International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 02, February-2015

A High Gain Non-Isolated DC - DC Converter with Low Voltage Stress

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***Abstract*—A non-isolated DC-DC boost converter with LCC resonant converter is presented here. The switches of the converter experiences lower voltage stress comparing with other topologies. The modular approach of the converter allows connection of multiple units to achieve larger voltage and power levels. The resulting converter will have larger voltage gain. The converter founds its application in medium voltage applications such as medium voltage dc grids. Simulation of the converter is presented. The results of the simulation are discussed in comparison with single unit and multi unit of the proposed converter. The effectiveness of the converter is justified based on the results of comparison.**

Keywords—DC-DC converters, mvdc grids.

1. INTRODUCTION

The DC power technology has been focused mainly on high-voltage DC for transmission systems. DC distribution grids have a wide scope in telecommunication, aircraft and navy ship boards.

One of the major requirements of dc grids is a dc-dc converter with a high stepping conversion ratios [1]. Normally the boost converters can provide a voltage gain in between 2 to 4. Basically the flyback or forward converters are used to provide high voltage gains, but the major dis-advantage is that they employ an A.C transformer which increases the weight of the converter circuit and due to inclusion of a transformer results in poor voltage transformation ratios [2], because of the issues like poor coupling, dielectric insulation and core losses.

To overcome the above issue of transformer a non-isolated i.e. transformerless dc-dc converter is designed. One of the recent trends of achieving high voltage boost is by using of switched capacitor modules without using of transformers is proposed. But to achieve a voltage gain of 10 it approximately requires nine capacitor modules, and over 18 switches are required [4]. This results in increased switching losses and gating of 18 switches will be a practical constraint.

This paper proposes a non-isolated dc-dc converter with high voltage conversion ratio. This converter is modular, so it allows for multiunit connection for higher voltage and power levels.

II. THE PROPOSED CONVERTER

The circuit diagram of the non-isolated dc-dc converter is shown in fig1. It comprises of two power switches (IGBT), one boost inductor (L_b), two output capacitors (C_1& C_2), one LCC resonant circuit (L_r, C_{r1}, C_{r2}) ,and five diodes. Under steady state, the converter passes through eight operating stages in a switching cycle. The various stages of operation of the converter is discussed below with the corresponding equivalent circuit.

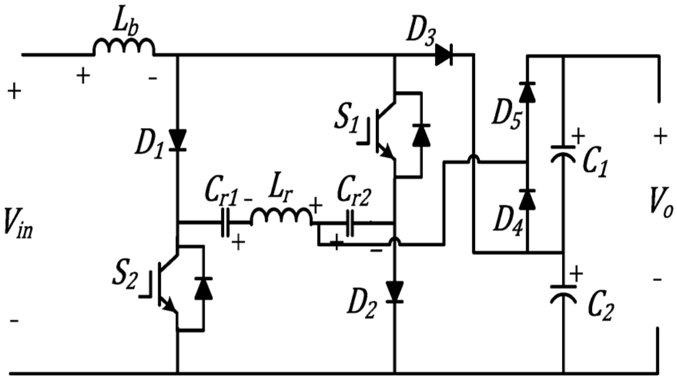

Fig1: Single unit converter

III. PRINCIPLE OF OPERATION

In a steady state the proposed converter goes through eight operating stages in a switching cycle,

Stage1:

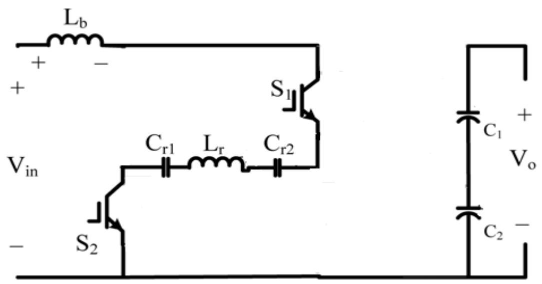

Fig 2: Stage 1

In this mode, both the switches of the proposed converter S_1 and S_2 are ON, and all the diodes are OFF. In this stage of operation, C_{r1} gets charged and C_{r2} gets discharged. Thus a series resonant circuit is formed in this stage of operation.

Stage 2:

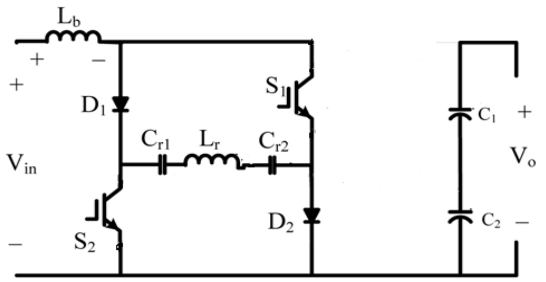

Fig 3: Stage2

In this mode, both its switches S_1 and S_2 and its diodes D_1, D_2 are ON and the remaining diodes D_3, D_4, D_5 are OFF. In this stage also C_{r2} gets discharged and the other resonant capacitor C_{r1} keeps on charging. This stage ends at the instant v_{cr2} drops to the resonant capacitor voltage V_{c2}.

Stage 3:

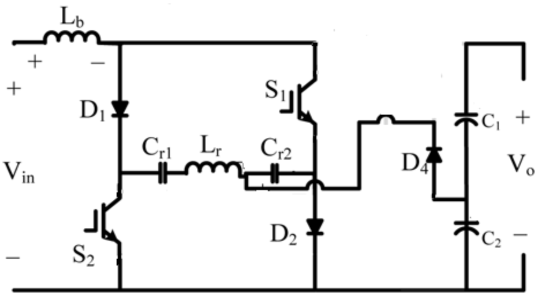

Fig 4: Stage3

In this mode , both the switches of the converter S_1 and S_2 and its diodes D_1, D_2 , D_4 are ON and diodes D_3, D_5 are OFF. In this stage also v_{cr2} remains at the value of V_{c2}.

Stage 4:

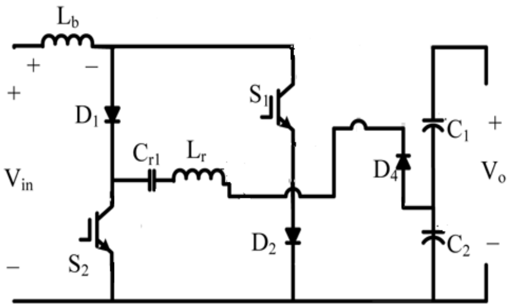

Fig 5: Stage4(a)

In this stage also the switches S_1 and S_2 and diodes D_1, D_2 , D_4 are ON and in this stage C_{r2} starts charging and C_{r1} starts discharging.

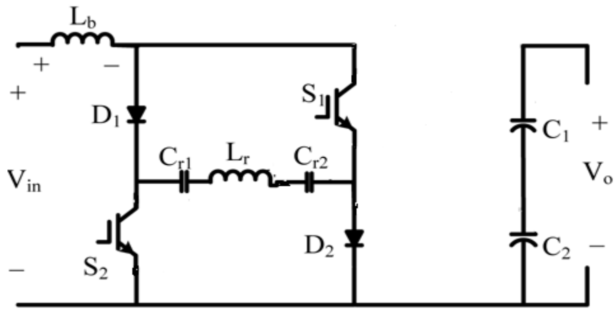

Fig 6: Stage 4(b)

When , the current through the resonant inductor i_{lr} goes negative, then at that instant diode D_4 is turned OFF.

Stage 5:

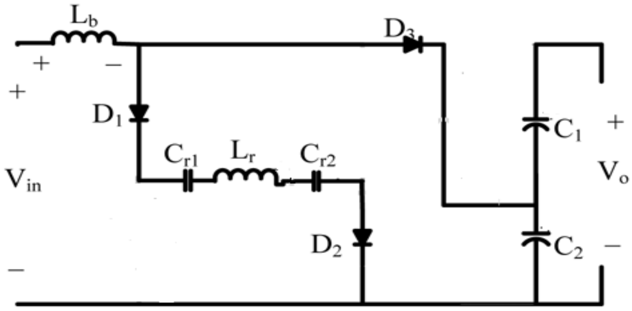

Fig 7: Stage 5

In this stage, the switches S_1 and S_2 and diodes D_4 and D_5 are OFF. The diodes D_1 and D_2 are ON. In this stage the energy stored in the boost inductor L_b is delivered to the series resonant circuit .

Stage 6:

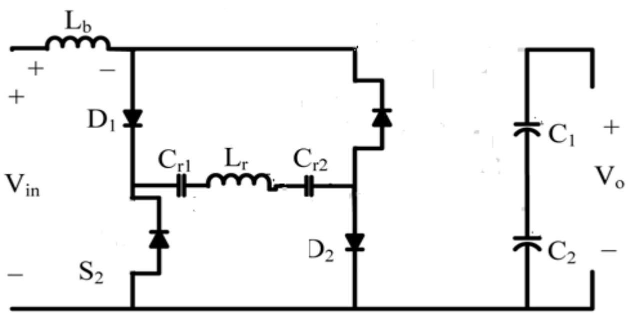

Fig 8: Stage 6

In this stage, the anti-parallel body diodes of the switches are turned ON .and the switches S_1 and S_2 and diodes D_3,D_4,D_5 are OFF.

Stage 7:

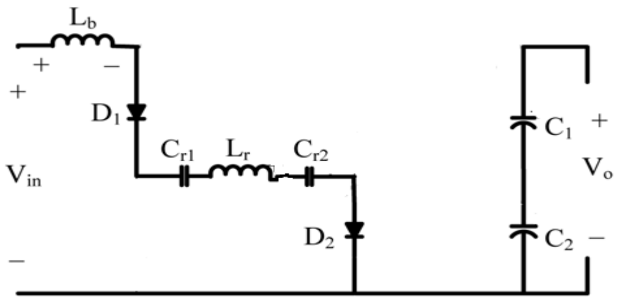

Fig 9: Stage 7

In this stage, the body diodes of the switches are OFF and the boost inductor continues to release the energy to the resonant circuit.

Stage 8:

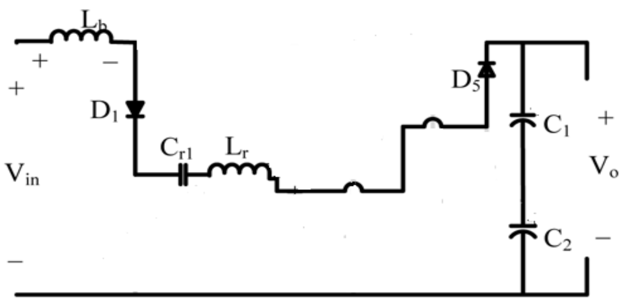

Fig 10: Stage 8

In this stage, the diodes D_1 and D_5 are ON. At the instant D_5 turned ON the voltage of C_{r2} is clamped to the output voltage.

Stage 9:

This stage exists when the converter is operating in the discontinous-current mode. At this instant the capacitors voltage V_{cr1} and V_{cr2} will not change.

The switches and diodes of this converter are subjected to low voltage stresses when compared to other converter topologies.

The main advantage of this converter is that only one gating signal is required i.e. for switching the two switches in synchronism with one another.

The output capacitances (C1, C2) of the proposed converter are taken considerably larger than the resonant converter capacitances (Cr1, Cr2).

The output voltages of the resonant circuit are of sinusoidal in shape.

IV. ANALYSIS, DESIGN AND PARAMETER SELECTION

The voltage gain of the proposed converter can be obtained by adding the gains of the boost and resonant converters. The voltage gain of this converter is controlled by the combination of both duty cycle and switching frequency.

For the selection of parameters let us assume that the boost and resonant converters can handle 40% and 50% of the total output power. Let us assume that the 40% and 60% of the total output voltage drops across the output capacitors of the boost and the resonant converter.

$$V_{c1}=0.6V_o$$

$$V_{c2}=0.4V_o$$

For an ordinary boost converter the input boost inductor Lb can be expressed as

$$L_b = \frac{R(1-d)^2 d}{2f_s}$$

Where, for the proposed converter the formulae for input boost inductor is modified as

$$L_b = \frac{R_L(1-d-t_1)^2(d-t_1)}{2f_s}$$

Where d is the duty cycle of the proposed converter, f_s is the switching frequency.

The formulae for the resonant converter is formulated as,

$$C_{r2} = \frac{P_{or,max}(V_{C1}-V_{in,r})}{4V_{in}V_{C1}^2 f_s}$$

Where Vc1 is the voltage across the output capacitor, where $P_{or,max}$ is the power that resonant converter handles.

The resonant inductor Lr can be formulated as,

$$L_r = \frac{V_{in,r}V_{C1}^2}{\pi^2 f_s P_{o,max,r}(V_{C1}-V_{in,r})}$$

The electrical stress on the switches and diodes in this converter is less when compared to other converter topologies and this can be formulated as,

$$V_{s1,s2}=V_{c2}$$

$$V_{d1}=V_{d2}=V_{c1}-V_{c2}$$

$$V_{d3max}=V_{c1}$$

$$V_{d4}=V_{d5}=V_{c1}$$

By the above formulas we can say that switch voltage stresses is less compared to other converter topologies.

V. MULTIUNIT OPERATION

The converter allows modular operation and hence multiple modules can be connected in series and parallel, when higher voltage and higher power levels are required. This multiunit approach increases the voltage gain of the power module.

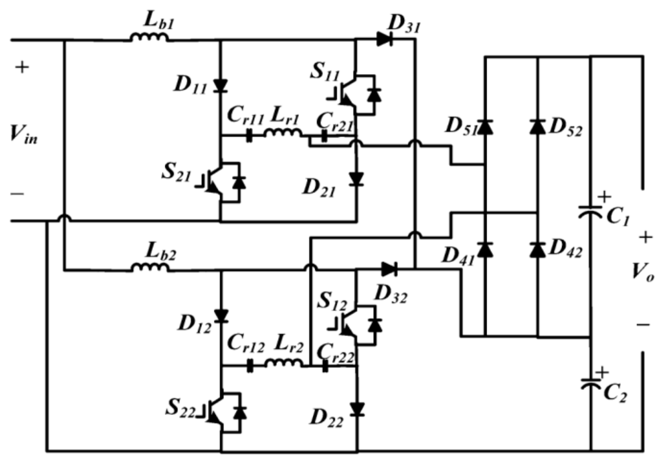

Fig 11: multiunit converter

In the above figure two multiunit converters are connected in cascade. These two units are identical and the units are operated from a single voltage source.

VI. SPECIFICATIONS

The specifications of the converter for single unit and two unit converter are given in table 1 and table 2 respectively. With these specifications, the converter was designed and implemented in Matlab / Simulink environment.

Table1: SINGLE UNIT CONVERTER

Input voltage	50v
Output voltage	500v
Switching frequency	5000Hz
Inductor(L_b)	240µH
Inductor(L_r)	330µH
Capacitor(C_{r1})	4.5µF
Capacitor(C_{r2})	3µF
Load	Resistive

Table 2: MULTIUNIT CONVERTER

Input voltage	50v
Output voltage	710v
Switching frequency	5000Hz
Inductor(L_b)	240µH
Inductor(L_r)	330µH
Capacitor(C_{r1})	4.5µF
Capacitor(C_{r2})	3µF
Load	Resistive

VII. SIMULATION RESULTS:

SINGLE UNIT CONVERTER

The proposed converter was simulated using the software package Matlab/Simulink. The Matlab circuit was shown in figure12. The results of simulation are shown in figure 13 to figure 15 for output voltage, voltage across the capacitor and switches respectively.

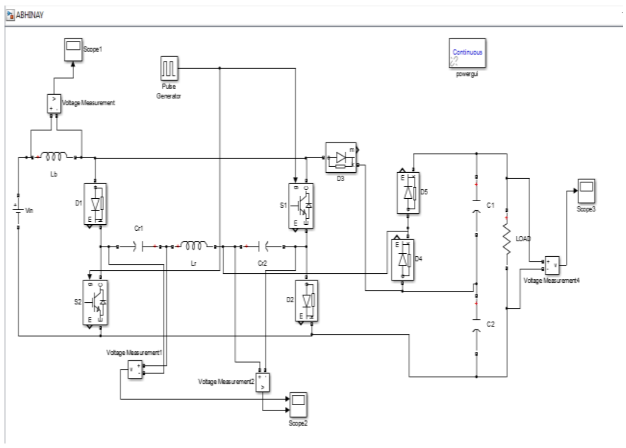

Fig 12: Simulation diagram of single unit converter

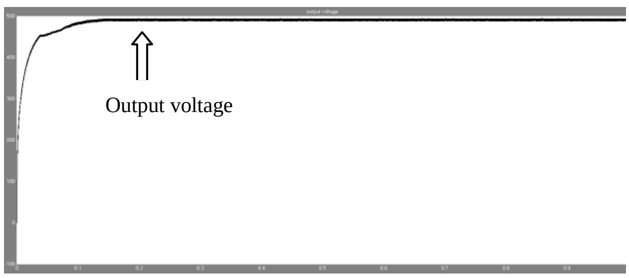

Fig 13: Output voltage waveform of single unit converter

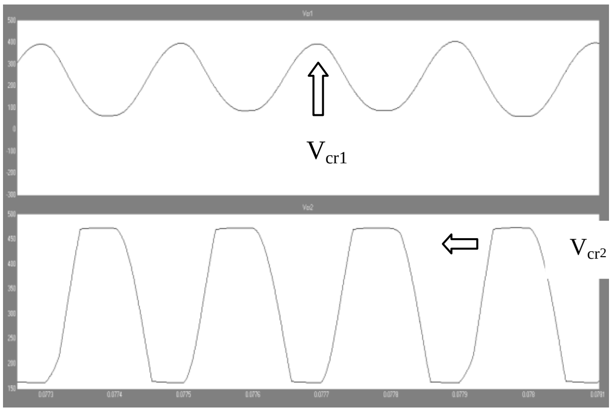

Fig 14: Voltage waveforms across resonant capacitors

From the figure 14, it is observed that the output voltages across resonant capacitors Cr1,Cr2 are sinusoids.

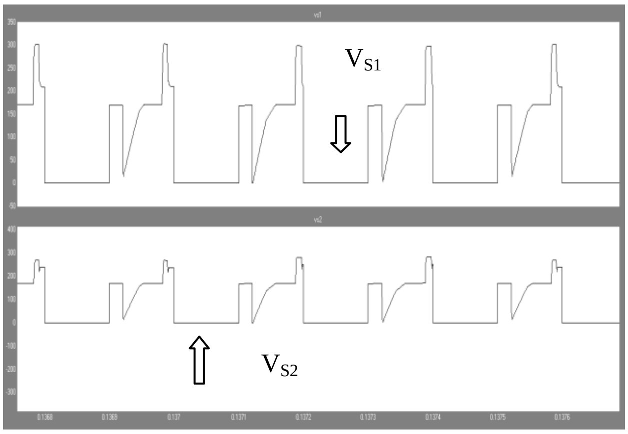

Fig15 : Output voltage waveform across switch S1,S2

From the above figure 15, it is clear that both the switches S_1 and S_2 are subjected to same voltage stress across them. The voltage stress across the switches is not subjected to the total output voltage, it is subjected to the voltage that is across the output of the resonant capacitor.

MULTIUNIT CONVERTER

The multi-unit converter comprising of two stages was simulated using the software package Matlab/Simulink. The Matlab circuit was shown in figure16. The results of simulation are shown in figure 17 and figure 18 for output voltage, voltage across the switches respectively.

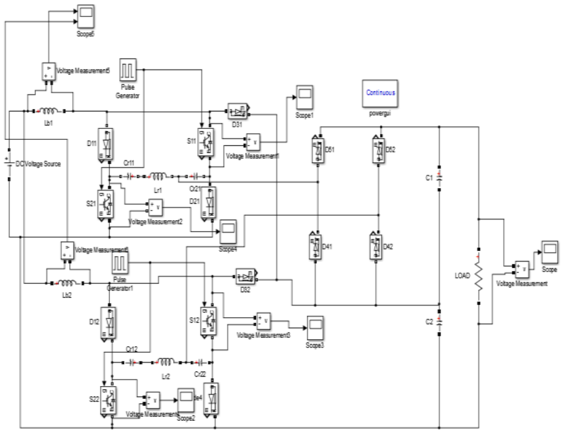
Fig 16:Simulation diagram of multiunit converter

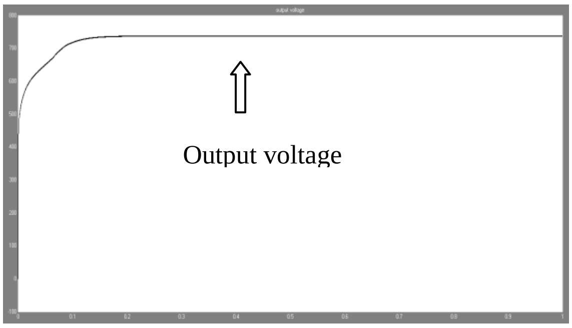

Fig 17: Output voltage waveform of multiunit converter

The output voltage waveform of a multiunit converters is shown in figure 17. It is observed that for a multiunit converter the output voltage is 730v and the gain is approximately 15 when compared with the single unit converter the gain is approximately increased by 5.

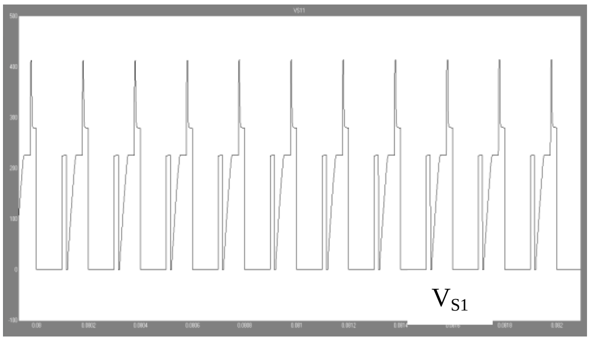

Fig 18: voltage stress across switch S1of multiunit converter

In multiunit converter also the voltage stress across switch is not subjected to the total output voltage. It is subjected to the voltage across the output resonant capacitor.

VIII. COMPARSION

The voltage stress across the switch of the proposed converter is compared with other converter topologies.

Table3:

Buck converter	Boost converter	Proposed converter
Input voltage V_{in} appears across the switch,	Output voltage V_o appears across the switch.	Resonant capacitor voltage V_{c1} appears across the switch

The comparsion between single unit and multiunit is tabulated as

Table4:

	Single unit	Multiunit
power	1KW	1KW
Input voltage	50V	50V
Output voltage	500V	730V
Voltage gain	10	15
Voltage Stress across switch V_{S1}	300	400
Duty ratio	0.5	0.5

IX. CONCLUSION

A high gain non-isolated dc-dc converter is and the proposed converter has low voltage stress on the switches. The proposed converter consists a cascade connection of boost converter and series-parallel resonant converter. The proposed converter attains a large voltage ratio. To get larger voltage and power ratings an identical unit of it can be connected in series or in parallel to the proposed converter. The proposed converter founds its main application in medium voltage dc grids. Simulation results are presented to determine the effectiveness of the proposed converter.

X. REFERENCES

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