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Review on High Gain DC/DC converters for Renewable Energy Applications and their comparison with proposed converter

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ABSTRACT

Conventional source are going to be exhaust in few years. So all our concentration is shifted over to the renewable sources. The output voltage from most renewable energy sources like photovoltaic, fuel cells or energy storage devices such as super capacitors and batteries deliver output voltage at very low ranges which are not useful for commercial usage. In order to make them to use we have to step up these levels to grid voltage level. So Boost converters are introduced to meet the above mentioned requirement. The boost converters, first of all stepped up voltage to sufficient level at which inversion of DC to AC can be performed. Overall performance of the renewable energy system is then affected by the efficiency of step-up DC/DC converters which are the key parts in the system power chain. This review is focused on comparison and discussion of different high efficiency step-up DC/DC converters. Different step-up topologies are compared with proposed high gain step up converter.

Key words: DC-DC converter, multiplier cell, high gain, duty cycle, switching frequency.

1. INTRODUCTION

Global energy consumption tends to grow continuously. To satisfy the demand for electric power against a background of the depletion of conventional, fossil resources the renewable energy sources are becoming more popular. According to the researches despite its fluctuating nature and weather dependency the capacity of renewable resources can satisfy overall global demand for energy. The international investments and R&D e orts are focused on reduction of Renewable energy production cost.

The conversion of the distributed energy sources like wind energy, fuel cell and photovoltaic's into the useful energy such as ac or dc power source increasing day by day in order to meet out the global energy requirement[1]. Earlier the environmental issues have accelerated the use of more efficient and energy saving technologies in renewable energy systems, here comes the importance of DC- DC converters. In the recent years, the high step up dc-dc converters are playing a vital role in DC-back up energy system for UPS, grid system, high intensity discharge lamp and automobile applications also. In many applications, high-efficiency, high-voltage step-up dc–dc converters are required as an interface between the available low voltage sources and he output loads, which are operated at much higher voltages [2]. In order to provide high output voltage, the classical boost converters are used, but these should operate at extreme duty cycle. The conventional boost converter can be advantageous for step-up applications that do not demand very high voltage gain, mainly due to the resulting low conduction loss and design simplicity. Theoretically, the boost converter static gain tends to be infinite when duty cycle also tends to unity. However, in practical terms, such gain is limited by the loss in the boost inductor due to its intrinsic resistance, leading to the necessity of accurate and high-cost drive circuitry for the active switch, mainly because great variations in the duty cycle will affect the output voltage directly. Because of high gain, the rectifier diode must sustain a short pulse current with high amplitude [3]. This results in severe reverse recovery as well as high stress on switching devices. Using extreme duty cycle may also lead to poor dynamic responses to line and load variations. Moreover, the input current in these high step up applications is usually large, but low-voltage-rated MOSFETs with small $R_{DS}(ON)$ may not be selected since voltage rating of the switch is the same as the high output voltage in the boost converter [4].

High step-up converters with coupled inductors can provide high output voltage without using extreme duty cycle and yet reduce the switch voltage stress. The reverse recovery problem associated with rectifier diodes is also alleviated [5-7]. However, they suffer from losses associated with leakage energy of the coupled inductor. Also, most of the converters with a coupling inductor have large input current ripple due to operation of the coupling inductor [8].

The switched-capacitor converter does not employ any inductor making it feasible to achieve high power density. However, the efficiency could be reduced to perform output voltage regulation. The switched capacitor circuit is integrated within a boost converter to achieve output voltage regulation without decreasing efficiency, but the numbers of components are high, and input current ripple is considerable [9-10]. Single-switch topologies based on the switched-

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capacitor circuit and switched-capacitor/switched-inductor hybrid structure exhibit continuous input current and reduced switch and diode voltage stresses [11-12]. A major drawback of theses topologies is that attainable voltage gain and power level without degrading system performances are restricted. An effective way of extending these schemes to achieve higher voltage gain or power level has not been discussed.

A single-switch converter with multiplier cells was proposed to attain high output voltage by adding multiplier cells, but current stress of the switch is nontrivial to get higher power [13]. It has been demonstrated that the interleaved technique provides advantages of handling high current and reducing passive component size. An interleaved converter with voltage doubler characteristic can have low input current ripple and reduced switch current stresses due to interleaved operation. An interleaved converter with voltage multiplier cells has been proposed to provide higher voltage gain[14-15]. In summary, preferable features of the high step-up DC-DC converter are low input current ripple, reduced volume and weight, low component voltage and current stresses and extendibility.

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2. DIFFERENT DC-DC BOOST CONVERTERS

2.1 Conventional boost converters

A boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

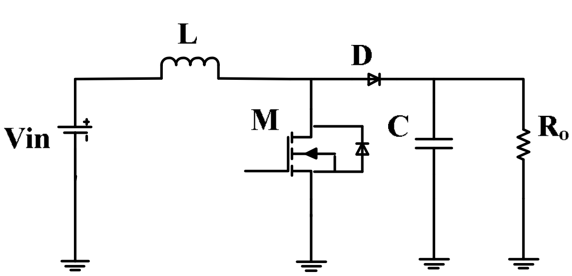

Figure 1. Conventional step-up converter

Voltage gain of this converter

$$M=\frac{1}{1-D}$$

Where D is duty ratio.

Step-up conversion with high efficiency because of the resistances of elements or leakage inductance. Thus, the coupled inductor converters were proposed. The single phase single switch boost converter is a basic step-up topology. The voltage gain theoretically is infinite when duty cycle reaches 1. But switch turn on period becomes long as the duty cycle (D) increases causing conduction losses to increase [16]. The power rating of single switch boost converter is limited to switch rating. In order to obtain higher gain several boost converters can be cascaded at the expense of efficiency decrease [17]. Interleaved parallel topology is the solution to increase the power and reduce input current ripple allowing lower power rated switches to be used. Theoretically, conventional step-up converters, such as the boost converter and fly back converter, cannot achieve a high step-up conversion with high efficiency because of the resistances of elements or leakage inductance. Thus, the coupled inductor converters were proposed.

2.2 Coupled inductor step up converter:

Coupled inductor can serve as a transformer to enlarge the voltage gain in non isolated DC/DC converters in proportion to winding turns ratio (Fig. 2). These converters can easily achieve high voltage gain using low R_{DS}–ON switches working at relatively low level of voltage [18]. The switch driving scheme is simple as the converter usually utilizes single switch. Common mode conducted EMI is reduced due to balanced switching. To reduce passive component size coupled inductors can be integrated into single magnetic core.

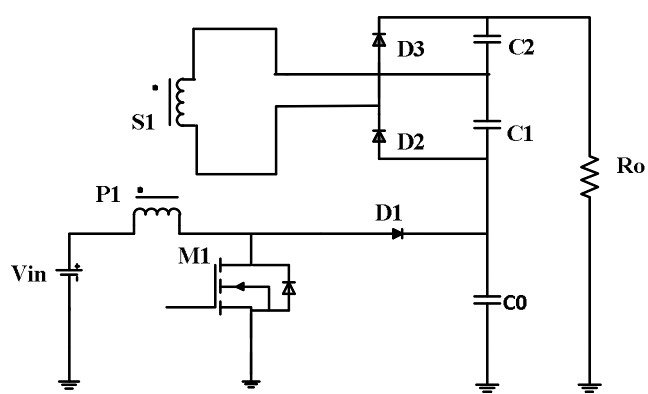

Figure 2. High gain step up converter with coupled inductor.

The normal boost converter topologies are not able to step up those voltages at low levels to the utility level high voltages. So the coupled-inductor boost converter came into picture. Coupled inductor step up converter is going to be a good solution to the previously discussed problems of the conventional boost converter. This is because the turn's ratio of the primary inductor ($L1$) to the secondary inductor ($L2$) of the coupled inductor can be effectively used to reduce the duty ratio and the voltage stress of the switch [19].

1) The converter is characterized by a low input current

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ripple and low conduction losses, making it suitable for high power applications.
2) The converter achieves the high step-up voltage gain that renewable energy systems require;
3) Leakage energy is recycled and sent to the output terminal, and alleviates large voltage spikes on the main switch.
4) The main switch voltage stress of the converter is substantially lower than that of the output voltage.

Coupled inductor topologies also have some disadvantages like they have the leakage components that cause stress and loss of energy that results in low efficiency**.** So to reduce the voltage stress of the primary side active switches and secondary-side output rectifier diodes, a new voltage-multiplier circuit is integrated into the proposed coupled boost topology.

2.3 Conventional boost converters with voltage multipliers

Multilevel converters have attracted interest in power conversion; they already are a very important alternative in high power applications. It has been shown that they are useful in virtually all power conversion processes such as ac-dc, dc-ac, dc-dc and ac-dc-ac. The DC-DC multi-level boost converter (MBC) which consists of a conventional boost converter with several voltage multiplier stages is presented. The number of levels can be increased by adding two capacitors and two diodes per extra level, thereby making it convenient for modular implementation [22].
The power circuit diagram of the 3-level multi-level boost converter is shown in Figure 3. Switch S,Inductor L, diode D1 and Co form the conventional boost converter stage. The output from the capacitor Co is considered as first level. Diodes D2, D3 and capacitors C2, C3 form the first VMC stage or the second output voltage level 2Vc.

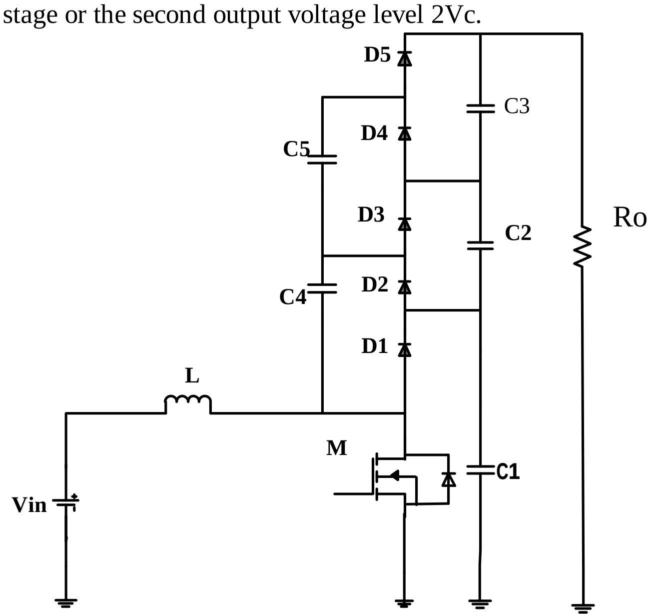

Figure 3 High gain step up converter with voltage multiplier.

Proceeding in a similar manner, it can be observed that diodes D4,D5 and C4,C5 form the third stages. The corresponding output voltage levels are obtained across capacitors C1, C2 and C3. In general, for an N-level converter, appropriate numbers of the diode capacitor combinations have to be used.
For an N-level multilevel boost converter, the voltage gain is given by

$$M = \frac{N}{1-D}$$

; where N indicate the level& D is duty ratio.

2.4 Coupled inductor with voltage multiplier

The power circuit diagram depicted in fig.5 is a conventional Boost converter which employs a coupled inductor and switched capacitor function to achieve higher output voltage. The circuit shows a 3-level multi-level boost converter with coupled inductor
The DC-DC converter using coupled inductor and switched capacitor is presented. This combines the boost converter, the coupled inductor and switched capacitor function to provide the require output voltage at the desired power level is proposed [23]. The proposed topology is a single switch design, employing one coupled inductor and (2N-1) capacitors and (2N-1) diodes for an N stage voltage multiplier. The output voltage can be further increase by adding more voltage doublers stages. The main advantages of this topology are (i) High gain without transformers; (ii) single switch topology; (iii) Continuous input current;(iv) Easily expanded to give higher gain. The operating principle along with the design details and simulation results are presented in the following sections.

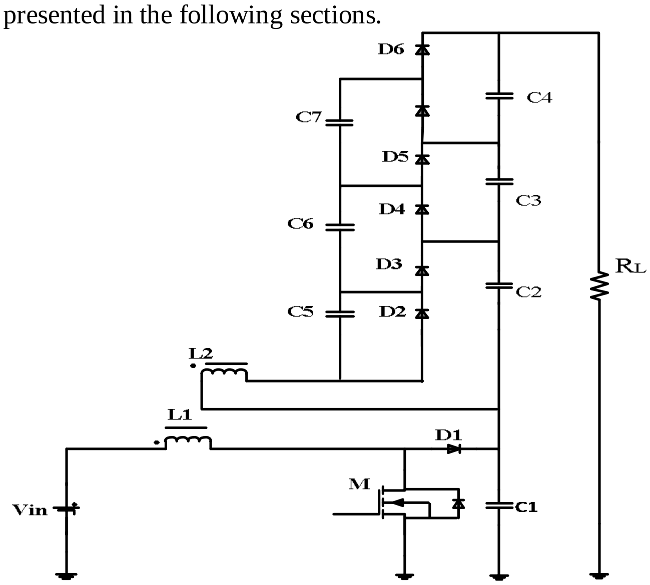

Figure 4. High gain coupled inductor boost converter with voltage multiplier.

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Voltagegain of this step up converter is

$$M = \frac{N}{1-D} + \sqrt{\frac{L2}{L1}}$$

Where
L1=Primary inductance
L2=Secondary inductance
It is proposed to operate at a duty cycle of 0.6 with 3 levels and a turns-ratio of 1. This provides ample turn off time for the power device and avoids excessive voltage stresses and flexibility to obtain additional gain if required.

2.5. Interleaved Boost Converter

The conventional interleaved boost converter is widely employed for the front-end applications. Unfortunately, it is not suitable for high step-up system due to its disadvantages of extreme duty cycle, large current ripple, high switch voltage stress and severe output diode reverse-recovery problem.

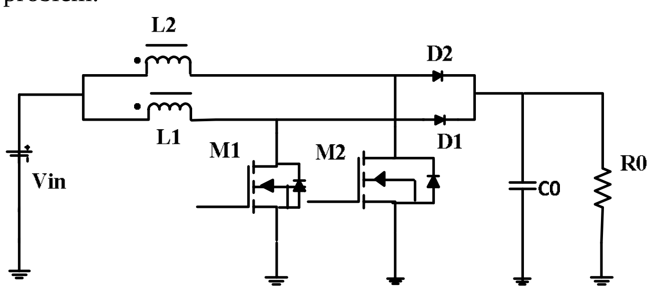

Figure 5. Interleaved boost converter.

For the above mentioned high step up coupled inductor boost converter if we add an interleaved structure it will further improves its efficiency. Interleaved boost converter is one such converter that can be used for these applications [20]. The Interleaved boost converter has high voltage step up, reduced voltage ripple at the output, low switching loss, reduced electromagnetic interference and faster transient response. Also, the steady-state voltage ripples at the output capacitors of mc are reduced. Though IBC topology has more inductors increasing the complexity of the converter compared to the conventional boost converter it is preferred because of the low ripple content in the input and output sides [21].

The advantages of the proposed converter are as follows:
1) The converter is characterized by a low input current ripple and low conduction losses, making it suitable for high power applications;
2) The converter achieves the high step-up voltage gain that renewable energy systems require;
3) Leakage energy is recycled and sent to the output terminal, and alleviates large voltage spikes on the main switch;
4) The main switch voltage stress of the converter is substantially lower than that of the output voltage;
5) Low cost and high efficiency are achieved by the low on state resistance and low voltage rating of the power switching device

2.6. Proposed High voltage gain interleaved boost converter with voltage multiplier cell

Proposed boost converter is combination of the above mentioned interleaved converter (2.5) and converter with voltage multiplier (2.3). It has two coupled inductors, two switches which are driven 180° out of phase.Voltage multiplier module are stacked on a boost converter to form an asymmetrical interleaved structure. Primary windings of the coupled inductors with N_p turns are employed to reduce current through each primary by connecting them in parallel, decrease input current ripple. Secondary windings of the coupled inductors with N_s turns are connected in series to extend voltage gain. The turn's ratios of the coupled inductors are the same and it is considered as 1:1.

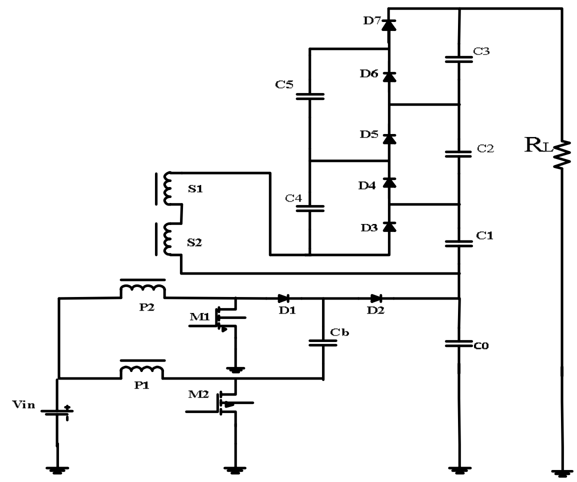

Figure 6. Proposed interleaved coupled inductor boost converter with voltage multiplier

gain of this converter

$$M = \frac{N*n+2}{1-D}$$

Simulation output of the proposed circuit is as shown in figure below

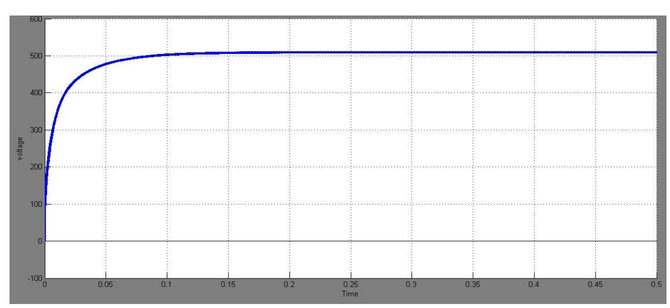

Figure 7. Simulation output of proposed converter

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The advantages of the proposed converter are as follows:
1) The converter is characterized by a low input current ripple and low conduction losses, making it suitable for high power applications;
2) The converter achieves the high step-up voltage gain that required for renewable energy systems to connect with grid;
3) Leakage energy is recycled and sent to the output terminal. and alleviates large voltage spikes on the main switch;

3. COMPARISON OF THE ABOVE MENTIONED CONVERTERS

Vin=40V,Turns ratio (n)=1, No of multiplier cells(N) =3, Duty ratio=0.6				
S.No	**Type of converter**	**Gain of the converter(M)**	**Gain for Above values (M)**	**V_o=M*V_{in}**
1	Conventional boost converter	$\frac{1}{1-D}$	2.5	100
2	Conventional boost converter With voltage multiplier cell	$\frac{N}{1-D}$	7.5	300
3	Coupled inductor boost converter with voltage multiplier cell	$\left(\frac{1}{1-D}+\sqrt{\frac{L2}{L1}}\right)*N$	10.5	420
4	High gain Interleaved coupled inductor boost converters with multiplier cell (proposed)	$\frac{N*n+2}{1-D}$	12.5	500

Table 1.comparison of the different converters

Comparison of the above mentioned converters is given in the below Table.1. The output voltage of the each converter is calculated based on the considered values. The input voltage of the converters is considered as 40V,the turns ratio of the coupled inductor(n) is considered as 1:1 (in S.No 3,4),the no of multiplier stages in the converters (N) is considered as 3(S.No 2,3,4). Based on these obtained output voltage values in the of the converters the proposed converter circuit is giving very high gain

4. SUMMARY

Different step-up DC/DC topologies have been presented in the review. However the solution chosen by the designer depends on particular design constraints there is a need to determine the most robust and best performance topology. High efficiency of step-up DC/DC converters can be achieved by decreasing duty cycle (lower conduction losses) and reducing voltage stress on switches (cheaper and lower RDS–on switches) applying soft switching technique minimizing switching losses) and utilizing active clamp circuits(recycling the energy stored in parasitic inductances).

The proposed converter employs 3 stages in conjunction with the interleaved boost converter which is operated at a duty cycle of 0.6.the input voltage of 40V is step up to 500V,A high voltage gain obtained without causing excessive device voltage and current stresses but there is a limitation that we cannot use multiplier cell with very high multiplier index which causes very low output current. The converter is proposed to be used in applications with renewable sources in conjunction with multilevel inverters such as those found in distributed generations systems

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