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Original Research Paper

Engineering

HIGH GAIN STEP UP CONVERTER FOR DC MICROGRIDS

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ABSTRACT A non-isolated high gain dc-dc converter without using voltage multiplier cell (VMC) and/or hybrid switched capacitor technique for renewable energy DC microgrids is presented in this paper. Direct current microgrids are characterized by the use of intermediate DC-DC converter, which acts as power conditioning units. Hence, the choice of an appropriate DC-DC converter becomes significant as the overall system efficiency is strongly dependent on the converter's performance. For any converter that uses single duty ratio, operation of extreme duty ratio is not reliable. In the proposed converter, the inclusion of the third switch and operation of three switches with two different moderate duty ratios to achieve high voltage gain are the main advantages. The converter design and steady state performance comparison with the conventional boost converter have been discussed in detail with supporting simulation results in PSIM software.

KEYWORDS : DC microgrids, high gain converter, non-isolated converter, voltage stress on switch

INTRODUCTION

Three phase AC power systems have existed for over many years due to their efficient transformation of ac power at different voltage levels and over long distance as well as the inherent characteristic from fossil energy driven rotating machines. Recently more renewable power conversion systems are connected in low voltage ac distribution systems as distributed generators or ac micro grids due to environmental issues caused by conventional fossil fueled power plants.

DC power generators produce low output voltage and hence require high efficient high gain DC-DC converters to meet the DC load requirements. Nowadays, high gain DC-DC converters are used in many applications other than the renewable energy conversion, such as battery backup systems for uninterrupted power supplies, high intensity discharge lamp ballasts for automobile headlamps, electric tractions and some medical equipment.

In the recent past, conventional DC-DC boost converters were used to step up the voltage. However, the voltage stress on the switch is equal to the output voltage. Therefore, switches were highly rated to meet the voltage stress on the switch which leads to conduction loss. The selection of large duty ratios causes diode reverse recovery problems.

The problem associated with the various isolated dc-dc converter topologies is the transformer core saturation. Therefore, non-isolated converters where galvanic isolation is not needed can be used for high gain applications with reduced size and cost. Some of the non-isolated high gain converters are cascade boost, the quadratic boost, voltage lift, the capacitor-diode voltage multiplier and the conventional boost converter integrated with switched-capacitor techniques. The inclusion of switched capacitor or a switched-inductor stage increases the cost and complexity of the circuit.

For the coupled inductor based boost converter topologies, input filters are needed to reduce current ripple. In this paper, a novel high gain DC-DC converter is developed to overcome the issues mentioned above.

A non-isolated high gain dc–dc converter is proposed without using voltage multiplier cell (VMC) and/or hybrid switched capacitor technique. The proposed topology utilizes two non-isolated inductors that are connected in series/parallel during discharging/charging mode. The operation of switches with two different duty ratios is the main advantage of the converter to achieve high voltage gain without using extreme duty ratio. The proposed converter has high voltage gain by selecting appropriate duty cycle for the three switches and by designing proper inductor and capacitor values.

PROPOSED NON-ISOLATED HIGH GAIN DC-DC CONVERTER

The proposed converter consists of three active switches S_1, S_2 and S_3, two inductors L_1 and L_2, two diodes D_1 and D_2 and one output capacitor C_O. The switches operate at a switching frequency of *fs*. The duty ratio of the switches S_1 and S_2 is D_1 and the third switch S_3 is D_2.

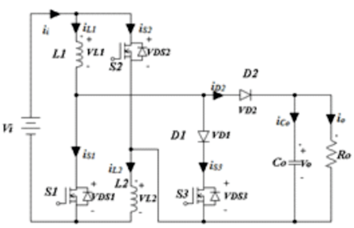

Figure 1: Proposed high gain converter

Some assumptions are being made for steady state operation of the converter: (i) All the components in the circuit are ideal. The effects of ON state resistance of the switches, forward voltage drop of the diodes, equivalent series resistance of the inductors and capacitors are neglected. (ii) The output capacitance Co is sufficiently large to maintain constant output voltage.

Let the number of turns in the two inductors is equal, so that

$L_1 = L_2 = L$

MODES OF OPERATION

There are three modes of operation for a single switching period with two different duty ratios.

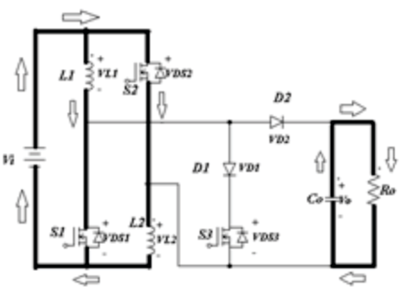

Figure 2. Mode I operation

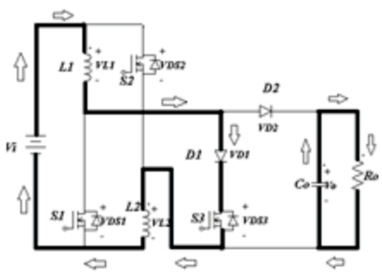

Figure 3. Mode II operation

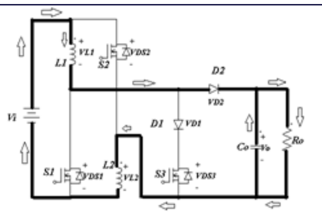

Figure 4. Mode III operation

Mode I: During the first time interval, S_1 and S_2 are turned ON and S_3 is turned OFF. The conduction voltage of the internal diode of S_3 appears across switch when it is turned *OFF*. Voltage across inductors are given as:

$$V_{L1} = V_{L2} = V_i$$

$$\frac{di_L}{dt} = \frac{Vi}{L}$$

Mode II: S_1 and S_2 are turned *OFF* and S_3 is turned *ON* for the next interval. In this mode, the voltage across the switch S_1 and S_2 is half of the input voltage. Voltage across inductors are given as:

$$i_{L1} = i_{L2} = i_L$$

$$V_{L1} + V_{L2} = V_i$$

$$\frac{di_L}{dt} = \frac{Vi}{2L}$$

Mode III: S_1, S_2 and S_3 are turned *OFF* for the next interval. The voltage across the switches S_1 and S_2 is the average of the input and output voltages, whereas, the voltage across switch S_3 is the addition of input and output voltages. Voltage across inductors are given as:

$$i_{L1} = i_{L2} = i_L$$

$$V_{L1} + V_{L2} = V_i - V_O$$

$$\frac{di_L}{dt} = \frac{Vi - Vo}{2L}$$

Using state space averaging method, the voltage gain is obtained as:

$$\frac{Vo}{Vi} = \frac{(1 + D1)}{(1 - D1 - D2)}$$

The critical value of the inductance to operate the proposed converter in CCM is obtained as:

$$L_{critical} = \frac{V_i\, D_1}{\Delta i_L\, f_s}$$

The value of capacitor is obtained as:

$$C_{critical} = \frac{P_O}{V_O \Delta V_C f_s}$$

PERFORMANCE COMPARISON

The proposed converter is compared with classical boost converter in terms of usage of components, voltage gain, voltage stress on the switches and diodes. The addition of switch S3 which is operating at the duty ratio of D2 increases the voltage gain of the proposed converter.

TABLE 1 PERFORMANCE COMPARISON

Parameters	Proposed Converter	Conventional Boost Converter
Voltage gain	$\frac{(1+D1)}{(1-D1-D2)}$	$\frac{1}{1-D}$
Voltage stress on switches	$V_{DS1} = V_{DS2} = \frac{Vo+Vi}{2}$ $V_{DS3} = Vo$	V_O
Voltage stress on diodes	$V_{D1} = V_i$ $V_{D2} = V_i + V_O$	V_O
No. of mosfets	3	1
No. of diodes	2	1
No. of inductors	2	1
No. of capacitors	1	1

The voltage gain corresponding to different duty ratios is plotted for the proposed converter in Figure 5. It is seen that the proposed converter is capable of providing high voltage gain by varying the duty ratios to the switches appropriately.

It is observed that the proposed converter provides a high voltage gain of 32 for the duty ratio of *D1*=0.6 and *D2*=0.35. However, for the same duty ratio of 0.6, the conventional boost converter provides a voltage gain of 2.5 respectively.

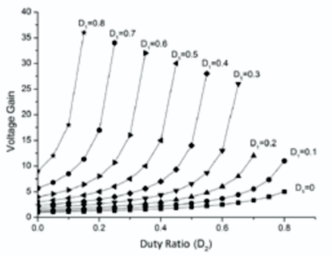

Figure 5: Voltage gain corresponding to variations in duty ratio D1 and D2 for the proposed converter

SIMULATION RESULTS AND DISCUSSIONS

The simulation of the proposed converter and conventional boost converter is done in PSIM software. The simulation is done with the specifications shown in Table 2.

TABLE 2 SPECIFICATIONS

Parameters	Values(Unit)
Rated Power(P_o)	100W
Input Voltage(V_i)	20V
Duty Ratio(D_1)	0.5
Duty Ratio(D_2)	0.35
Switching frequency(f_{sw})	50kHz
Inductors	360mH
Capacitor	100mF

The conventional boost converter is simulated with input voltage Vi=20V and duty ratio of 0.5 at switching frequency of 50kHz. The output voltage is observed to be 40V with a voltage gain of 2 as shown in Figure 6.

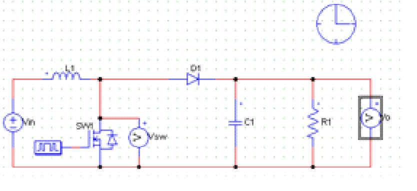

Figure 6. Simulation diagram for conventional boost converter

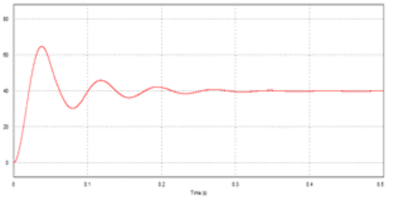

Figure 7: Output voltage of conventional boost converter

Figure 8 and 9 shows that the voltage stress on the switches and diode is found to be as high as output voltage i.e. 40V in this case.

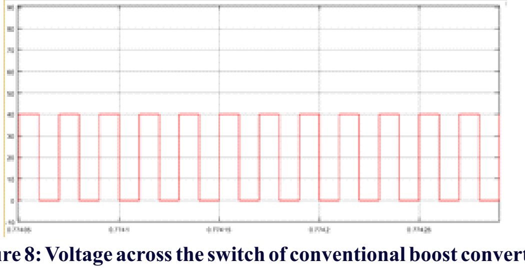

Figure 8: Voltage across the switch of conventional boost converter

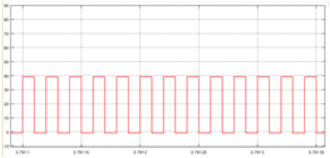

Figure 9: Voltage across the diode of the conventional converter

The proposed converter is simulated with same input voltage Vi=20V and duty ratios of 0.5 and 0.35 at 50kHz switching frequency.

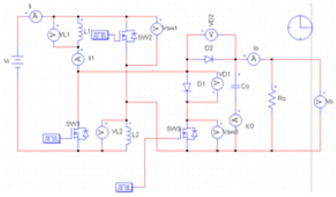

Figure 10: Simulation diagram for proposed converter

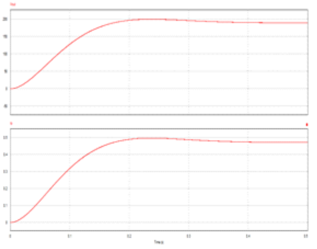

Figure 11: Output voltage and current of the proposed converter

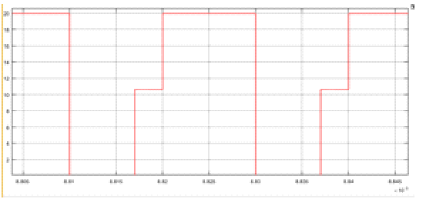

Figure 13: Voltage stress across the diode of the proposed converter

Figure 11 shows the output voltage and current waveform for the proposed converter. It can be seen that a voltage gain of 9.6 with a ripple voltage of 2% is observed when the input is 20V. The output current waveform $i_{o.}$ It is observed that the output current is approximately 5mA. Figure 12 and 13 shows the switch and diode voltage stresses. It is observed that the voltage stress on switches S_1 and S_2 is the average of the input and output voltages. Whereas, the voltage stress on switch S_3 is equal to the output voltage.

CONCLUSION

For any converter that uses single duty ratio D, the extreme duty ratio operation is not reliable but the proposed converter has high voltage gain by selecting appropriate duty cycle for the three switches and by designing proper inductor and capacitor values. It has the advantage of higher voltage gain compared to the conventional boost converter without VMC and/or hybrid switched capacitor techniques or additional clamping circuits; It is also characterized with reduced voltage stress on the diodes and switches based on the percentage output voltage. To regulate the output voltage variation, closed loop control strategy is to be implemented which makes the converter suitable for microgrid applications.

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