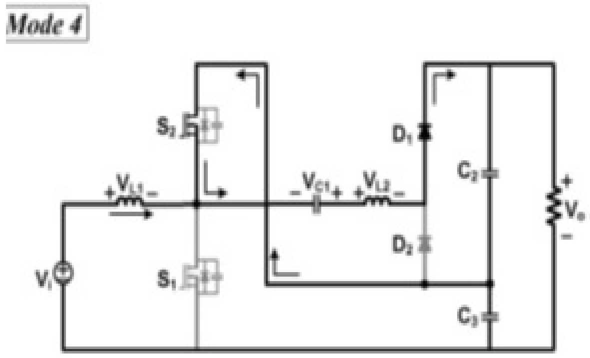

Fig 5.Mode 4 Operating Circuit

Mode V: In starting of this mode inductors current $iL_1$and iL_2 are same. The diode D_1 keeps conducting and current through inductor iL_2 increases. Switch S_2 maintain it's on state condition. Inductor current iL_1 decreasing with the slope determined by the following equations:

$$\frac{diL1}{dt} = \frac{Vi-Vc3}{L1} \qquad (8)$$

$$\frac{diL2}{dt} = \frac{Vc1-Vc2}{L2} \qquad (9)$$

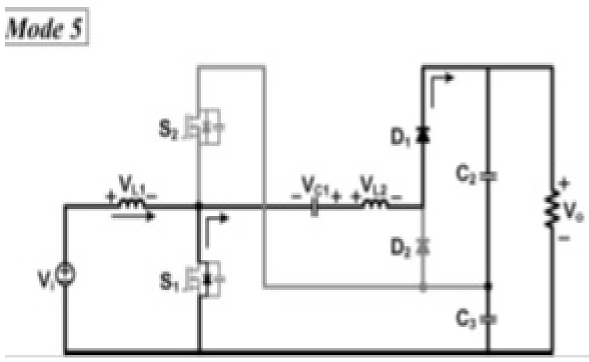

Fig 6. Mode 5 Operating Circuit

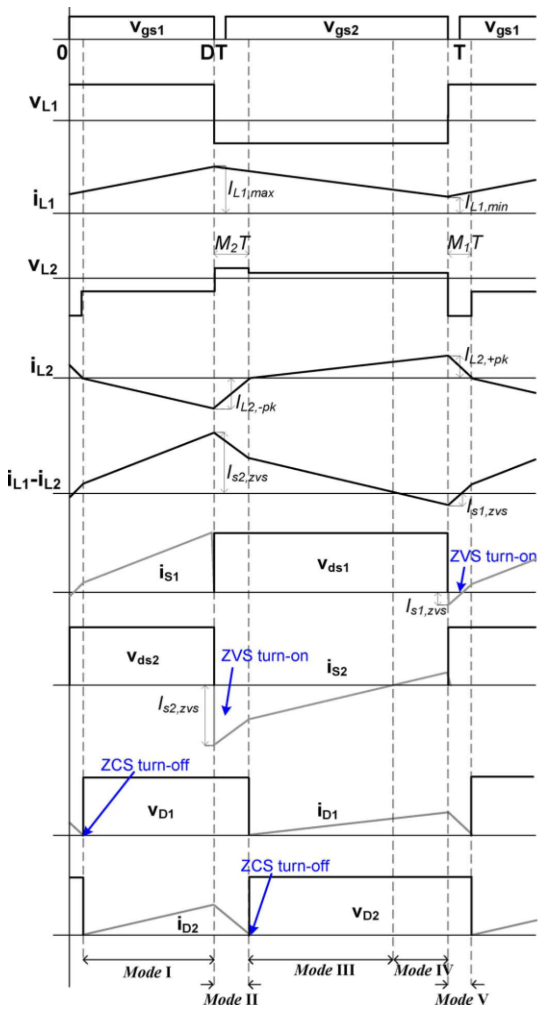

Fig.7 Key waveforms of the proposed converter.

4. Voltage Conversation Ratio

The effective voltage gain of the proposed soft-switched high step-up DC-DC converter is compared with

The conventional boost converter. This comparison is plotted between duty ratio and voltage gain which is shown in figure below.

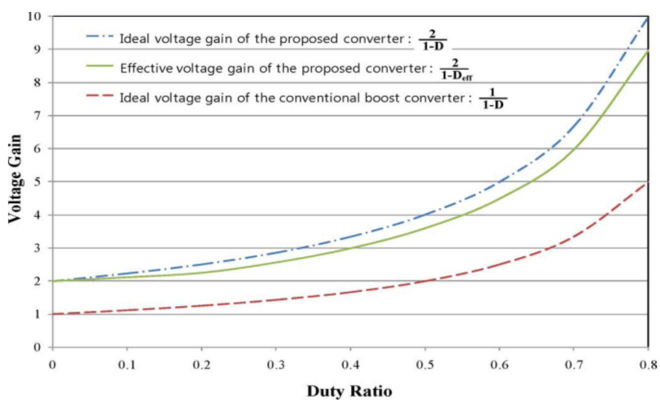

Fig. 8 Voltage Conversion Ratio

Duty cycle is calculated as $D = \frac{Vout-Vin}{Vout}$ (10)

Effective duty cycle is calculated as $D_{eff}= \frac{Vout-2Vin}{Vout}$ (11)

Voltage gain of the conventional boost converter $= \frac{1}{1-D}$ (12)

Voltage gain of soft-switched high step-up DC-DC converter $= \frac{2}{1-Deff}$ (13)

V_{out} = Voltage gain * V_{in} (or)$\frac{2Vin}{1-Deff}$ (14)

The plot shown in figure there is a slight drop of the ideal voltage gain, which is caused by duty loss, the effective voltage gain of proposed converter is almost twice compared to the conventional boost converter. This is a very desirable feature in high voltage gain application since reduced duty ratio leads to reduced current stresses upon the component resulting in increased efficiency.

5. Simulation Design and Result

The simulation model of modified soft-switched high step-up DC-DC converter was done by using MATLAB.

The model of open loop soft-switched CCM Boost converter with R load is shown in figure. The simu link model was done for an input voltage of 40 V and have given voltage of 130 V. The load resistance value is 60 ohms and our converter worked at switching frequency of 16 KH Switches S_1 and S_2 are operated separately owning pulse generator. Switches $S_{1,}$ S_2 are operated with asymmetrical complimentary switching to regulate the output voltage.

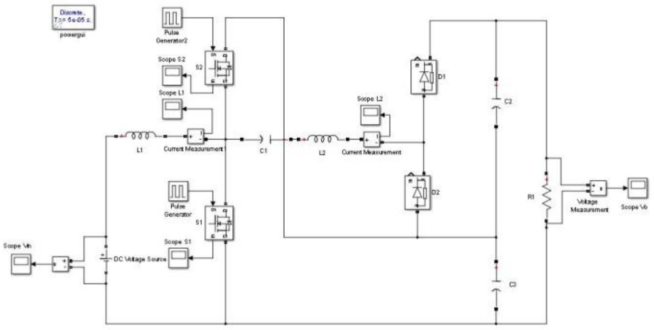

Fig 9 Soft-Switched High Step-up DC-DC Converter with R Load

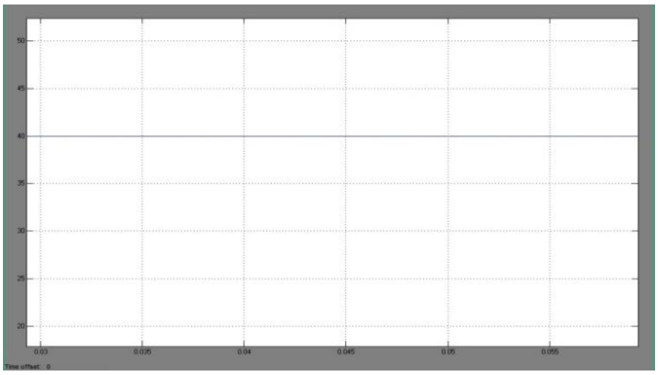

Fig 10 Input Voltage Waveform

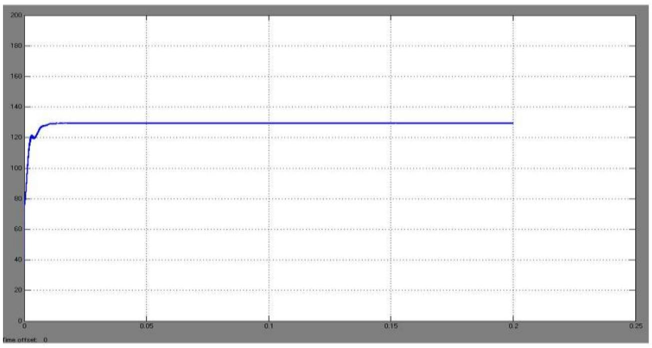

Fig 11 Output Voltage Waveform

Closed Loop Soft-Switched High Step-up DC-DC Converter for R Load with input disturbance

In closed loop soft-switched DC-DC converter used the Proportional Integral (PI) to control the output voltage as required. The reference voltage gives to the circuit by using constant block. In resulting output voltage and reference voltage are compared therefore error signal is produced which is processed by PI controller. The PI controller controls the circuit and gives required output. In closed loop input here we give 5V disturbance with 40V input voltage. Resulting the input side has a disturbance and output voltage obtained with constant. Output voltage of CCM boost converter is comparatively higher than open loop. As shown in figure 14.

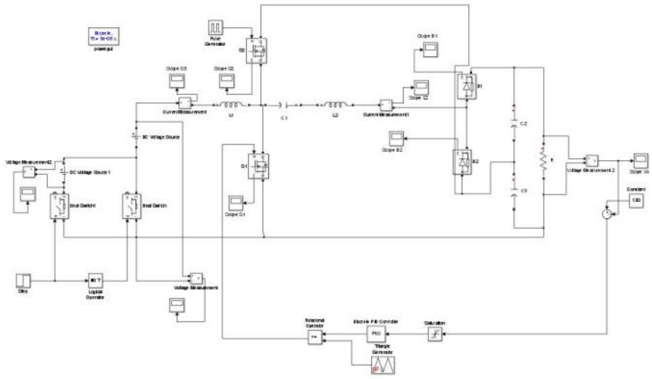

Fig 12 Closed Loop Soft-Switched CCM Boost Converter

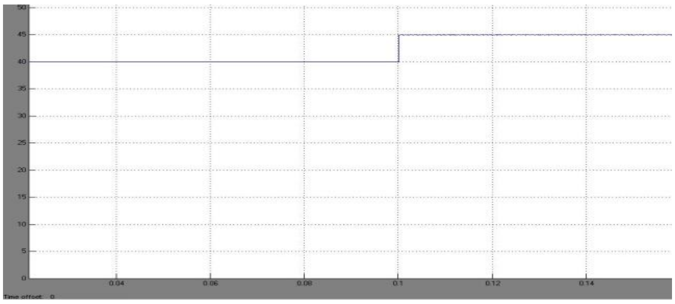

Fig 13 Input Voltage Waveform with Disturbance

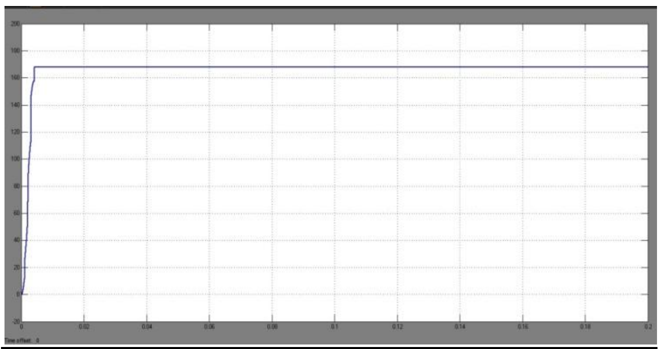

Fig 14 Output Voltage Waveform

Here for soft-switched high step-up DC-DC converter can be extended with the same concept of multi-phase DC to DC converter

6. Conclusion

The soft-switched high efficiency CCM boost converter with high voltage gain is successfully implemented and result is observed on the simulation scope. From the result was observed that in the close loop system the output is 167V DC, where' as in open loop the output is 130V DC. From the output of close loop system gives more satisfactory compare to output of open loop system. The effective voltage gain of soft-switched high step up DC-DC converter compared with conventional boost converter resulting voltage gain of soft-switched DC-DC converter is twice of boost converter.

From the analysis, the major challenges in these applications can be drawn as follows:

1) How to extend the voltage gain and how to avoid the extreme duty cycle to reduce the current ripple;
2) How to reduce the switch voltage to make low-voltage MOSFETs available to reduce the power device cost and the conduction losses;
3) How to realize the soft-switching performance to reduce the switching losses;
4) How to alleviate the output-diode reverse-recovery problem to reduce the reverse-recovery losses.

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