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A HIGH CONVERSION NON-ISOLATED BIDIRECTIONAL DC-DC CONVERTER WITH LOW STRESS FOR MICRO-GRID APPLICATIONS

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Abstract:
This paper tackles a common ground non-isolated bidirectional DC-DC converter for applications of micro-grids. The suggested converter consists of four main switches with their body diodes, three inductors, and four capacitors. Simple structure, vast voltage gain scope, low voltage tension in the switches and joint common ground among the input and the output are the merits of the suggested converter. Furthermore, the suggested converter provides high step up/step-down voltage gain. Regarding the simplicity in this configuration, the control concept of the suggested converter is a straightforward conception. Doing so, this paper deals with steady-state analyses in both directions, voltage stress across the power switches, and a watchful survey in comparison between other bidirectional converters. Finally, the simulation results are concluded to validate the effectiveness of the analyses in the suggested converter.

Key Words: Bidirectional Converter, micro-grid, high step-up/ step-down voltage gain, wide voltage gain range, common ground.

1. INTRODUCTION

Penetration of the distributed generations (DGs) has increased in the micro-grids (MGs), considering the growth of energy demand, depletion of fossil fuel reserves, and the subsequence of using them. However, the generating capacity of DGs is low and depends on environmental conditions and climate [1, 2], thus, researchers and experts use the power electronic converters to solve the abovementioned problems. The DC micro-grid system has become increasingly popular due to the growth of dc-coupled subsystems like photovoltaic (PV), wind turbine and battery [3]. Fig.1 depicts a DC micro-grid system. According to Fig.1, DGs (PV and wind turbine) inject power to the DC bus bar. Vice versa, DC and AC loads feed from the DC bus bar. If the generated power of DGs is more than the loads' consumption, the extra power will store in the energy storage systems (like a battery), [3, 4].

The bidirectional DC-DC converter is necessitated as a link between the energy storage systems and the DC bus bar with different levels of voltage. Generally, the bidirectional DC-DC converters are bisected isolated and non-isolated. The isolated type of bidirectional converters contains fly back; forward fly back, half bridge and full bridge converters. The aforementioned converters own a vast voltage gain scope in both operational status. In fly back converters, the saved energy in the leakage inductor of the coupled inductor cannot be retrieved. So this converter has low efficiency. The half bridge converters have a complex structure, because they require a center-tapped transformer and the full bridge converters that have many semiconductors.

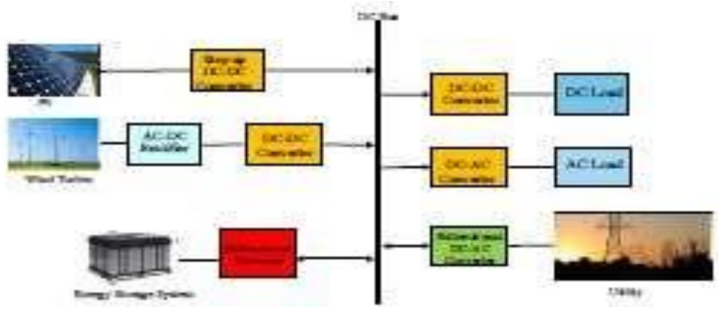


Figure – 1: Typical DC micro – grid System

2. DC-DC CONVERTERS

DC –DC converters are power electronic circuits that convert a dc voltage to a different voltage level. There are different types of conversion method such as electronic, linear, switched mode, magnetic, capacitive. The circuits described in this report are classified as switched mode DC-DC converters. These electronic devices are used whenever change of DC electrical power from one voltage level to another is needed. Generically speaking the use of a switch or switches for the purpose of power conversion can be regarded as an SMPS. From now, onwards whenever we mention DC-DC converters we shall address them with respect to SMPS. A few applications of interest of DC-DC converters are where 5V DC on a personal computer motherboard must be stepped down to 3V, 2V or less for one of the latest CPU chips; where 1.5V from a single cell must be stepped up to 5V or more, to operate electronic circuitry. In all of these applications, we want to change the DC energy from one voltage level to another, while wasting as little as possible in the process. In other words, we want to perform the conversion with the highest possible efficiency. DC-DC Converters are needed because unlike AC,

DC can't simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the DC equivalent of a transformer. They essentially just change the input energy into a different impedance level. So whatever the output voltage level, the output power all comes from the input; there is no energy manufactured inside the converter.

3. SYSTEM MODELLING

The suggested converter contains four power semiconductors (S1-S4), four capacitors, and three inductors. The suggested converter can perform in step-up and step-down. For the convenience of the steady-state analysis of the suggested converter, the following hypothesis are considered:

1. The suggested converter is studied in the steady state.
2. All of the elements are acted ideally. So, all resistances of elements are refused.
3. The capacitors' capacitances are grand sufficient hence, the capacitors' voltage are assumed to be fixed.

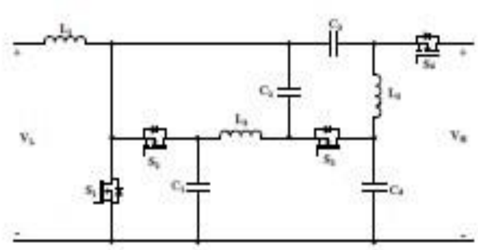


Figure - 2: Simplified circuit model of the suggested converter

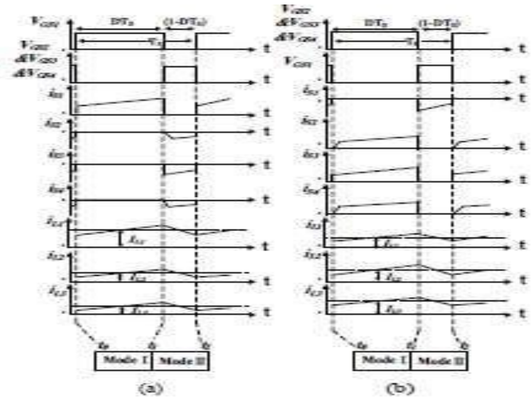


Figure - 3: commonplace waveforms of the suggested converter at CCM performance. (a) Step-up status. (b) Step-down status.

A. Step-Up Mode of the Proposed Converter

In the step-up status, S1 performs as a power switch and others perform as the synchronous rectifiers. Some commonplace waveforms of the suggested converter are depicted in Fig.2 (a). Also, Fig.3 depicts the current flow paths.

Mode I: During this time period, the switch S1 is conducted. The paths of current flow are displayed in Fig.3 (a). As it is seen in this figure, the energy of U low is conveyed to inductor L1. The capacitor C1 is discharged to the inductor L2 and capacitor C2. Also, the capacitor C4 is discharged to the inductor L3 and capacitor C3. The load energy is prepared by the capacitor C high. The following formulas can be written in this mode:

$$V_{L1} = V_{low} \quad (1)$$

$$V_{L2} = V_{C1} - V_{C2} \quad (2)$$

$$V_{L3} = V_{C4} - V_{C3} \quad (3)$$

Mode II: During this time period, the switch S1 doesn't conduct and the anti-parallel diodes of S2, S3, and S4 are conducted. The current flow paths are displayed in Fig.4 (b). As it is seen in this figure, the inductors L1 and L2 are discharged to capacitor C1 and C4 respectively. The capacitors C2 and C3 are discharged to the load by the diodes of S3 and S4. The DC source, inductor L1, L2, and L3 prepare the energy of the load. The next formulas can be written in this mode:

$$V_{L1} = V_{low} - V_{C1} \quad (4)$$

$$V_{L2} = V_{C1} - V_{C4} = -V_{C2} \quad (5)$$

$$V_{L3} = V_{C2} - V_{C3} = V_{C4} - V_{high} \quad (6)$$

By executing the volt-second balance basis to L1, L2 and L3, the capacitors voltage and the DC voltage gain in step-up status can be reached as follows:

$$V_{C1} = \frac{V_{low}}{1 - D_{Boost}} \quad (7)$$

$$V_{C2} = \frac{D_{Boost}}{1 - D_{Boost}} V_{low} \quad (8)$$

$$V_{C3} = \frac{2D_{Boost}}{1 - D_{Boost}} V_{low} \quad (9)$$

$$V_{C4} = \frac{1 + D_{Boost}}{1 - D_{Boost}} V_{low} \quad (10)$$

$$M_{Boost} = \frac{1 + D - 2D^2}{(1 - D)^2} \quad (11)$$

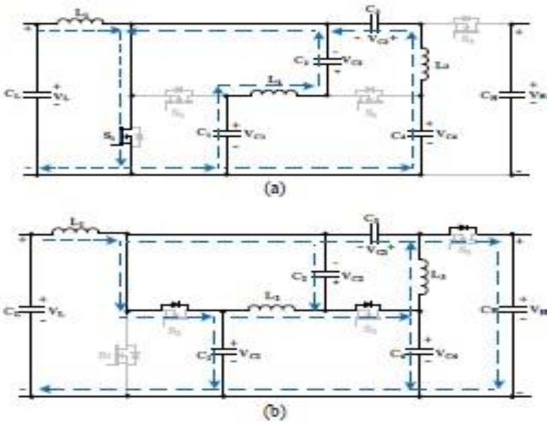


Figure - 4: Current flow path in step-up status. (a) Mode I. (b) Mode II.

B. Step-Down Status of the Suggested Converter

In this status, the switches S2, S3, and S4 operate as the power switch and the switch S1 operates as the synchronous rectifier. Some commonplace waveforms of the suggested converter are depicted in Fig.1.b and Fig.3, which exhibits the paths of current flow.

Mode I: During this time period, the switches S2, S3, and S4 conduct. Paths of the current flow are displayed in Fig 4(a). As it is seen in this figure, the energy of the U high is transferred to inductor L1, L2, and L3. The capacitors C3 and C4 are charging through the switches S3 and S4. Also, the DC source and the capacitors C4 and C1 prepare the energy of the load. The next formulas can be written in this mode:

$$V_{L1} = V_{C1} - V_{low} \quad (12)$$

$$V_{L2} = V_{C4} - V_{C1} = V_{C2} \quad (13)$$

$$V_{L3} = V_{C3} - V_{C2} = V_{high} - V_{C4} \quad (14)$$

Mode II: During this time period, the switches S2, S3, and S4 are don't conduct and the diode of S1 is conducted. The current flow paths are depicted in Fig.4 (b). As it is seen in this figure, the energy of the inductor L2 and capacitor C2 is transmitted to the capacitor C1. Also, the energy of the inductor L3 and capacitor C3 is conveyed to the capacitor C4 and C2 and the energy of inductor L1 is conveyed to the capacitor C low which prepares the load energy. The next formulas can be written in this mode:

$$V_{L1} = -V_{low} \quad (15)$$

$$V_{L2} = V_{C2} - V_{C1} \quad (16)$$

$$V_{L3} = V_{C3} - V_{C4} \quad (17)$$

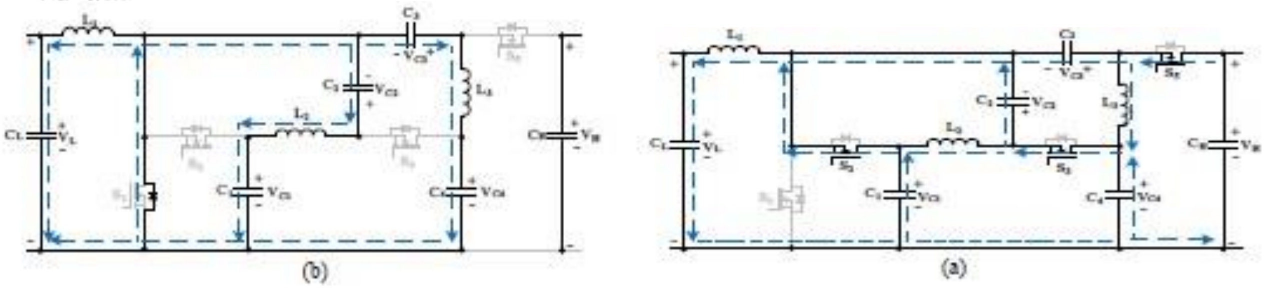
$$V_{C1} = \frac{V_{low}}{D_{Buck}} \quad (18)$$

$$V_{C2} = \frac{(1 - D_{Buck})V_{low}}{D_{Buck}} \quad (19)$$

$$V_{C3} = \frac{2(1 - D_{Buck})V_{low}}{D_{Buck}} \quad (20)$$

$$V_{C4} = \frac{(2 - D_{Buck})V_{low}}{D_{Buck}} \quad (21)$$

$$M_{Buck} = \frac{D}{(3 - 2D)} \quad (22)$$



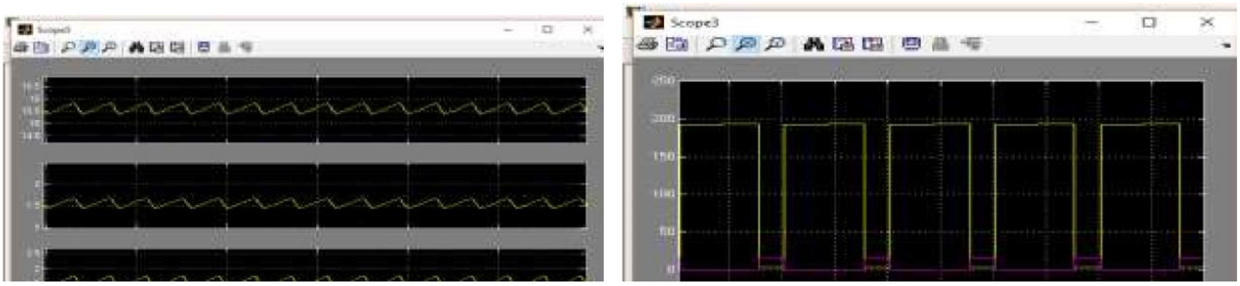
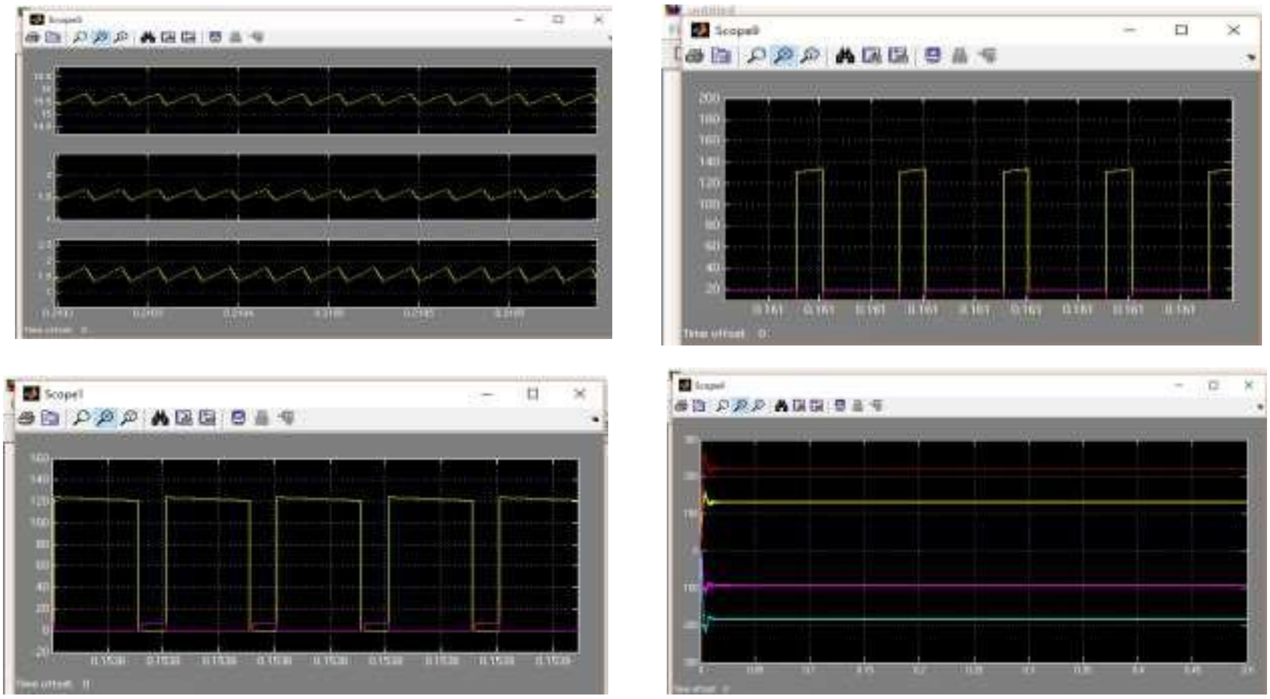


Figure - 5: Current flow paths in step-down status. (a) Mode I. (b) Mode II.

4. SIMULATION RESULTS



1. Output of Booster Converter
2. Output of Bulk Converter

CONCLUSION

This project tackles a common ground non-isolated bidirectional DC-DC converter for using in DC micro grid has been proposed. The suggested converter profits from some merits such as continuous input current, high step-up/step-down voltage gain, vast voltage gain scope, low voltage tension of switches and common-ground. The biggest advantage the suggested converter will bring to DC micro-grid is its ability to control the DC microgrid easily. The steady-state analysis of the suggested converter in CCM and the comparison with other bidirectional converters are discussed in both step up step-down status. Finally, in order to confirm the suggested analyses in this project, the suggested converter is simulated in 400w power in MATLAB software.

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