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Non-Isolated DC-DC Converter for Renewable Based Grid Application

Saravanan S[a], Ramesh Babu N[a]*

[a]*School of Electrical Engineering, VIT University, Vellore, Tamilnadu, India.*

Abstract

A high voltage gain dc-dc converter with improved efficiency is proposed in this article for Photovoltaic (PV) based grid application. This converter topology provides high voltage gain with fewer components. The efficient power conversion is achieved with reduced voltage stress across the semiconductor devices. The working principle and analysis of the converter is described in this article. The converter design is made for 250 W power rating and connected to the grid through an inverter. Performance of the proposed converter is simulated and analyzed using MATLAB/Simulink.

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Keywords: Non-isolated; high voltage gain; low voltage stress; Photovoltaic (PV)

1. Introduction

The clean energy source based power generation to meet the grid power demand is a tremendous growing sector in the world. Due to that many researchers are focusing on this area for improvement of alternative energy technologies such as photovoltaic (PV) [1],[2], wind energy [3], and fuel cells [4]. However, the characteristics of these renewable energies are having low output voltage, and required high step up voltage gain demand by using dc-dc converter, for any potential real time applications.

Some requirements are necessary for converter based applications such as low inrush current, reduced switching stress, low weight and volume. The dc-dc converter is divided into two types namely, isolated and non-isolated based converters. The transformer based converters like flyback, pushpull, and forward

* Ramesh Babu N. Tel.: +91-416-2202467.
E-mail address: nrameshbabu@vit.ac.in.

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converters. The main drawback of these isolated converters is its dependency on the turns ratio of the transformer for step up process. It also affect the main switch with high voltage spike and power dissipation because the leakage inductor of the transformer [5]. The conventional boost converter cannot generate high voltage gain for applied voltage because of high turns ON resistive issue for semiconductor devices. It also required large duty cycle to produce the high voltage gain for the required application [6],[7].

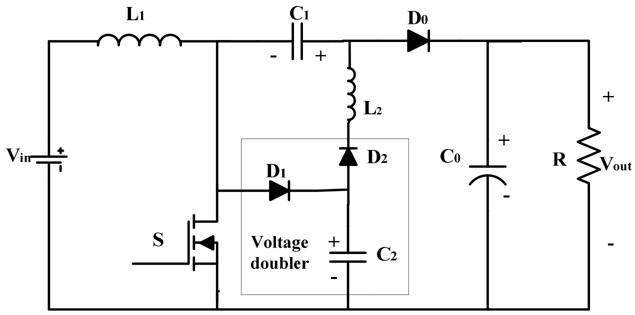


Fig. 1. Proposed converter topology circuit diagram.

The above disadvantages of the converters are recovered by incorporated with the coupled inductor [8], switched capacitor and inductor types [9], voltage doubler circuits [10], voltage multiplier cells [11], and voltage lift techniques [12]. The proposed topology is performed by integrate the Single Ended Primary Inductor Converter (SEPIC) with voltage doubler circuit. The proposed topology achieves the fast response with low voltage stress for semiconductor devices and reaches the high static gain by using single switch. The proposed converter topology is most suitable for PV integrated based grid connected system. The ratings of PV system with maximum output power (P_{MPP}= 250 W) and maximum output voltage (V_{MPP}= 30 V) has been considered for this study. In this article, the proposed topology is simulated using MATLAB/Simulink for grid application.

2. Operating Principle of Proposed Converter

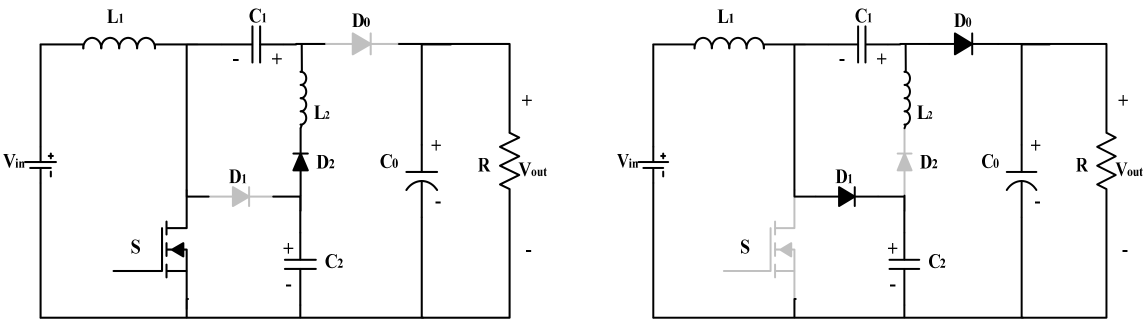
The proposed converter topology circuit diagram is shown in Fig. 1. The converter circuit consists of main switch *S*, inductors L_1 and L_2, three diodes D_1, D_2 and D_0, two capacitors C_1 and C_2, and output capacitor C_0. The voltage doubler circuit is combined with SEPIC converter to improve the high voltage gain. The elements of the voltage doubler circuit are capacitor C_2, and diodes D_1, and D_2. The capacitor C_2 is charged similarly as a classical boost converter operation.

The continuous conduction mode (CCM) of the proposed converter topology presents two modes of operation. For theoretical analysis it is assumed that all the capacitors are considered as voltage source and the semiconductor switch and diodes are taken as ideal.

Mode I [t_0-t_1]: In this mode, the switch *S* and diode D_2 is in turned ON condition and the diodes D_1 and D_0 are in reverse biased as shown in Fig. 2(a). The inductors L_1 and L_2 store the energy. The input voltage is flowing through the inductor L_1 to capacitors C_1, C_2 and the inductor L_2. The output capacitor C_0 discharges the stored energy and flows to the load.

Mode II [t_0-t_1]: In this mode, the switch *S* and diode D_2 is in turned OFF condition and the diodes D_1 and D_0 are in forward biased condition as shown in Fig. 2(b). The stored energy from the inductors L_1 and L_2 starts discharging. The inductor L_1 current is transferred to the capacitor C_1 and energy stored in inductor L_2 flow through the diode D_0 and charges the output capacitor C_0.

The main theoretical waveforms for the proposed converter topology under CCM are presented in Fig. 3. The voltage across all diodes and the main switch is equal to the voltage across capacitor C_2. The sum of the capacitors C_1 and C_2 voltage is equal to the output voltage of the proposed converter. The input current of converter is equal to the average inductor L_1 current and output current of the converter is equal to the average inductor L_2 current.



(a) (b)

Fig. 2. Operational mode of proposed converter. a) Mode I, b) Mode II.

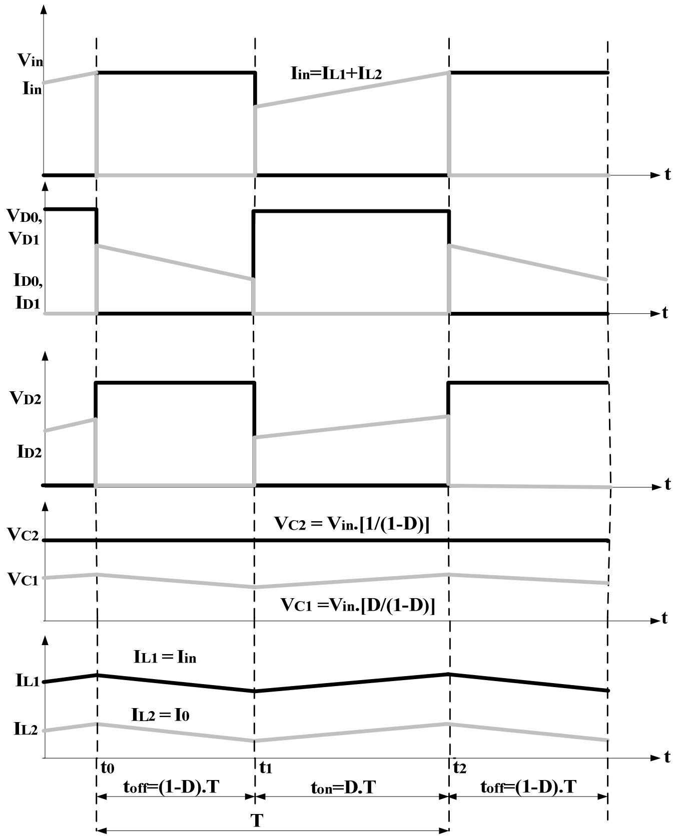


Fig. 3. Main theoretical waveforms of proposed converter at CCM operation.

The voltage gain of the proposed converter can be formed by considering both the average inductors voltage is null at steady state condition in CCM operation (1). The maximum main switch voltage is equal to the capacitor voltage C_2 and hence it is lower than the output voltage.

$$\frac{V_O}{V_{in}} = \frac{1+D}{1-D} \tag{1}$$

$$\frac{V_{C2}}{V_{in}} = \frac{1}{1-D} \tag{2}$$

$$\frac{V_{C1}}{V_{in}} = \frac{D}{1-D} \tag{3}$$

The capacitor voltage C_2 is derived by (2) which is equal to the output voltage of the conventional boost converter. The capacitor voltage C_1 is calculated by (3) that obtained as like SEPIC converter.

The current ripple for both the inductors is derived by using same value. The capacitors C_1 and C_2 are designed by using the same ripple voltage. The capacitance with low series resistance is used and the value of resistance is assumed as zero for computation which results in small capacitance value. The average current of diodes is equal to the output current. The sum of the both inductors L_1 and L_2 current is equal to the switch current.

3. Results & Discussion

A 250-W system has been considered for simulation study using MATLAB/Simulink. The designing of the proposed converter topology is done by considering the specifications listed in Table 1. The proposed converter generates output voltage of 311 V; when an input voltage of 30 V is fed and the inductor current of the converter varies between 8 A and 12 A as shown in Fig. 4. The switching voltage reaches 168 V with the current of 13.2 A and these waveforms are illustrated in Fig. 5. The voltages across the diodes D_1 and D_0 voltage is 167 V and 154V respectively as illustrated in Fig. 6. The capacitors C_1 and C_2 produces voltage of 162 V and 167.4 V and its waveforms are shown in Fig. 7. From the waveforms, it is clear that the voltage across all the semiconductor devices like switch S, diodes D_1 and D_0 is equal to the capacitor voltage C_2. The sum of the capacitors C_1 and C_2 voltage are equal to the output voltage converter.

Table 1. Components and Parameters of proposed converter

Components	Parameters
Maximum Output Power, P_O	250 W
Input Voltage, V_{in}	30V
Output Voltage, V_O	300V
Switching Frequency, f_S	24 kHz
Inductors, L_1 and L_2	205 μH
Capacitors, C_1 and C_2	2.08 μF
Output Capacitors, C_O	140 μF

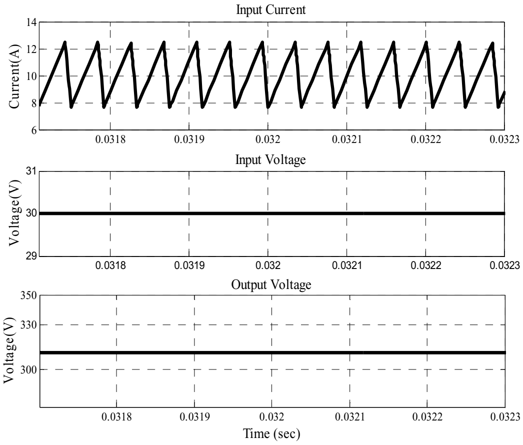


Fig. 4. The input current, voltage and output voltage waveforms.

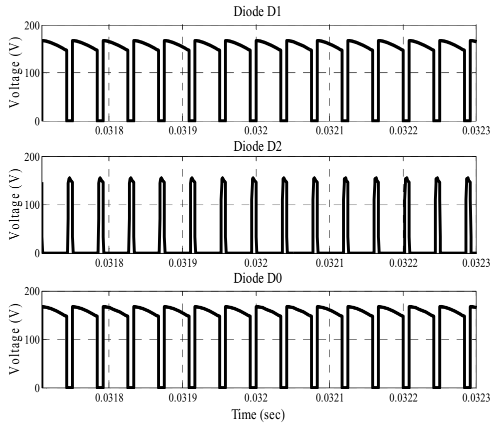


Fig. 6. The diodes voltage waveforms of the proposed converter.

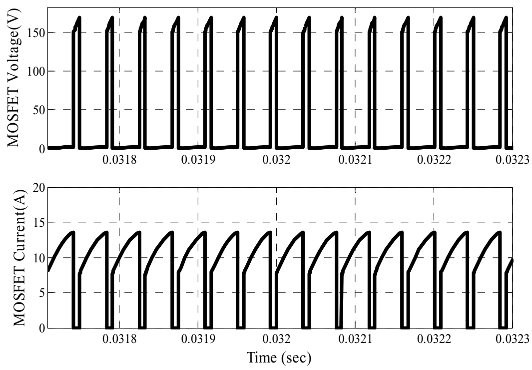


Fig. 5. The switching voltage and current waveforms.

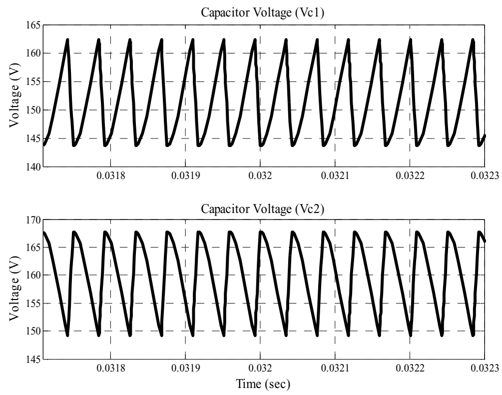


Fig. 7. The capacitors voltage waveforms.

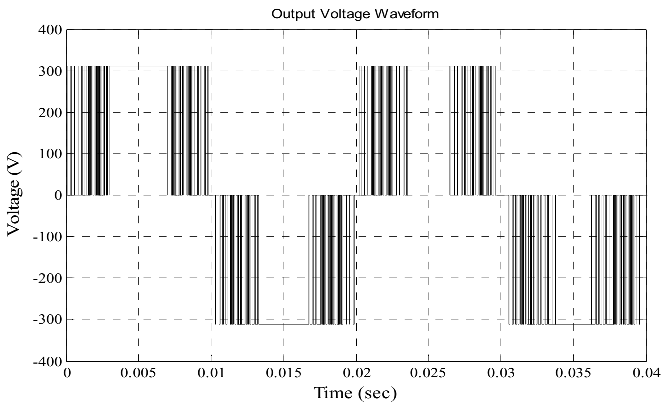


Fig. 8. Inverter output voltage waveform.

The output voltage of proposed converter is given as an input for single phase inverter with the rating of 250 W. The output voltage of proposed converter produces 311 V DC, which is sufficient enough to get converted into 220 V (r.m.s) AC for grid applications and it is shown in Fig. 8. From the above observations, it is clear that the proposed converter exhibits reduced conduction and switching losses when compared to other converters [13].

4. Conclusion

In this paper, the non isolated converter with high step up voltage gain for PV based grid application is studied. The proposed converter topology is able to produce the high static gain with fast response and low switching voltage stress. The voltage across all the semiconductor devices like switch and diodes having half of the converter output voltage is obtained. The proposed converter is validated using MATLAB/Simulink. The simulation result shows the performance of the proposed converter is efficient for high voltage gain operations. The converter design uses low rating components and hence it reduces the converter overall cost. The proposed converter output voltage is connected through the inverter and validated the appropriate r.m.s AC voltage suitable for grid applications.

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