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Switched Inductor Based Single Switch Buck-Boost DC-DC Converter

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ABSTRACT: DC-DC converters with continuous input current are used in renewable energy system for achieving better performance. So, a novel buck-boost DC-DC converter with continuous input current based on switched inductor is proposed. A comparative study of different buck-boost DC-DC converter are carried out. The voltage gain of presented converter is higher than conventional converters. This converter works only by one switch and voltage stress across the switch is low. Input current of proposed converter is continuous so a large filter at the input is not needed. Continuous input current have made this converter suitable for renewable energy and fuel cell applications. In this converter, non-inverting output voltage is obtained and also high gain of voltage is achieved. So it can operate at wide output voltage range only by changing the duty cycle of the power switch pulse. Presented converter can easily controlled in CCM mode operation, because of using only one power switch. The performance study of a novel buck-boost DC-DC converter with continuous input current is carried out with MATLAB 2017a/SIMULINK. High gain buck-boost DC-DC converter with low output ripple is obtained.

KEYWORDS: Buck Boost DC-DC Converter, Switched Inductor, High Gain.

I.INTRODUCTION

Power electronic devices are used in many applications. Global energy consumption tends to grow endlessly. To fulfill the demand for electric power the renewable energy sources are becoming more relevant. Renewable energy provides reliable power supplies and fuel diversification, which increases energy security, lowers the risk of fuel spills. Fuel cells represent one of the most efficient and effective alternative renewable energy sources for many applications, such as hybrid electric vehicles, telecom backup facilities, undisturbed power supplies, and portable electronics. Several energy sources, like solar panels, fuel cells, exhibit low terminal voltage, which calls for a high-gain step-up converter to interface with the inverter for grid connection. Also, PV and wind need an additional converter to have a maximum power extraction. Due to the instabilities in the output voltage of these energy resources, an extra DC-DC buck-boost converter is required to regulate the output voltage. But, the traditional buck-boost converter is not satisfactory for fuel cells sources because of interrupted input current. Conventional buck-boost converters are expected high efficiency, however, they are limited by the effects of diodes, switches, and equivalent series resistance (ESR) of capacitors and inductors. Some types of converter are capable of providing both step-up, and step-down voltage conversion involves conventional converters such as inverting buck-boost converter, the flyback converter, the Cuk converter, and the single-ended primary inductance converter (SEPIC) [2]. However, these converters have high stress across the switches and low efficiency of the flyback converter because of its high leakage inductance. A new scheme of a step-up converter with very high voltage gain based on a natural combination of the switched coupled-inductor boost converter and the diode-capacitor multiplier is proposed in [3]. Both steady-state and dynamic operations of the converter are analyzed.

In [6], a transformer-less buck-boost DC-DC converter with voltage gain 2D/1-D, is given, that it has a suitable voltage gain, but the input current of that and the converter in [7] is discontinuous. In a transformer-less high gain buck-boost converter, the gain of that converter is 3D/1-D, but the input current is discontinuous, and negative voltage polarity is obtained. A single-switch quadratic buck-boost DC-DC converter has a wide range of voltage conversion ratios. In a two-stage inverting buck-boost converter[10], two switches and discontinuous input current are some of the drawbacks of this converter. So a novel single switch non-isolated buck-boost DC-DC converter with high step-up voltage gain is proposed. This converter is a single-input single-output converter. It isderived from a conventional SEPIC converter at the input to have a continuous input current and to obtain both buck and boost capabilities, and also a combination of inductors, capacitors, and diodes are used to have a higher gain rather than a SEPIC and get a high gain buck-boost

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DC-DC converter. For the proposed converter, the voltage stress on the power switch is low. The voltage transfer gain of the proposed converter is 3D/1-D, which is higher than the typical buck-boost converter, CUK, SEPIC, and ZETA converters. This converter contains only one power switch, so the control of the converter will be simple. The input current of the proposed converter is continuous, hence it can be used in renewable energy applications and also can take advantage in many applications like PV mppt, fuel-cell systems, and LED drivers.

II.METHODOLOGY

The single switch non-isolated converter based on the switched inductor consists of power switch S, five diodes, five inductors, and six capacitors. Following assumptions are considered for the easy analysis of the operating principles:

• The voltage across capacitors is assumed to be constant and the capacitors of this converter are large enough.

• The main switch is considered ideal and so the parasitic capacitor of the main switch can be ignored.

The proposed converter can be operated in two primary conditions, the discontinuous conduction mode (DCM) and continuous conduction mode (CCM) Operation principles. Analyses of a converter in CCM, contain two main modes.

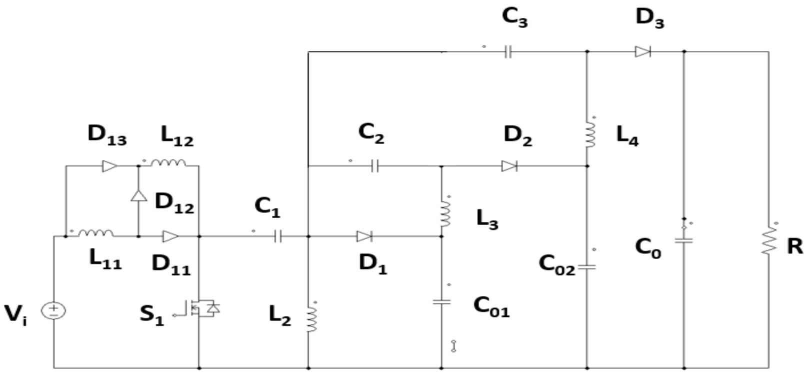

Fig. 1. SEPIC Based Single Switch Buck-Boost DC-DC Converter with Improved Gain

III.MODES OF OPERATION

1. Mode 1 [0 - DTs]: In this mode as shown in Figure 2, switch S is turned on, and the diodes D_1, D_2, D_3, D_{12} are turned off. The inductors L_{11}, L_{12}, L_2, L_3, and L_4 are magnetized linearly. The capacitor C_1 is discharged, and C_2 and C_3 are respectively charged by the capacitors C_{01} and C_{02}. Corresponding theoretical waveform is also shown in Fig 2.

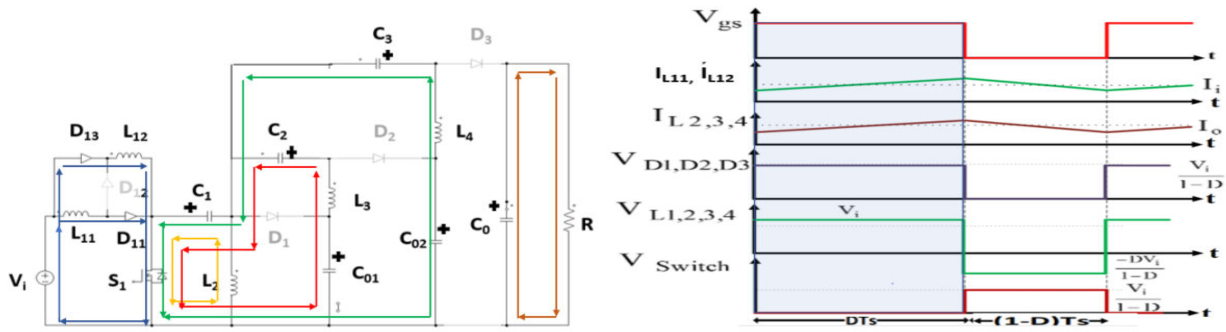

Fig. 2Operating circuit and waveform of Mode 1

2. Mode 2 [DT - (1-D)Ts]: The corresponding circuit is shown in Fig 3. During this mode, the power switch S is turned off, and the diodes D_1, D_2, D_3, D_{12} are turned on. The inductorsL_{11}, L_{12}, L_2, L_3, and L_4 are demagnetized linearly. The capacitor C1 is charged by the inductor L_1, capacitors C_{01} and C_{02} are charged by L_2, L_3 respectively, and capacitors C_2, C_3 are discharged. Fig 2 shows the waveform of mode 2operations.

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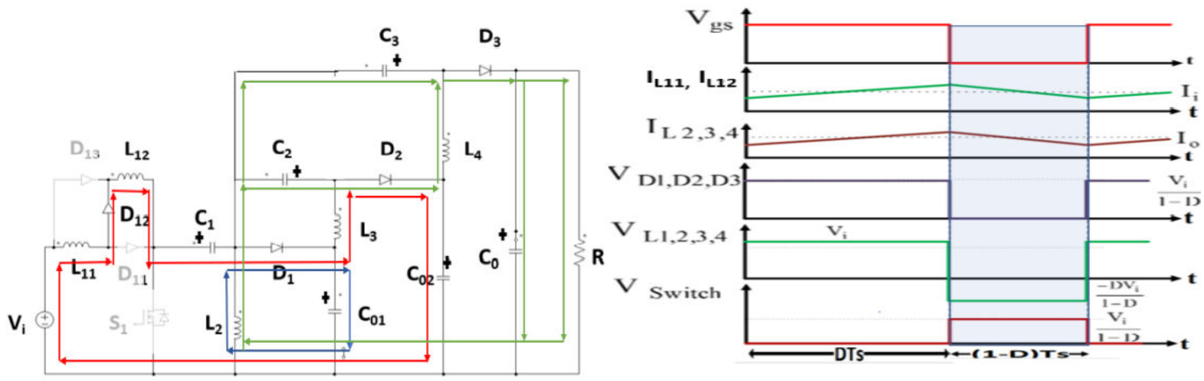

Fig. 3Operating circuit and waveform of Mode 2

IV.DESIGN OF COMPONENTS

In order to operate the converter properly, the components should be designed appropriately. Design of high gain DC-DC Buck-Boost converter are going to discuss in this chapter. The input voltage is taken as 22V. The pulses are switched at the rate of 33 kHz with a duty ratio of 0.6. Consider the output voltage as 230V and output power as 460W.

$$M = \frac{V_O}{V_{in}} = \frac{3*D}{1-D} \quad (1)$$

$$D = \frac{V_0}{3*Vin+V0} \quad (2)$$

Load Resistor R is obtained as 110 Ω from the following equation (3).

$$R = \frac{{V_O}^2}{P_O} \quad (3)$$

Value of inductor L_{11} and L_{12} is obtained by the current flowing through it (equation 5) and substituting ΔI_{L11} in equation (6).ΔI_{L11} is obtained by calculating 40% I_L. Hence L_{11} and L_{12} are obtained as 130 ∗ 10−6H.

$$I_o = \frac{P_O}{V_O} \quad (4)$$

$$I_{L11} = I_0 * \frac{3*D}{(1-D)} \quad (5)$$

$$L_{11} = L_{12} \geq \frac{D*V_{in}}{f_S*\Delta I_{L11}} \quad (6)$$

$$L_2 = L_3 = L_4 \geq \frac{D*V_{in}}{f_S*\Delta I_{L2}} \quad (7)$$

Inductor values of L_2, L_3, and L_4 are obtained as 510 µH from the above equation(7). The value of CapacitorC_1, C_2, C_3, C_{01} are obtained as 100µF from equation(8), and C_{02}, C_0 is obtained from equation (9) as 470µF.

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$$C_1, C_2, C_3, C_{01} \geq \frac{3*DT_S*V_O}{R*\Delta V_{c1}} \quad (8)$$

$$C_3, C_{01} \geq \frac{DT_S*V_O}{R*\Delta V_0} \quad (9)$$

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V.SIMULATION AND RESULTS

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy way to use environment where problems and solutions are expressed in familiar mathematical notation. SIMULINK is a software package for modeling, simulating, and analyzing dynamical systems.

The simulation parameter for switched inductor-based DC-DC Buck-Boost converter are given with an input voltage of 22V, which is boosted to an output voltage of 231.1V. The switching frequency is 33kHz with a duty ratio of 0.6. Inductor L_{11} and L_{12} is 130 µH.

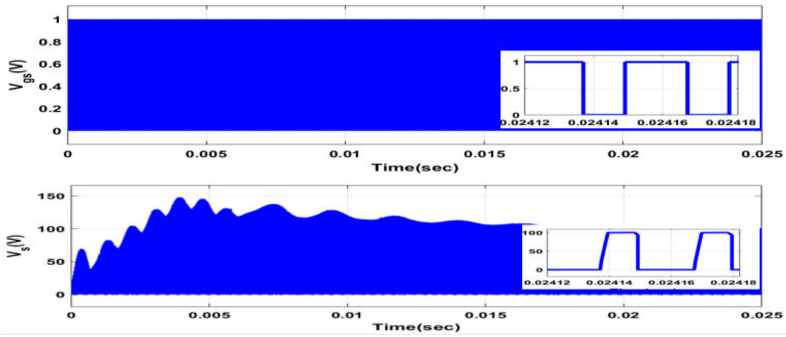
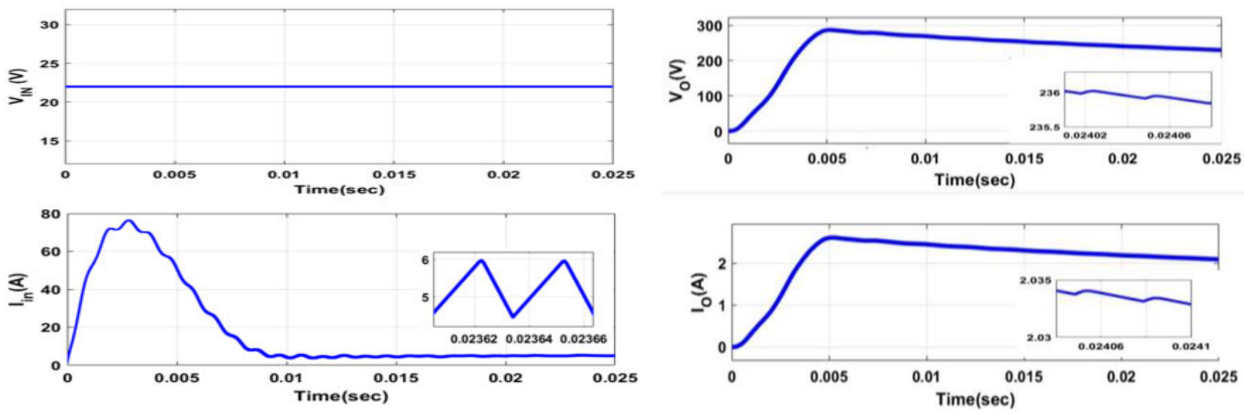


Fig. 4. Gate pulse and voltage stress Vs Simulation time of Switch S_1

The switched inductor-based DC-DC Buck-Boost Converter simulation results are discussed below: Fig 5(a) shows the input voltage, V_{IN} = 22V, and input current, I_{IN} = 4.7A with high transient and ripple of 1A.Fig 5(b) shows the Output Voltage Vo = 231.1V with a ripple of ΔVo = 0.02V. The output voltage increases with a gain of 10.5 by combining the switched inductor concept with the basic circuit. The output current, Io = 2.102A with the ripple of ΔIo=0.61A.The voltage across capacitors C_2 and Co are shown in Fig 6(a). Fig 6(a) gives voltage across capacitor C_2,V_{C2} = 92.15Vripple of 0.05V and (b) gives the voltage across co, V_{CO} = 231.1V with a ripple of 0.02V. Current through inductor L_{11} is shown in Fig. 6(b), V_{L11} = 2.3A with a ripple of 2A. Current through inductor L_2 is shown in Figure 8(b),I_{L2} = 0.9038A with a ripple of 1A. The value of voltage obtained across the switch is Vs = 95V.



(a) (b)

Fig. 5(a).Input voltage and currentVs time and (b)Output voltage and currentVs time

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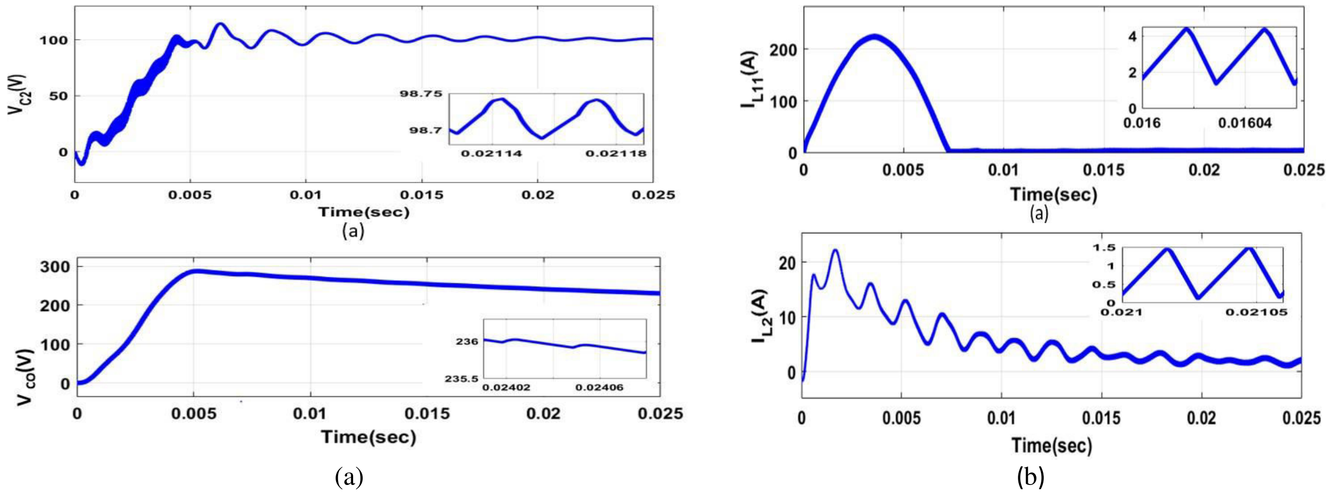

Fig. 6(a). Capacitor voltage of $C_2$and C_{02}Vs Time and (b) Inductor current of $L_{1,}$ $L_{2,}$ L_3 Vs Time

VI.PERFORMANCE ANALYSIS

The efficiency of power equipment is defined as the ratio of output power to input power. The efficiency tells the fraction of input power delivered to the load. Fig. 7(a) shows the efficiency versus Output power graph with R load and RL load. The converter efficiency is around 94 for R Load, as shown in Fig. 10. The converter efficiency is around 92% for RL Load, as shown in Fig. 7.

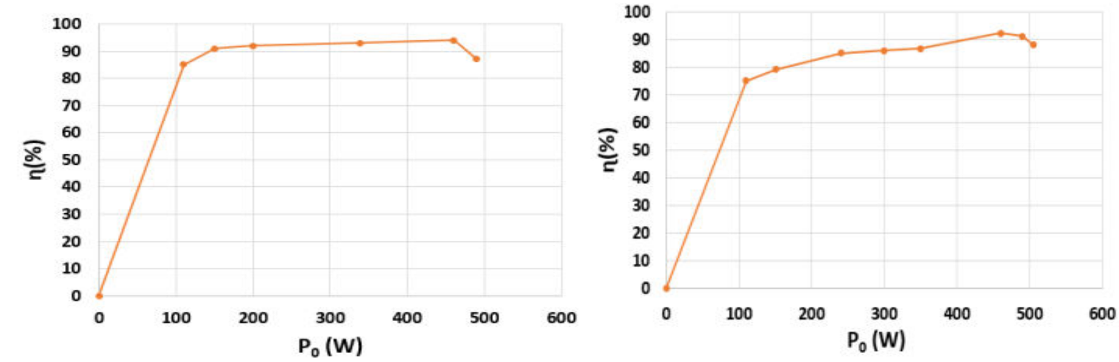

Fig .7 Efficiency analysis R and RL load Vs Output power

The plot of the Voltage gain to duty ratio for R load and RL Load are shown in Fig. 7(a) ,7(b) respectively. The voltage gain increases with the duty ratio. When the duty ratio rises above 0.6, voltage stress starts to increase. So, simulation is done with a duty ratio of 0.6.

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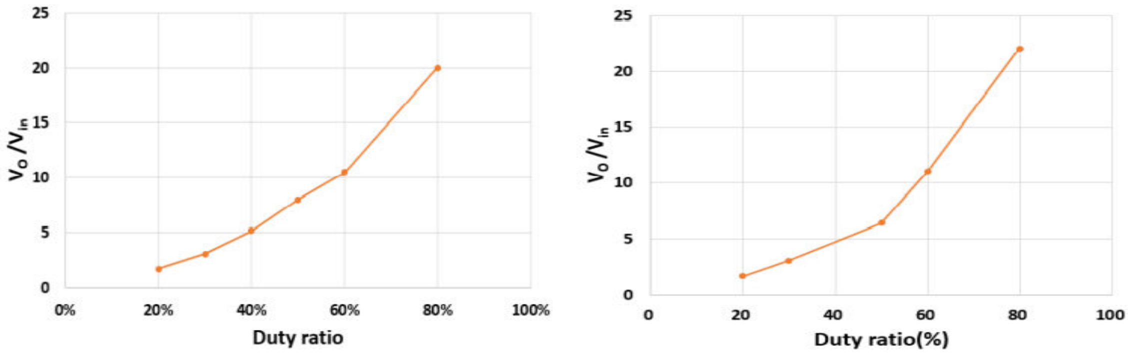

Fig.8Analysis of Gain Vs Duty ratio (R and RL Load)

VII. CONCLUSION

A single switch DC-DC Buck-Boost converter based on switched inductor is introduced. Continuous input current, using a single switch, non-inverting output, and high gain of voltage are the advantages of this converter. The voltage gain, voltage stress of the main switch, number of elements and other specification of this converter has been compared with some other converters. The input voltage is 22V, and the output voltage is 231.1V and the output current is about 2.107A. Output voltage ripple is about 0.025%. Output current ripple is about 0.6%. The maximum efficiency of the converter is about 94% with R load.

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