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An Analysis of Interleaved High Gain DC-DC Converter with Voltage Multiplier

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Abstract: DC power distribution is an appealing prospect in many applications, including telecommunications, data centres, commercial buildings and microgrids. A dc-dc power converter for high gain may utilised to independently link low voltage components like solar panels, fuel cells and batteries to the 400 V dc voltage bus. In this study, a comparative analysis of some of the existing topologies and their construction is presented. Next, a non-isolated high voltage gain interleaved converter with voltage multiplier is introduced. This converter offer a voltage gain of 20 and to step up a 20 V input to 400 V output. It can draw power from a single source as well as from two independent sources and continuous input current in both cases. The voltage multiplier creates extra boost in high voltage gain under same duty cycle and similar turns ratio. Moreover, the proposed converter is symmetric, the semiconductor components experience same voltage and current stresses which therefore reduces the effort and time spent in the component selection during the system design. The converters presented are extremely efficient and modular. The results are provided handling operating modes, dc voltage gain, and design processes of the converter. A 200 W, 0.5 A simulation model is proposed to validate the design. The results obtained from the simulation agree with the required ratings.

Keywords: High Voltage-Gain DC- DC*;* Power Electronic Converter

1. Introduction

Distribution systems at 400 V dc have been gaining popularity as they offer better efficiency, higher reliability at an improved power quality, and low cost compared to ac distribution systems. They offer a simpler integration of renewable energy and energy storage systems. Currently, telecommunication centres, data centres, commercial buildings, residential buildings, and microgrids are among the emerging examples of dc distribution systems (Chieh et al., 2018).

One of the challenges facing such systems is the power electronic converters for integrating renewable sources into the 400 V dc bus. A typical voltage range for solar panels is between 20 V dc to 40 V dc. Stepping up these voltages to 400 V dc using classic boost and buck-boost converters requires high duty ratios which results in high component stress and lower efficiency. Therefore, a typical choice would be using two cascaded converters; which results in inefficient operation, reduced reliability, increased size, and stability issues.

High voltage gain dc-dc converter based on the modified Dickson charge pump voltage multiplier circuit is introduced in this study. This converter is capable of stepping up voltages as low as 20 V to 400 V. The proposed converter offers continuous input current and low voltage stress ($1/4^{th}$ of its output voltage) on its switches. This converter can draw power from a single source or two independent sources while having continuous input currents, which makes it suitable for applications like solar panels.

2. Research Methodology

The general procedure of the research methodology can be described by the flowchart as shown in Fig. 1. The interleaved as well as the voltage multiplier by their construction in will be studied. The non-isolated converters are a broad family consisting of many different topologies which has been reviewed. Hence, studying these topologies will allow understanding of their limitations. Next, different converters will be studied and analysed based on their performance. Then, the proposed topology will be constructed and tested in Matlab/Simulink to observed the results in terms of characteristics. Thus, conclusions will be made if the results suit the characteristics.

The proposed converter full schematic diagram has been constructing using Piecewise Linear Electrical Circuit Simulation (PLECS) lockset Matlab/Simulink in Fig. 2 by referring the simulation parameters that tabulated in Table 1. Meanwhile, modes of operation of topology are introduced and the voltage gain of the proposed has been derived.

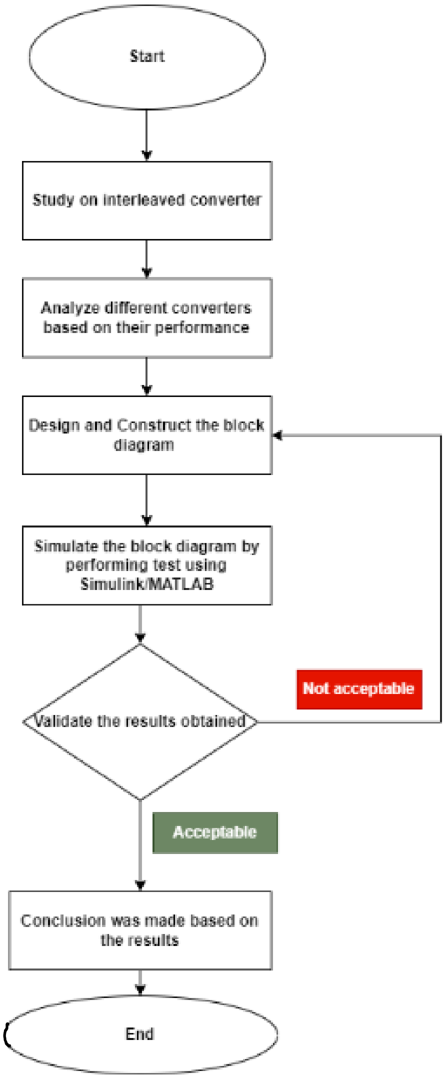

Fig. 1 Flowchart

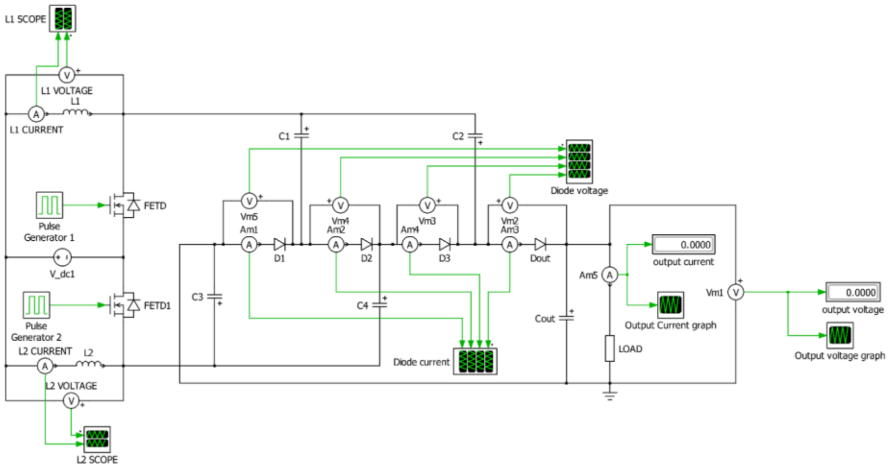

Fig. 2 Schematic diagram

Table 1 Simulation parameters

Parameters	Value
Input voltage	20 V
Output voltage	400 V
Load Resistance	800 Ω
Duty cycle of switches S1 and S2	80%
Switching Frequency - fsw	100 kHz
Boost Inductors L1 and L2	6.8μH
VM capacitors	60 μF
Output Capacitor	22 μF

3. Results and Discussions

The simulation waveform shows the output current and the output voltage of the converter as in Fig. 3 and Fig. 4. It can be observed that the output voltage achieved to 400 V and the voltage ripple is almost negligible. Moreover, the output current achieved 0.5 A.

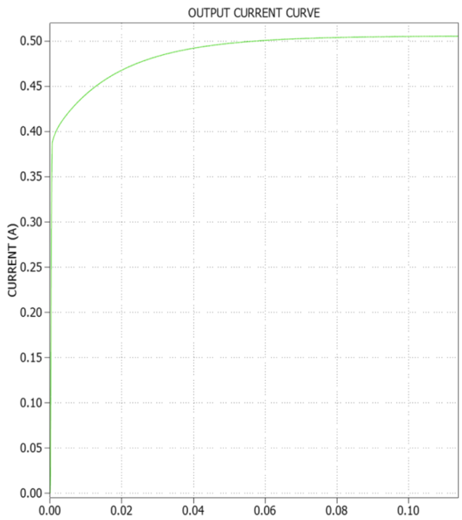

Fig.3 Output current waveforms

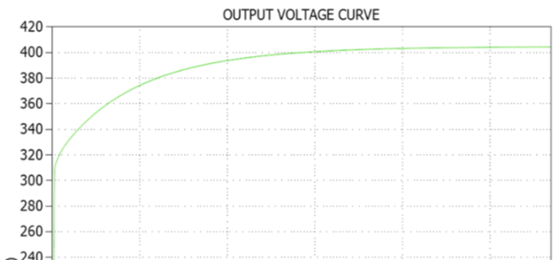

Fig. 4 Output voltage waveforms

Other than that, results also determine the waveform of inductor voltages and currents as well as the diode voltage the input current. PLECS simulation shows the current and voltage inductor shapes produced. Both inducers have a current of 5 A with a ripple of 1.6 A each at 200 W of output power as shown in Fig. 5 and Fig. 6.

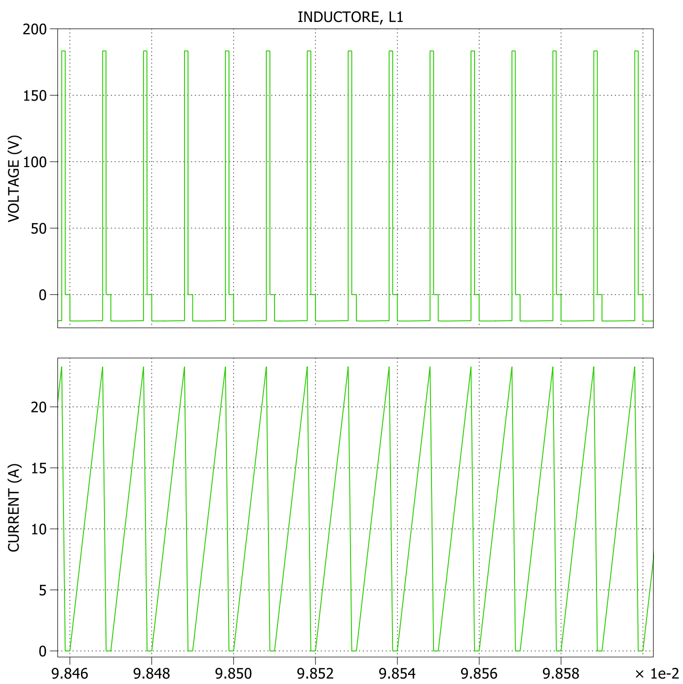

Fig. 5 Inductor $L1$ current and voltage waveforms.

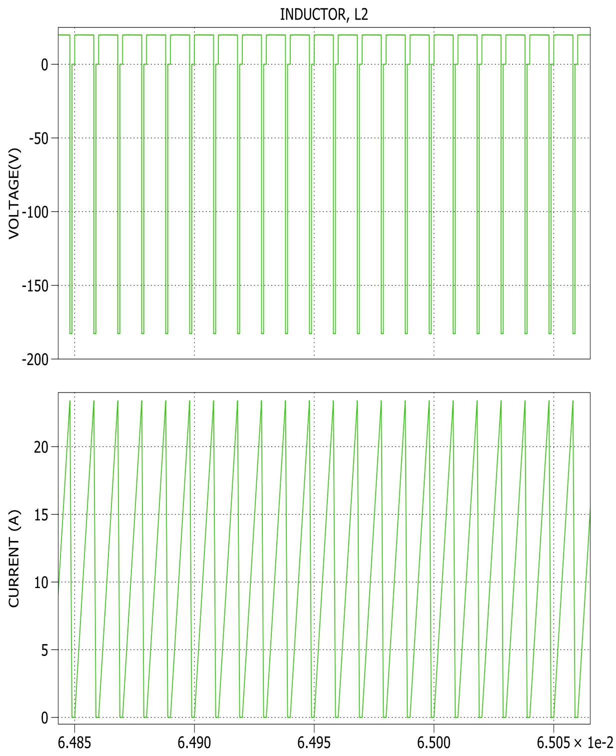

Fig. 6 Inductor *L*2 current and voltage waveforms.

The voltage and current waveforms of diodes D_1, D_2, D_3, and D_{out} are shown in Fig. 7 and Fig. 8 respectively operating at 80 % switching duty cycle and 20 V input, the maximum blocking voltage seen by the diodes is 200 V(Nia et al., 2022). All the diodes carry an average current of 5 A which is equal to the output current. The diodes conduct either only during Mode II or Mode III of the converter operation. Diodes D_2 and D_{out} have different current waveforms. This is because of the voltage imbalance in the capacitors during the start of Mode II. Only diode D_{out} initially conducts in order to charge the output capacitor and bring in a balance in the voltage. Once the voltage loops are balanced, then the current flowing through the diodes is dependent on the impedance of the capacitor (Prashant Baddipadiga & Ferdowsi, 2016).

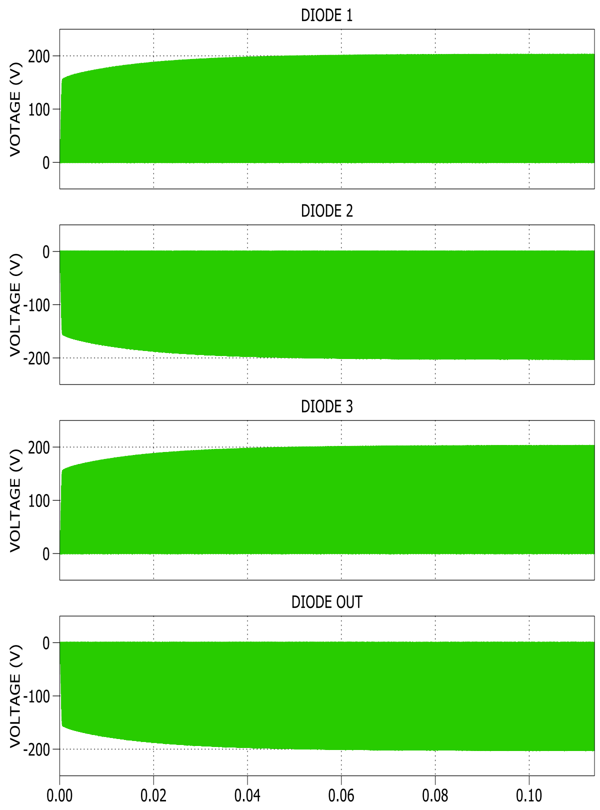

Fig. 7 Voltage waveforms for diodes D_1, D_2, D_3 and D_{out}

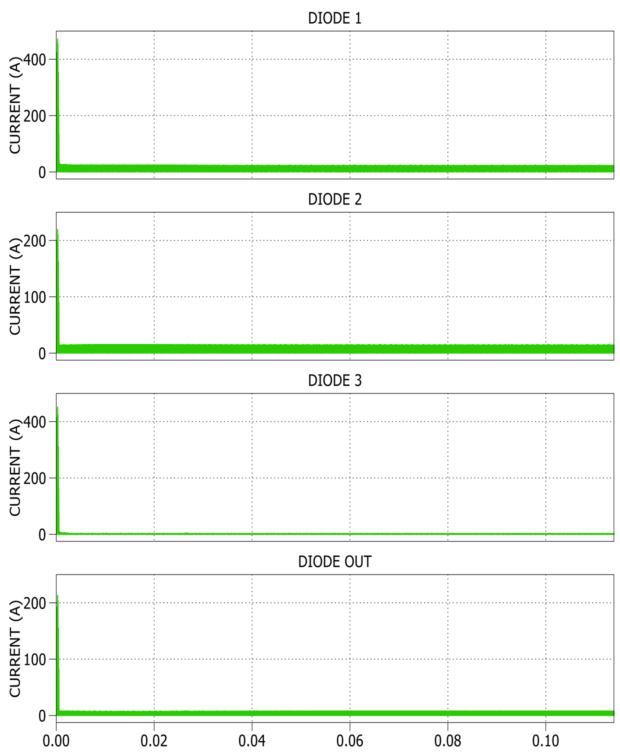

Fig. 8 Current waveforms for diodes D_1, D_2, D_3 and D_{out}

Fig. 9 illustrate the percentage distribution of losses in the system components. It is observed that the major perent of losses occur in the diodes which are about 56 %. With 4 diodes in the converter, each diode has a loss of around 14 %. When a diode's losses grow, its junction temperature rises, reducing the forward voltage drop across it as a result. This decrease in forward voltage drop reduces the power loss and helps in preventing a further increase in junction temperature which can lead to diode failure. In the worst case scenario, the losses in the selected diode were estimated to be within its power dissipation limits.

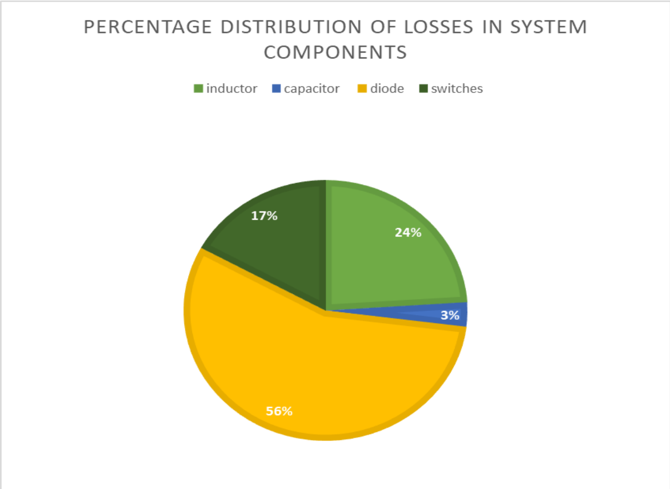

Fig. 9 Percentage distribution of losses in system components

This particular heat sink contributes to a minimal increase in the volume of the converter. Around 24 % and 17 % of losses occur among the inductors and switches, respectively. The conduction losses in the inductors can be reduced by selecting an inductor with lower value of DC Resistance (Gomes de Assis et al., 2019). The selected switches have similar conduction and switching losses. Losses in the capacitors are very small as the ESR of the film capacitors used is in the order of few milliohms and the rms currents are around 1 A. Therefore, an efficiency of 96.8 % was observed at 200 W of output power.

4. Conclusion

In this study, a 200 W high oltage gain dc-dc converter is introduced that can offer a voltage gain of 20, to step up a 20 V input to 400 V output. The proposed converter is based on a two-phase interleaved boost and the modified Dickson charge pump voltage multiplier circuit. It can draw power from a single source as well as from two independent sources while offering continuous input current in both cases. This makes the converter well suited for renewable application. From results and discussions, it is proved that interleaved converter with voltage multiplier has been designed in this study which achieved the required voltage and current rating.

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