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.

I. 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 (Lb), two output capacitors (C1 & C2), one LCC resonant circuit (Lr, Cr1, Cr2) , 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](image)

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](image)
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 $v_{c2}$ 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 $v_{c2}$ 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.

Stage 5:

![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 6:

![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:

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:

In this stage, the diodes D1 and D2 are ON. At the instant D3 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 discontinuous-current mode. At this instant the capacitors voltage V_c1 and V_c2 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 L_b can be expressed as

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

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

\[ L_b = \frac{R_t(1-d-t_s)^2(d-t_s)}{2f_s} \]

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,

\[ C_{r2} = \frac{P_{\text{or, max}}(V_{c1} - V_{in,r})}{4V_{in}V_{c1}f_s} \]

Where Vc1 is the voltage across the output capacitor, where P_or, max is the power that resonant converter handles.

The resonant inductor L_r can be formulated as,

\[ L_r = \frac{V_{in,r}V_{c1}^2}{\pi^2f_sP_{\text{or, max}}(V_{c1} - V_{in,r})} \]

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,

\[ V_{s1,s2} = V_{c2} \]
\[ V_{d1} = V_{d2} = V_{c1} - V_{c2} \]
\[ V_{d3} = V_{d5} = V_{c1} \]
\[ V_{d4} = V_{d5} = V_{c1} \]

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](image)

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.

Table 1: SINGLE UNIT CONVERTER

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Input voltage</td>
<td>50v</td>
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<tr>
<td>Output voltage</td>
<td>500v</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>5000Hz</td>
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<tr>
<td>Inductor(Lb)</td>
<td>240µH</td>
</tr>
<tr>
<td>Inductor(Lr)</td>
<td>330µH</td>
</tr>
<tr>
<td>Capacitor(Cr1)</td>
<td>4.5µF</td>
</tr>
<tr>
<td>Capacitor(Cr2)</td>
<td>3µF</td>
</tr>
<tr>
<td>Load</td>
<td>Resistive</td>
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</table>

Table 2: MULTIUNIT CONVERTER

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
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<tr>
<td>Output voltage</td>
<td>710v</td>
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<tr>
<td>Switching frequency</td>
<td>5000Hz</td>
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<td>Inductor(Lb)</td>
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<tr>
<td>Inductor(Lr)</td>
<td>330µH</td>
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<tr>
<td>Capacitor(Cr1)</td>
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<td>3µF</td>
</tr>
<tr>
<td>Load</td>
<td>Resistive</td>
</tr>
</tbody>
</table>

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](image)

![Fig 13: Output voltage waveform of single unit converter](image)
From the figure 14, it is observed that the output voltages across resonant capacitors Cr1, Cr2 are sinusoids.

From the above figure 15, it is clear that both the switches S1 and S2 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 figure 16. The results of simulation are shown in figure 17 and figure 18 for output voltage, voltage across the switches respectively.

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. COMPARISON

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

Table 3:

<table>
<thead>
<tr>
<th></th>
<th>Buck converter</th>
<th>Boost converter</th>
<th>Proposed converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>V_in appears</td>
<td>Output voltage</td>
<td>Resonant capacitor</td>
</tr>
<tr>
<td></td>
<td>across the</td>
<td>V_o appears</td>
<td>voltage V_c1</td>
</tr>
<tr>
<td></td>
<td>switch.</td>
<td>across the</td>
<td>appears across the</td>
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<tr>
<td></td>
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<td>switch.</td>
<td>switch.</td>
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</table>

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


