

Wide range hybrid boost DC-DC converter with active clamp for fuel cell applications

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Abstract: With growing technologies, the exhaustion procedure of fossil fuels occurs at a faster pace. At the moment, research area mainly emphasizes on efficient utilization of the renewable energy resources. To achieve this, many converters have been developed over the years, but there exist some disadvantages in almost all the topologies which may be related to either the gain of the converter, or the overall efficiency, or the voltage stabilization, or the ripple content etc. In this paper, an active clamped, high gain, hybrid, forward boost converter has been developed which will attenuate the above-mentioned problems that are observed in the conventional converters. In the proposed converter topology, two modes are attainable, which maybe further controlled using a push button only. One of the modes involves the closing of the push button, wherein the input voltage will be less and with the help of a less duty cycle, expected voltage is acquired. This mode is known as a hybrid mode. In the second mode i.e. boost mode, required output voltage is obtained from the lower input voltage. In both the modes, high gain and high efficiency are obtained from the converter. The converter simulation and the required results are furnished and provided.

Keywords:Hybrid forward boost DC-DC converter; Active clamped circuit; Renewable energy resources; regulated voltage; voltage stabilization; ripple content.

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1. Introduction

The demand and need for renewable energy resources have been escalated over the past few years. To meet these prerequisites, technologies with high efficiency have been proposed. In order to mitigate the impact of the shortage of fossil fuels, Shahidehpour and Schwartz have proposed in [1], more and more research works are being performed for the proper utilization of renewable energy resources which are associated with some imperfections such as poor efficiency, unregulated output voltage, and high installation cost proposed in Zhao et al. in [6]. In Power Electronics, DC-DC converters play an inescapable role. Various topologies are available. These are common in the areas where high DC voltage is required. This field of Power Electronics is expanding rapidly. Many converters were developed previously Chen et al. in [2] and Zhou et al. in [3] to assimilate with the renewable energy resources efficiently. Many complications are associated with these converters which will lead to poor utilization of the renewable energy resources. Here, we need to step up the output voltage of these resources. In this paper, many DC-DC converters have been studied and compared. In case of boost converter proposed in Wuhua Li et al. in [4] and Baek et al. in [7], the problem is associated with the duty cycle. If its duty is nearing one, we may observe the drooping characteristics because of the losses in circuit components. The switch may get short-circuited which may, in turn, be protected by keeping the duty lesser than 0.8. In case of a forward converter, high voltage gain can be obtained by increasing the number of turns in the transformer. But this will result in a low efficiency because of the leakage flux and adding further windings may lead to increase in the copper losses. In case of boost fly back converter discussed in Lin and Chen in [4], the circuit is complicated because of the added components which lead to losses, high cost, and noise. For obtaining a higher output, larger core of the transformer is required which will result in size issues and increased core losses. The topology which has been suggested will overcome some of the above problems. Some of the advantages of the propounded converter are high gain, high efficiency, negligible ripple, high power density, etc. The required voltage can be obtained employing a low duty cycle and galvanic isolation between input and output. The block diagram of the converter is shown in Fig. 1.

Some of the applications of the converter are an electric siren, electric winch, and adaptor. The electric siren works when there is any emergency condition like fire, natural disaster, smoke, etc. The electric siren helps in perceiving the emergency condition and then making people aware of the situation through any video, display or sound. This alert will get conveyed further from people to people. These are more common in health centers, industries, etc. The electrical winch is a mechanical device which needs a supply of $120V_{AC}$. It helps in tension adjustments of the rope or helps in moving the rope inwards or outwards. There are different types of the electrical winch which are mainly used for lifting heavy things. AC adaptor is indirectly known as AC-DC converter which is also known as AC plug. The source voltage which is required for the adaptor is $120V_{AC}$. Adaptors are used in the electrical equipment where there is no provision for storage of power and voltage. After getting the output voltage of 170V from the propounded converter, it is given to the inverter to get an output voltage of $120V_{AC}$.

2. Steady State Analysis

To study the steady state analysis of the proposed converter as shown in Fig.2, it is necessary to emphasize on the modes of operation of the propounded converter. The suggested converter is a combination of the conventional boost converter and the forward converter. The suggested converter is consisting of the components such as one MOSFET switch, one transformer, four diodes, two inductors, and four capacitors.

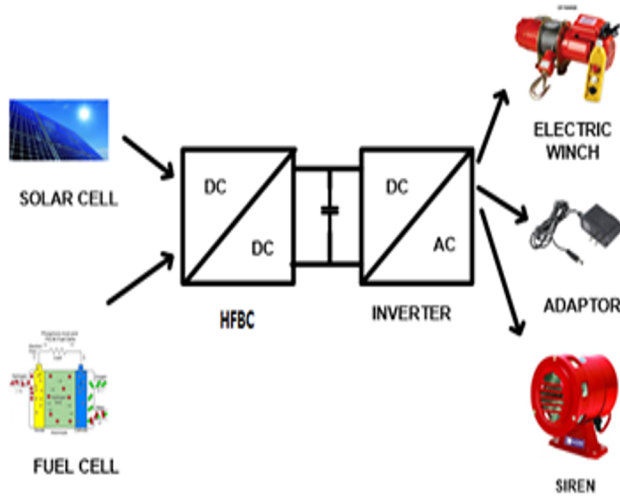


Fig. 1. Block diagram of the proposed converter.

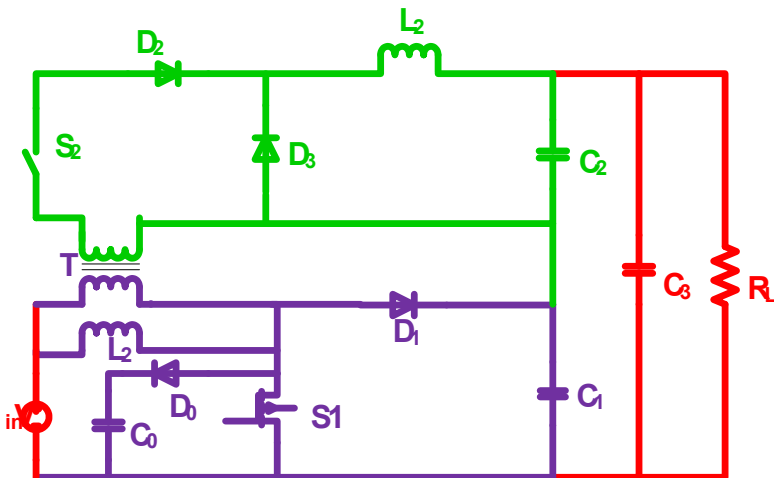


Fig. 2. Circuit diagram of the proposed converter.

2.1. Mode 1 (Hybrid Mode)

S₁ is on:

When the switch S_1 is in the on position, the primary voltage of the transformer is equal to the input voltage. L_1 is the magnetizing inductor. The input current is having two components. One is the magnetizing current in the inductor i.e. i_{L1} and the another one is the transformer's primary (ideal part) current i.e. i_p . There is an increase in the magnetizing current of the transformer due to the voltage at the primary. When the switch S_1 is in the on position, Δi_{L1} can be found by the following equation.

$$V_p = V_{in} = L_1 \frac{\Delta i_{L1}}{\Delta T_{on}} \quad (1)$$

Since transformer's secondary is having positive voltage, diode D_2 is not conducting but diode D_3 conducts.

The voltage (V_{L2}) across the inductor L_2 and the change in current through L_2 can be found by following equations.

$$V_L = \left(V_{C1} - V_{in} \frac{N_s}{N_p} \right) - V_o = L_2 \frac{\Delta i_{L2}}{\Delta T_{on}} \quad (2)$$

Since diodes D_1 and D_2 are at off condition, the current through them are zero. The respective voltages are as follows.

$$V_{D1} = V_s = V_{in} \frac{N_s}{N_p} \quad (3)$$

S_1 is off:

When the switch S_1 is at off position, the primary voltage and secondary voltage of the transformer can be found from the following equations.

$$V_s = (V_{in} - V_{C1}) \frac{N_s}{N_p} \quad (4)$$

Let us now assume that V_{C1} value is higher than V_{in} , then the secondary voltage of the transformer is negative. So the diode D_3 is not conducting but diode D_2 conducts. But the current through the secondary side of the transformer is zero. This implies that the current at the primary side is due to i_{L1} i.e. the magnetizing current. Now the magnetizing current flows through the diode D_1 . This current is divided into two parts, one part is for charging C_1 and the other part moves up and through D_2 it flows to supply current to the load resistor. The voltage (V_{L2}) across the inductor L_2 and the change in current through L_2 can be found by following equations.

$$V_L = -V_{C2} = L_2 \frac{\Delta i_{L2}}{\Delta T_{off}} \quad (5)$$

For one complete cycle, the current flow is shown in Fig.4. For steady state operation, the addition of Δi_{L2} value for turn on and turn off of the switch should be zero. With the help of the equation 1 to 8, the following analysis can be done. The equivalent circuits of Mode 1 are shown in Fig.3. and Fig.4.

$$-V_{C2}(1-D) + \left(V_{C1} + V_{in} \frac{N_s}{N_p} \right) D + V_o D = 0 \quad (6)$$

By using KVL across the resistive load R_L and the two capacitors C_1 and C_2 , the following can be obtained.

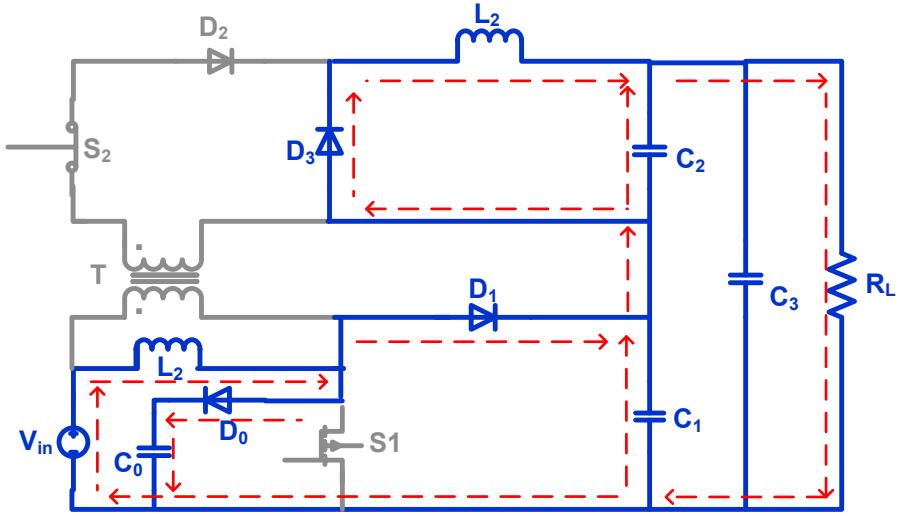


Fig. 4. Flow of current in Mode 1 when S_1 is at off position.

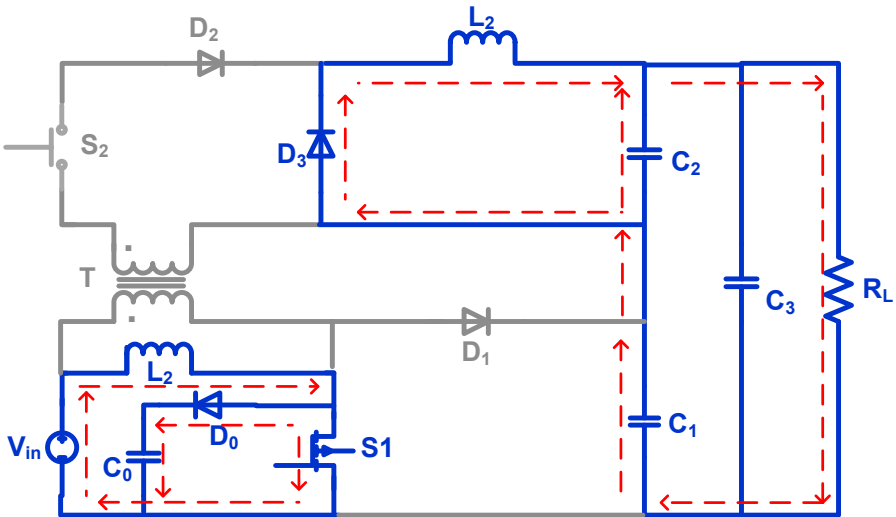


Fig. 5. Flow of current in Mode 2 when S_1 is at on position.

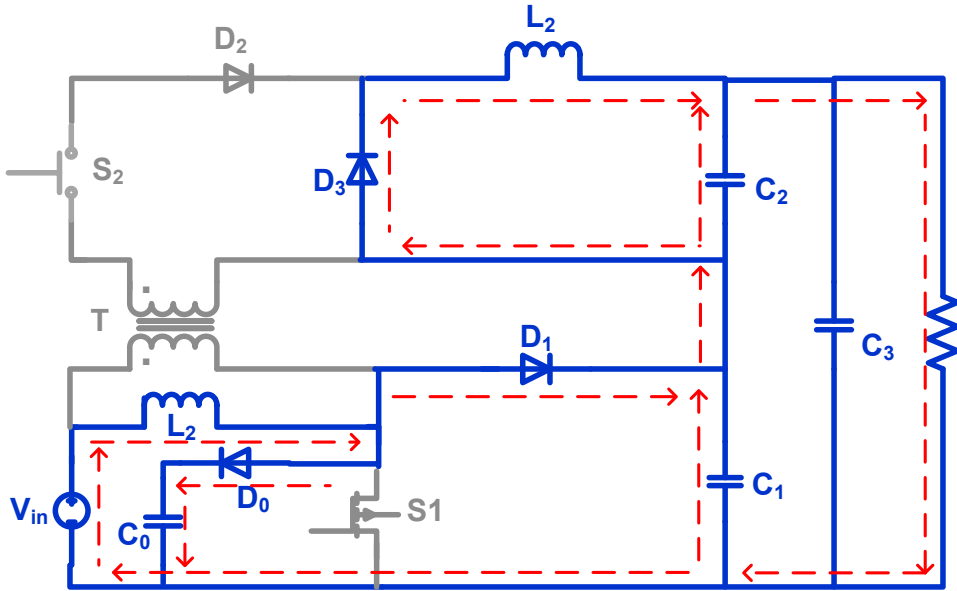


Fig. 6. Current flow in Mode 2 when S_1 is at on condition.

Here also since the switch (S_1) is at off position, only magnetizing current flows through the primary of the transformer. For one complete cycle, the flow of current in the hybrid converter, when the push button is open, is shown in Fig.6. For a stable system, the starting and the ending point of current should be at the same point in each cycle. For steady state operation, the addition of Δi_{L2} value for turn on and turn off of the switch should be zero.

$$\frac{\Delta T_{on} V_{in}}{L_1} + \frac{(V_{in} - V_{C1}) \Delta T_{off}}{L_1} = 0 \quad (9)$$

Using the concept of duty ratio and with the help of equation 23, the voltage at capacitor C_1 is as follows.

$$V_{C1} = \frac{V_{in}}{(1-D)} \quad (10)$$

2.3. Design of the Proposed Converter

The converter is designed with the following specifications. The input voltage given to the converter (V_{in}) is 30-50V. Expected output voltage is 170V. The converter is operated with a switching frequency of 100 kHz. Output power is 200Watts. Turns ratio of the transformer used is 1:3. To operate the proposed converter in continuous conduction mode, the inductor values should be more than the below-mentioned minimum values.

$$L_{1\min} = \frac{D(1-D)^2 R_L}{2f} \quad (11)$$

The designing equation of the inductor (L_2) consists of switching frequency, load resistance and duty cycle, the input voltage (V_{in}), turns ratio (N_s/N_p), the voltage across the capacitor C_2 (V_{C2}) and inductor current ripple (Δi_{L2}). It is derived from the forward converter.

Mode 2 (Boost Mode)

$$L_{2\min} = \left[V_{in} \left(\frac{N_s}{N_p} \right) - V_{C2} \right] \frac{D}{f \Delta i_{L2}} \quad (12)$$

For calculation of capacitor value, voltage ripple should be kept in mind. The designing of the capacitor (C_1) is derived from boost converter. Here the accepted has been taken as 5%.

$$C_{1\min} = \frac{D}{f \times R_L \times \%ripple} \quad (13)$$

Similarly, designing of the capacitor (C_2) is derived from the forward converter. Here also the accepted limit has been taken as 5%.

$$C_{2\min} = \frac{1-D}{f \times R_L \times \%ripple} \quad (14)$$

3. Simulation of the proposed Hybrid Forward Boost Converter

For the simulation, an input voltage of 30V-50V was given to the converter which is shown by the DC voltage source in the simulation circuit. The converter is tested for an output voltage of 170V and 200W. With the help of PSIM software, the simulation is done.

3.1. Mode 1 (Hybrid Mode)

Here an input voltage of 30V is given to the converter and an output of 170V is obtained. The converter is operated with the duty of 0.6 with a switching frequency of 100kHz. The simulation results are shown in Fig.7. In this mode of operation, an input voltage of 50V was given to the converter and an output of 170V was obtained.

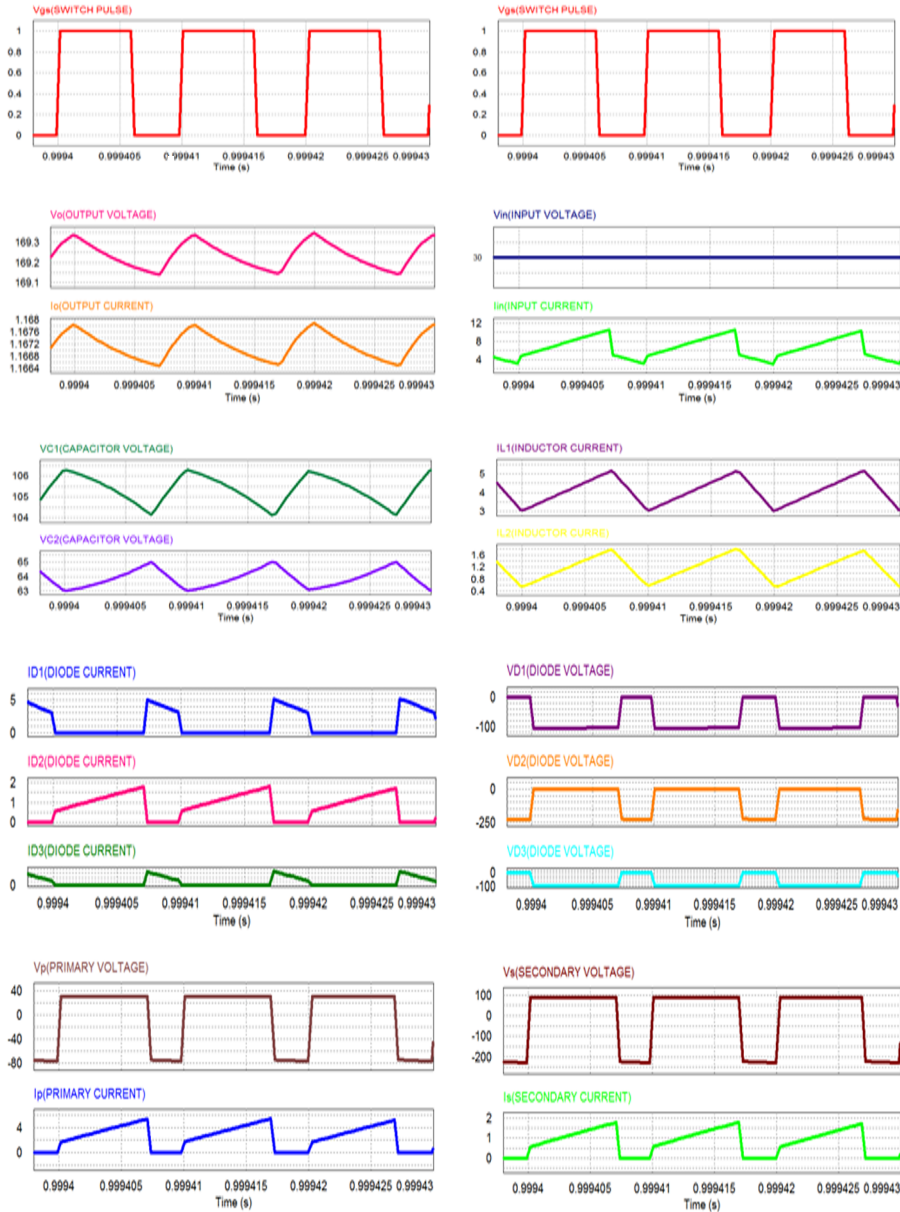


Fig. 7. Waveforms of gate pulse, input voltage, input current, output voltage, output current, inductor currents of L_1 and L_2 , voltages of capacitor C_1 and C_2 , currents of diode D_1 , D_2 and D_3 , voltages of diode D_1 , D_2 and D_3 , primary voltage and current, secondary voltage and current.

The converter was operated with the duty of 0.7 with a switching frequency of 100 kHz. The simulation results are shown in Fig.8.

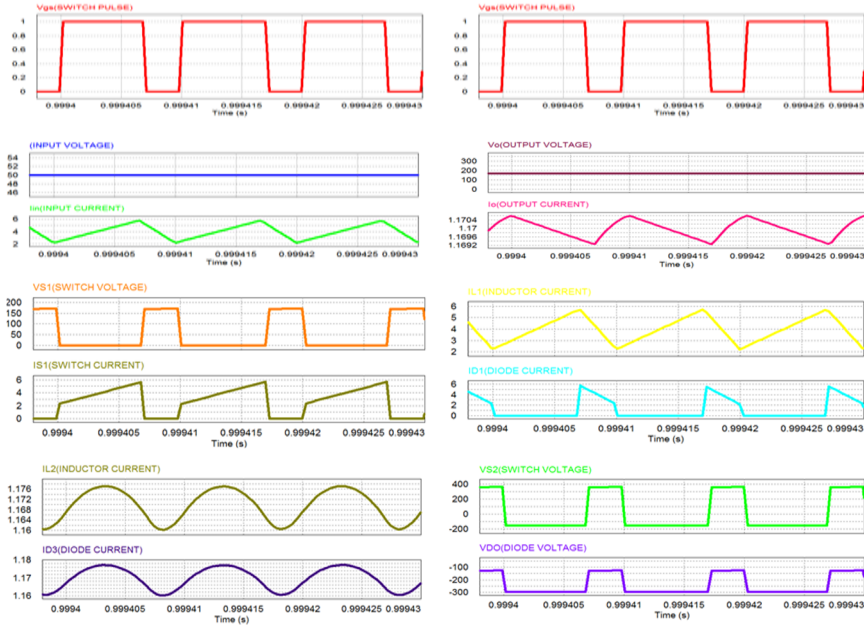


Fig. 8. Waveforms of gate pulse, input voltage, input current, output voltage, output current, switch voltage and current, current of L_1 and D_1 , Current of L_2 and D_3 , switch voltage and clamping diode voltage.

4. Conclusion

There are so many problems associated with all the converters developed before and the renewable resources are also prone to many issues. The proposed converter helps in reducing these problems. The proposed converter has been simulated for the 200W load. The converter gives an efficiency of 90% (for hybrid mode) and 95.4% (for boost mode). The converter is also having an negligible ripple, high gain, galvanic isolation, and high power density. The proposed converter can be automated by replacing push button with a MOSFET (controlled by the sensor) and can be fabricated in a PCB board for household purpose.

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