Transformer-less High gain Boost Converter with Input Current Ripple Cancellation at Selectable Duty Cycle

Manish.G.Rathi[1], Gururaj.Sajjan[2]
[1](Electronics and Communication Engineering Department, Poojya Doddappa Appa College of Engg, Gulbarga-585102/ Visvesvaraya Technological University, India)
[2](Electrical and Electronics Engineering Department, Poojya Doddappa Appa College of Engg, Gulbarga-585102/Visvesvaraya Technological University, India)

ABSTRACT : *This paper proposes a boost dc-dc converter with out transformer gives the novel capability of cancelling the input current ripple with high gain output voltage atpreselectedduty cycle. There are several solutions available in literature to get the high gain voltage but they use number of components, But in this proposed system withoutincreasing the number of components, the converter features a high voltage gain withoututilizing boosting transformers the main purpose of proposing this system is to make best use of electric power coming from low voltage power generating sources such as renewables. Finally a prototype circuit of the proposed converter is implemented in labratory to varify the performance of the converter.*

Keywords *dc/dc converter, Current ripple cancellation, Power conversion, Pulse width modulation*

I. INTRODUCTION

The dc-dc converters are widely used in regulated switch mode dc power supplies and in dc motor drive applications. The input to these converters is an unregulated dc voltage which is obtained by either rectifying line voltage or from the battery and therefore it will fluctuate due to changes in line voltage magnitude .Switch mode dc-dc converters are used to convert unregulated dc input into controlled dc output at a desired level. Looking ahead to the applications of these converters we find the converters are very often used with an electrical isolation transformer in switch mode dc power supplies and almost always without an isolation transformer in case of dc motor drives[1]-[2].

As we know that Regulated dc power supplies are needed for most analog and digital electronic systems most power supplies are designed to meet some of the requirements- Regulated output- The output voltage held constant within a specified tolerance for changes within a specified range in the input voltage and the output loading ,Isolation –The output may be required to be electrically isolated from the input, Multiple outputs-There may be multiple outputs that may differ in their voltage and current ratings such outputs may be isolated from each other.

In addition to these requirements common goals are to reduce power supply size and weight and improve their efficiency Traditionally linear power supplies have been used however advances in the semiconductor technology have led to switching power supplies which are smaller and much more efficient compared to linear power supplies the cost comparison between linear and switching supplies depends on power rating. By considering all the above factors this project proposes such as follows-The voltage provided by number of small power generating sources such as renewables is usually low in amplitude as a result of this a boost type of architecture with a large voltage gain is required to link this voltage to an inverter. Another important requirement for a converter in renewable energy applications (for ex: Fuel cells) is to drain a continuous current with a minimum ripple therefore converters combining these two features are expected to find many applications within the renewable energy context.

In addition to experiencing a supply shortage in recent years fossil fuel causes serious environmental pollution problems. Therefore developing a high efficiency renewable energy power system has become an urgent issue of concern due to wide range of low dc output voltage the renewable energy sources(solar cell) can't directly support the ac or dc appliances consequently a step up converter is required to provide high voltage gain from low dc output voltage. The dc-dc converters with high step up voltage gain are widely used for many applications such as fuel cell energy conservation systems and high intensity discharge lamp ballast for automobile head lamps. The limited availability of energy sources has become an inevitable global problem, therefore energy conservation and carbon emissions reduction are important issues in modern day society currently environmental protection is a primary concern in which available energy from natural resources is developed for ease of use such developments are also designed to generate inexpensive and effective energy sources while highlighting the importance of minimizing environmental destruction and pollution Solar energy is one of the most extensively exploited sources of effective natural energy. Hence in order to full fill all the requirements proposing new concept "A Transformer less high gain Boost converter with input current ripple cancellation at Selectable Duty cycle".

This project proposes a boost dc- dc converter topology with novel capability of cancelling the input current ripple at an arbitrarily preselected duty cycle. This is accomplished without increasing the count of the number of components in contrast to other solutions available in the literature. In addition, the converter features a high voltage gain without utilizing extreme values of duty cycle or boosting transformers. These features make the converter ideal to process electric power coming from low-voltage power-generating sources, such as renewables. Several topologies have been proposed in literature uses the different methods in order to get high voltage gain such as coupled inductor and voltage doubler circuits, coupled inductors with voltage multipliers and also in case of dual inductor boost converter ripple cancellation uses smaller transformer ratio to get high voltage gain. Hence this proposed converters with high voltage gainwhich do not require a transformer, coupled inductors or extreme duty cycle values are highly desirable gives the quick penetration of low voltage power generating sources. Another main challenge is renewable energy power processing circuit is expected low input current ripple[3]-[4].

Finally this project accomplishes without increasing the count of number of components, in addition the converter features high voltage gain without utilizing extreme values of duty cycle or Boosting transformers. These features makes the converter ideal to process electric power coming from low voltage power generating source such as renewables. Moreover, the rapid development of silicon carbide and other wide-band gap fast-switching power semiconductors will enable the use of smaller reactive components and hence provide further advantages to the approach proposed herein against transformer or coupled-inductor-based topologies.

This paper is organized as follows. Section II provides the topological details of proposed converter, Section IIIexplain design considerations for proposed system, Section IV explains DSPIC30F4011 Microcontroller used in the prototype, Section V Experimental results validate the approach ,in section VI conclusion.

II. PROPOSED HIGH GAIN BOOST CONVERTER

The proposed topology is shown in Fig.1(a). As the figure suggests, the topology contains two transistors (Q_1 and Q_2), three diodes (d_1, d_2, and d_3), three capacitors (C_1, C_2, and C_3), two inductors for energy storage (L_1 and L_2), and a small inductor (L_3) for current limiting through d_3. The transistors switching is complementarily, i.e. Q_1&Q_2 operate vice versa. The operation of the converter may be explained considering the small-ripple approximation for the voltage across capacitors and continuous conduction mode for L_1 and L_2. The converter operation can be explained using two modes i.e., mode1 and mode2 and the equivalent circuits for both the modes are shown in figure 1(b) and 1(c) respectively, where in switches are operated complementarily. During mode1 the diode d_1 is reversely biased, blocking the voltage across C_1. Similarly, diode d_3 is reversely biased, blocking the voltage across C_3. The current through L_2 forces the diode d_2 to be closed since transistor Q_2 is open. During mode2$Q2$ is on (and $Q1$ is off) during this time, the $L1$ discharges, while $L2$ charges and the capacitors $C2$ and $C3$ are connected in parallel, leading to an SC-type behaviour. As a result of this, a small inductor ($L3$) is needed in order to limit the peak current around this loop.

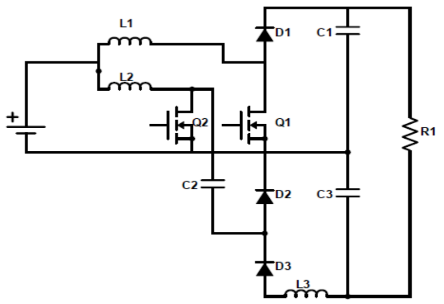

Fig: 1(a)

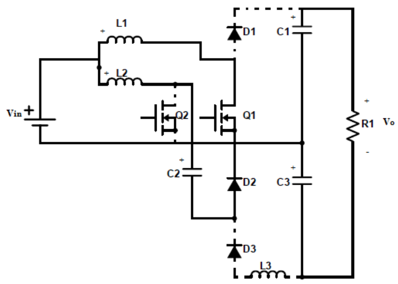

Fig: 1(b)

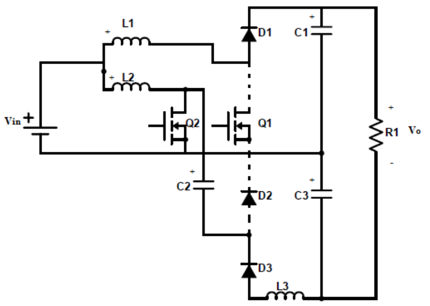

Fig: 1(c)

Fig:1(a) Circuit diagram of converter (b)and(c) Equivalent circuit for each switching state.

III. Design considerations, for proposed converter

As referring from Fig 1 it suggests, proposed boost converter with input ripple cancellation, this topology features a small inductor for peak current limiting which has no effect on the basic operation of the converter for power transfer,along with two inductors allows current ripple cancellation at an preselected duty cycle.

A.Voltage analysis

The dynamics of L_1, L_2, and C_1 may be conveniently analysed considering their average behaviour as their state variables feature triangular waveforms similar to those in traditionaldc/dc converters. On the other hand, C_2, C_3, and L_3form an SC circuit, and therefore, their dynamic behaviour has to be formulated with additional considerations. However, a number of the converter’s features can be explained focusing on L_1, L_2, and C_1, where dynamic averaging applies. Under this assumption, switching functions may be readily replaced by their corresponding duty cycles. For the analysis hereinafter, the converter’s duty ratio $d(t)$ is defined as percentage of time over the switching period that the switch Q_2 is on, i.e.,

$$d(t)=\frac{1}{T_s}\int_t^{t+Ts} q_2(t)\,dt \qquad -(1)$$

Where $T_s$switching period q_2 is switching function of Q_2 that is equal one while Q_2 is closed to zero otherwise. Under this assumption, and neglecting for now the inductors equivalent series resistance (ESR), the equations that represent the dynamics for inductors L_1 *and* L_2 are

$$L_1\frac{di\,L_1}{dt}=d(v_{in}-v_{c1}) \qquad -(2)$$

$$L_2\frac{di\,L_2}{dt}=d(v_{in})+(1-d)\,(v_{in}-v_{c2}) \qquad -(3)$$

In steady state, the average voltage across the inductors must be equal to zero.

Hence equation (2) and (3) becomes

$$V_{c1}=\frac{1}{D}v_{in} \qquad -(4)$$

$$V_{C2}=\frac{1}{1-D}V_{in} \qquad -(5)$$

Voltage across C_1 and C_2 are proportional to each other i.e..

$$V_{c1}=\frac{1-D}{D}V_{c2} \qquad -(6)$$

$$V_{c2}=\frac{D}{1-D}V_{c1} \qquad -(7)$$

On the other hand equation that represents the average dynamics for C_1

$$c_1\frac{dv_{c1}}{dt}=di_{L1}-\frac{V_{c1}+V_{c2}}{R} \qquad -(8)$$

In steady state the average current through C_1 must be equal to zero, which leads to the following expressions for the current through $L1$

$$I_{L1}=\frac{1}{D}\left(\frac{v_{c1}+v_{c3}}{R}\right) \qquad -(9)$$

As $C2$ and $C3$ form an SC circuit, average dynamic equations do not apply. However, the steady-state current through $L2$ can be computed by input/output power balance considerations. It becomes

$$I_{L2}=\frac{1}{1-D}\left(\frac{v_{c1}+v_{c3}}{R}\right) \qquad -(10)$$

Furthermore, from Fig. 1(a), the output voltage is$V_o=V_{c1}+V_{c3}$ -(11)

Thus, combining (4), (5), and (9)–(11), the converter gain becomes

$$\frac{V_o}{V_{in}}=\frac{1}{D(1-D)} \qquad -(12)$$

As mentioned earlier, this circuit has an SC stage which may be increased by including additional capacitors and diodes. Capacitors $C2$ and $C3$ work in an SC way because $C2$ clamps the voltage across $C3$ while the switch $Q2$ is closed. This is because the energy stored in $L3$ is negligible compared to other energy storage elements in the converter. Furthermore, in steady state, $C2$ and $C3$ feature the same average voltage i.e.,

$$V_{c2}=V_{c3} \qquad -(13)$$

The gain expressed by (12) corresponds to an ideal case as the inductor’s.The leakage resistance in inductors greatly limits this gain. In order to quantify this, consider first rewriting (9) and (10) using (6) and (7) and (11)

$$I_{L1}=\left(1+\frac{D}{1-D}\right)\frac{1}{D}\frac{V_{C1}}{R}=\frac{1}{D(1-D)}\frac{V_{C1}}{R} \qquad (14)$$

$$I_{L2}=\left(1+\frac{1-D}{D}\right)\frac{1}{1-D}\frac{V_{C2}}{R}=\frac{1}{D(1-D)}\frac{V_{C2}}{R} \qquad (15)$$

IV. DSPIC30F4011MICROCONTROLLER

In this prototype DSPIC30F4011 microcontroller is used for setting switching frequency for the switches. The DSPIC30F family encompasses a wide range of performance requirements, making it an ideal architecture for anyone considering a 16-bit digital signal processor (DSP), or even a 32-bit DSP. The devices were designed to provide a familiar look and feel to DSP users. The DSP features were seamlessly integrated to ease adoption by new users of DSP technology. Moreover, the pricing structure of dsPIC30F devices makes them affordable for embedded control applications.

The DSPIC30F devices were architected from the grounds-up to provide all the features a user. A rich instruction set, coupled with extensive addressing modes, operate on a generous set of general purpose working registers and a software stack. The result is very good C compiler efficiency. All the devices use Flash memory technology for its Program Memory and Data EEPROM, in order to provide maximum manufacturing cycle time flexibility. Fast, in-circuit self-programming technology enables remote updating of Program Memory and Data EEPROM. The high reliability of the Flash memory enables 40 years of data retention and up to one million program or erase cycles at 85 degrees Centigrade. Competitive DSP performance is enabled by a powerful set of DSP features. A single-cycle 17-by-17 Multiplier; two 40-bit accumulators and a 40-bit barrel shifter; zero overhead Do and Repeat loops; rounding or saturation of results; and special addressing mode support for circular buffers and FFTs. The DSPIC30F4011 architecture also supports a very flexible interrupt processing structure. Each device includes an extensive set of peripheral modules, including timers, serial subsystems, and analog to digital converter channels. Some devices also contain advanced peripherals geared towards specific applications like motor control, audio, or internet connectivity. Last but by no means the least, the devices contain hardware logic that enables in-circuit debugging and Flash programming without removing the device from the board.

Table no.1 Operating parameters of DSPIC30F4011

Operating speed at 5V	30 MIPS
VDD	2.5 to 5.5V
Temperature	-40ºC to 125ºC
Program memory	Flash
Data memory	SRAM, EEPROM
Analog	10-bit & 12-bit precision

DSPIC30F4011 is used in this prototype for generating PWM signals at 30 kHz for switches. Table no.1 shows operating parameters for DSPIC30F4011 microcontroller.

V. EXPERIMENTAL RESULTS

The converter proposed herein was prototyped in the laboratory in order to validate its principle of operation and the results are first simulated in MATLAB-2013a as shown in figure (2), figure 2(a) shows the simulated circuit and 2(b) represents its simulation results, in which current ripples are cancelled at 70% Duty cycle and thus high voltage gain. The topology in Fig. 1(a) was implemented in hardware, as shown by the photograph in Fig.3. In which key parameters used are tabulated in table no. 2.

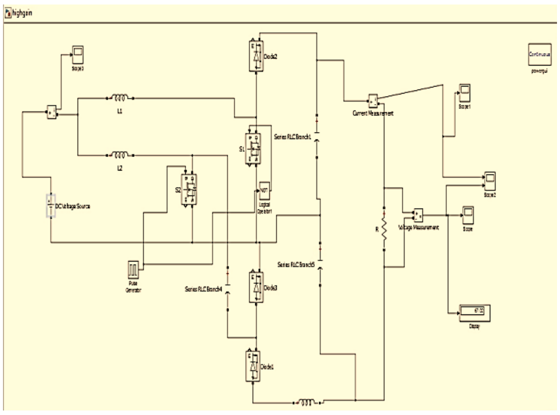

Figure 2(a): Simulink model of the converter.

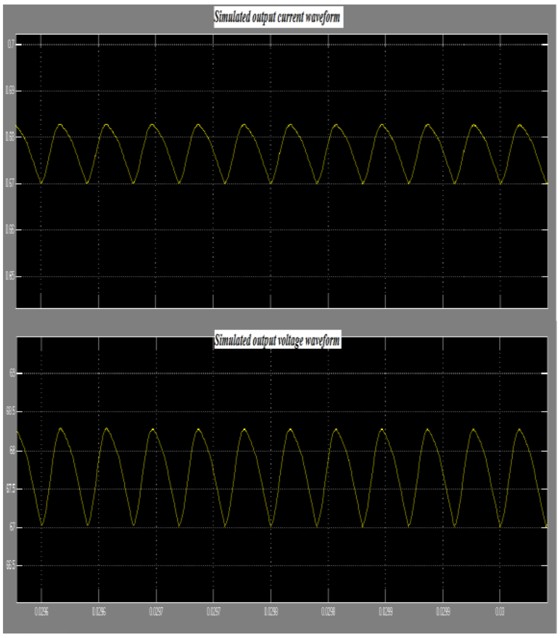

Figure 2(b): Simulated results.

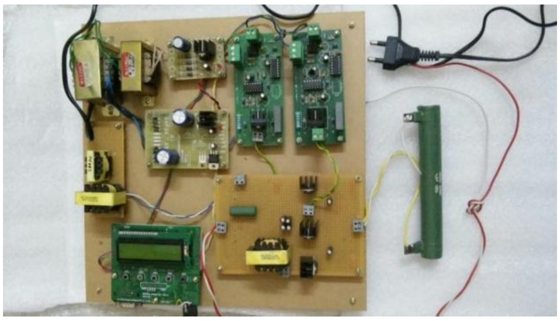

Figure 3: Prototype of High gain boost converter.

Table no.2: key parameters used in the prototype

Parameter	Value
Input voltage	12V
Duty cycle	70%
Output voltage	48V
L_1	140 μH
L_2	330 μH
C_1,C_2,C_3	10μF
MOSFETs	IRF250
Diodes	BYQ28E
Fs	25kHz

VI. CONCLUSION

This project proposes a boost dc- dc converter topology with novel capability of cancelling the input current ripple at an arbitrarily preselected duty cycle. This is accomplished without increasing the count of the number of components in contrast to other solutions available in the literature. In addition, the converter features a high voltage gain without utilizing extreme values of duty cycle or boosting transformers. These features make the converter ideal to process electric power coming from low-voltage power-generating sources, such as renewables.

REFERENCES

1) Julio Cesar Rosas ,Fernando mancilla, David jonathancarlos Mayo-maldonado, Johan migues,Ganzalez-Lopez,HildaLizethtarres -Espinosa and Elias Valdez –Resendiz- "A Transformerless High-gain boost converter with input current Ripple cancellation at a selectable duty cycle", IEEE Transaction on Industrial Electronics, vol.60 no.10 October 2013 .
2) Ching Shan lou, Pin yu Huang, Ming huide-"A Novel Dual Inductor boost converter with ripple cancellation for High Voltage Gain Applications ",IEEE transactions Industrial Electronics, Vol.58 NO.4, April 2011.
3) Lung –Sheng Yeng, Tsorng-JuuLiong ,Haucheng lee and Jiann –Fuhchen- " Novel High Step Up dc-dc converter with coupled inductor and voltage doubler circuits", IEEE Transaction on Industrial Electronics,Vol.58 No.09, September 2011
4) Jain Hsieng lee, Tsorng –Juuliang ,Jiann –Fuhchen- " Isolated Coupled Inductor Integrated DC–DC Converter with Non-Dissipative Snubber for Solar Energy Applications", Journal paper based on IEEE 2013
5) Abbas A Fordoun, Esam H. Ismail- "Ultra Step up dc-dc converters with Reduced Switch Stress", IEEE transactions on Industry Applications Vol.46,No.5October 2010
6) Shih-Ming chen , Tsorng –Juu Liang , Lung-Sheng yang and Jiam –Fuhchen -" A Cascaded High step up dc-dc converter with single switch for micro source applications" ,IEEE Transaction on Industrial Electronics, vol.26 no.4 October 2011
7) Nedmohan Tore M .undeland William P.Robbins, Power electronics converter ,applications and design ,(Wiley india (P) Ltd,third edition ,2008) 172-178