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High Step-Up Converter for Residential Power Generation System

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Abstract: The DC-DC converter with high step-up voltage gain is widely used for many applications such as uninterruptible power supply, solar-cell energy conversion systems, and high-intensity-discharge lamp ballasts for automobile headlamps. In these applications, a classical boost converter is normally used, but the voltage conversion ratio is not so high. Other techniques for boosting the voltage may lead to increasing the complexity of the circuit. This paper presents a high voltage boosting DC-DC converter topology intended for residential power systems. The high step up converter is based on charge pump capacitors and boost inductors. The converter will function appropriately even though boost inductor values are different.The output of this converter is connected to a single phase inverter for powering residential loads. The simulation is carried over by the MATLAB-Simulink.

Keywords: Step Up Converter, Charge Pump Capacitor, Boost Inductor.

I. INTRODUCTION

Generally high step up converters have numerous applications in the industry, such as in uninterruptible power supply, high intensity discharge lamp and solar cell system [1]. A dc-dc converter converts the fixed dc voltage to variable dc voltage. If the output voltage is more than the input voltage the converter to be referred as boost (step-up) converter. In PV system the output voltage of a typical photovoltaic panel is 12V, in order to increase the voltage level step up converter is used. Then a dc-ac converter is used for transferring dc voltage to ac voltage output which can be used for powering residential loads.

The structure of boost converter is simple and theconversion ratio is not high, in case of fly-back convertereven though the conversion ratio is high there will be high leakage inductance. Many other step up converters [2]-[9] have been presented. By increasing the number of inductors high voltage conversion ratio may obtain. With inductors connected in series, during the demagnetizing period the input voltage and the energy stored in the inductors will be added to the output voltage to have the high voltage conversion ratio. The current flowing through the inductor can be considered as a current source [2]. If inductors with different values are connected in series mean current source with different values are connected in series there by Kirchhoff's current law (KCL) is violated and failing such a circuit. Another method of obtaining high voltage gain is using coupled inductors in the circuit, but the problem is due to the presence of leakage inductors complexity of circuit increase and as a result circuit analysis become difficult.

From the above reasons, high conversion ratio step up converter based on two boost inductors and two charge pump capacitors is presented. Although, two different inductors are connected in series during demagnetizing period these converters will function appropriately. Here in this paper explanation of modes of operation of the converter along with simulation results are given and also the converter output is given to a single phase inverter for feeding residential loads.

II. CONVERTER TOPOLOGY

Fig. 1.shows the block diagram of the converter topology. Here input supply is a dc source which is connected to the high step up converter with charge pump capacitors and boost inductors and then it is given to a single phase inverter for feeding loads.The switching signals will control the power semiconductor switches in the circuit

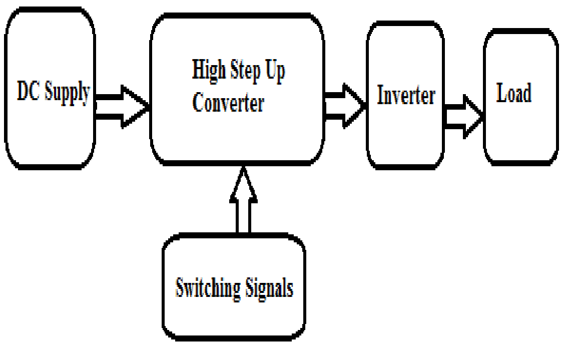

Fig. 1. Block diagram of the converter

The high step upconverter circuit is shown in Fig. 2. The circuits consist of three MOSFET switches S_1, S_2, and S_3, two charge pump capacitors C_b and C_e, two boost inductors L_1 and L_2, threecharge pump diodes D_1, D_2, and D_b, one output capacitor C_0, one output diode $D_0$and the resistance load R_L.Here $V_i$represents the input voltage and Vo represents the output voltage. The voltages across C_b, C_e, D_1 and D_2 are represented as V_{Cb}, V_{Ce}, v_{D1}, $v_{D2,}$respectively, and i_{L1}, i_{L2}, i_{Do} represents the currents flowing through L_1, L_2, D_0, respectively.

The principle of operation of converter is based on charge pump principle of KY converter [9] and series boost converter. The voltage conversion ratio will be $\frac{3+D}{1-D}$incontinuous conduction mode of operation, where D is the duty cycle of PWM control signal of switch S_1 which is created by the controller. The converter gives high conversion ratio on the basis of modes of operation. Thus the converter is suitable for industrial application.

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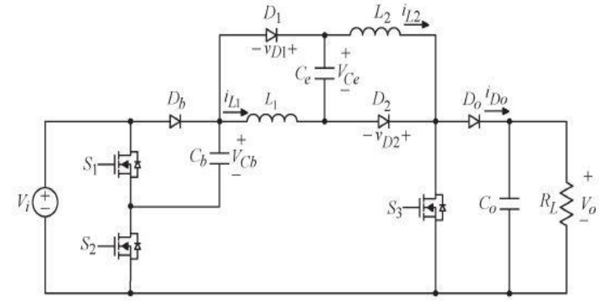

Fig. 2.Circuit diagram of high step up converter based on charge pump capacitors and boost inductors

III. OPERATING MODES OF THE CONVERTER

Some assumptions are considered for the analysis of the converter which is given as follows:

1) The blanking time between switches are not considered.
2) The voltage drops across switches and diodes are neglected during the turn-on time.
3) The capacitors C_b and C_e works on charge pump principle, hence the values of these capacitors are large enough to keep the voltage across them constant.

Table I shows the PWM turn-on types for three switches and the voltage across charge pump capacitors. The switches S_1 and S_3 triggered at the same time with a duty ratio of D and switch S_2 is triggered with duty ratio 1-D. Voltage across charge pump capacitors C_b and C_e are V_i and $2V_i$ respectively.

TABLE 1 PWM TURN-ON FOR SWITCHES AND VOLTAGE ACROSS CHARGE PUMP CAPACITORS

S_1	S_2	S_3	V_{cb}	V_{ce}
D	1-D	D	V_i	$2V_i$

Converter can be operated in continuous conduction mode and discontinuous conduction mode. Here circuit is analyzed for continuous conduction mode for equal values of inductance.

Mode 1: In this mode switches S_1 and S_3 are turned on and S_2 is turned off. The diode D_1 and D_2 are forward biased and D_o is reverse biased due to turning on the S_3 switch. The capacitor Ce is immediately charged to input voltage plus voltage across capacitor C_b and the inductors are magnetized. During this period the output capacitor will supply the power to the load. Fig.3. Shows power flow of mode1 operation. Voltage across L_1 and L_2 can be written as

$$v_{L1-ON} = V_i + V_{cb} \quad (1)$$
$$v_{L2-ON} = V_i + V_{cb} \quad (2)$$

Mode 2: In this mode switch S_2 is turned on and S_1 and S_3 are turned off. Diode D_b is forward biased since S_2 being turned on. The capacitor C_b is immediately charged to input voltage and the capacitor C_e is going to be discharged and the inductors are demagnetized. Along with input voltage the energy stored in inductors L_1 and L_2 plus energy stored in capacitor C_e is given to the load and also output capacitor C_0 is energized.

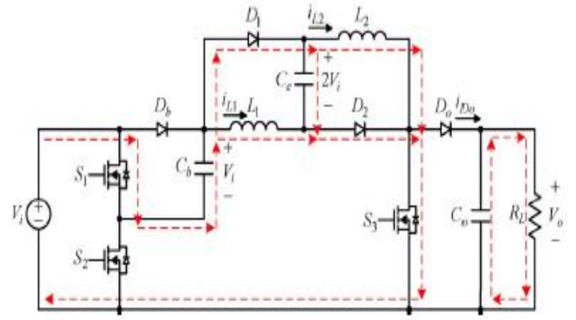

Fig. 3.Power flow of high step up converter in mode 1 operation

Thus output voltage becomes much higher than input and output voltage of the converter is boosted up to a high value.

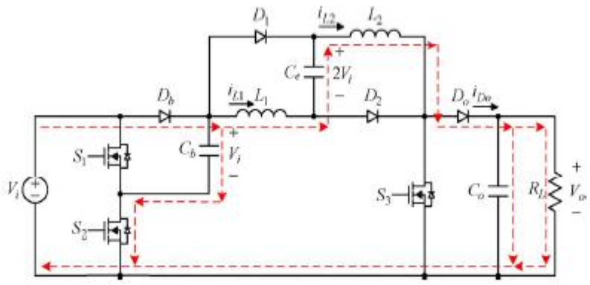

Fig. 4.Power flow of high step up converter in mode 2 operation

Fig. 4.shows power flow of mode 2 operation. Voltage across L_1, L_2 and output voltage can be obtained by voltage- second balance principle.

$$v_{L1-OFF} = \frac{-D}{1-D} v_{L1-ON} \quad (3)$$
$$v_{L2-OFF} = \frac{-D}{1-D} v_{L2-ON} \quad (4)$$
$$V_O = -v_{L1-OFF} - v_{L2-OFF} + V_i + V_{ce} \quad (5)$$

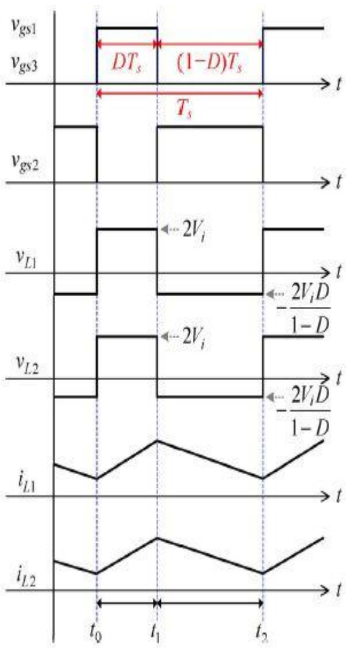

Fig. 5.Waveforms of high step up converter in continuous conduction mode

Since the voltage of charge pump capacitors are V_I for C_b and $2V_i$ for Ce, equations (1), (2), (5) can be written as

$$v_{L1-ON} = v_{L2-ON} = 2V_i \qquad (6)$$

$$V_O = -v_{L1-OFF} - v_{L2-OFF} + 3V_i \qquad (7)$$

Substituting equation (6) in (3) and (4), $v_{L1\text{-}OFF}$ and $v_{L2\text{-}OFF}$ can be written as

$$v_{L1-OFF} = V_{L2-OFF} = \frac{-D}{1-D} 2V_i \qquad (8)$$

Fig. 5. Shows the waveforms of gate pulses for switches S_1, S_2 and S_3 which is denoted as v_{gs1}, v_{gs2}, v_{gs3} respectively. Voltages across inductances L_1 and L_2 are denoted as v_{L1} and v_{L2} and i_{L1} and i_{L2} are current through L_1 and L_2.

Substituting (8) in (7), the voltage conversion ratio in continuous conduction mode is given by

$$\frac{V_0}{V_i} = \frac{3+D}{1-D} (9)$$

IV. SIMULATION RESULTS

Simulation of the high step up converter with inverter circuit can be done using MATLAB SIMULINK..Fig. 6.shows the simulink model of overall circuit.Closed loop control is adopted here. The high step up converter which transfers low voltage to high voltage which will be transferred to the ac output voltage via dc-ac converter.

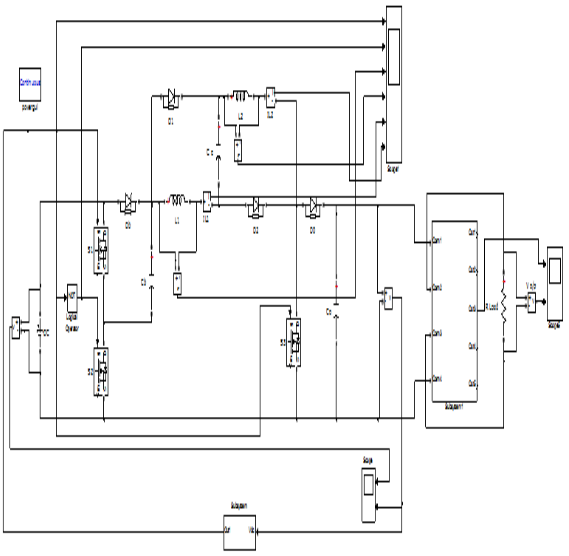

Fig. 6.Simulink model of the overall circuit

The circuit which consists of mainly two sections.High step up converter unitand inverter unit. The input of converter is a dc supply which can be from a solar cell or fuel cell, so it requires a high step up converter for boosting low voltage to a higher value. The output of this boosting converter is connected to a single phase inverter for obtaining single phase alternating voltage. This ac voltage can be used for powering residential loads. MATLAB simulink model of high step up converter unitwith closed loop control is shown in Fig. 7 and Fig. 8 shows the inverter unit and load is taken as resistive.

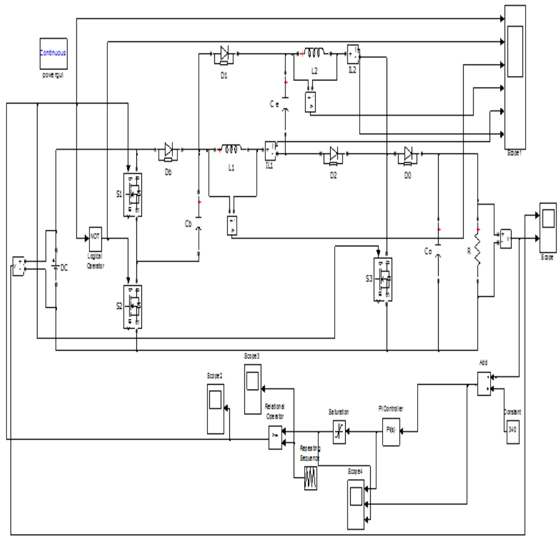

Fig. 7.Simulink model of high step up converter

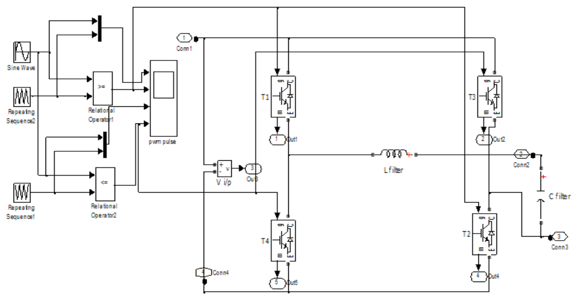

Fig. 8.Simulink model of inverter subsystem

PWM gate driving signals for switches of high step up converter unit are shown in Fig. 9. Switch S_1 and S_3 triggered simultaneously and triggering of S_2 is compliment.

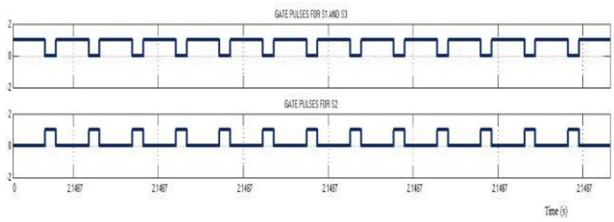

Fig. 9.PWM gate driving signals for switches of high step up converter unit

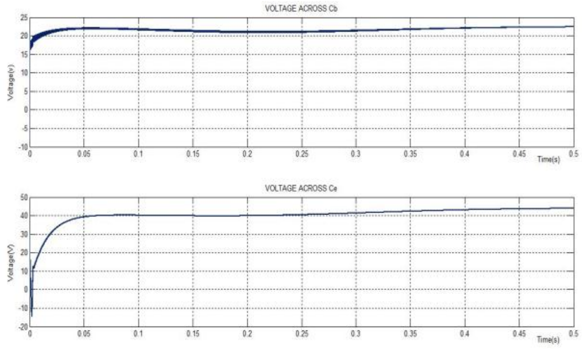

Fig. 10.Voltage across capacitor C_b and C_e

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Since the capacitors work on the principle of charge pump, Capacitor C_b is charged to a voltage V_i and capacitor C_e is charged to $2V_i$. Fig. 10 shows the voltage waveform across capacitor C_b and C_e .
The voltage across inductors L1 and L2 and corresponding current through it are shown in Fig. 11. For an input voltage of 24V, output of step up converter is obtained as 340V for a duty ratio of 0.75 which is shown in Fig. 12. Single phase inverter is connected to output of converter for obtaining single phase ac voltage. Sinusoidal pulse width modulation is used for pulsing the switches of inverter. For the inverter circuit switches T1 and T2 is triggered simultaneously for 180 degrees and then T3 and T4 conducts for next half cycle. Pulses for switching are formed by comparing sinusoidal wave with triangular signal. Fig. 13 shows pulses for inverter switches and output waveform of inverter is shown in Fig. 14.

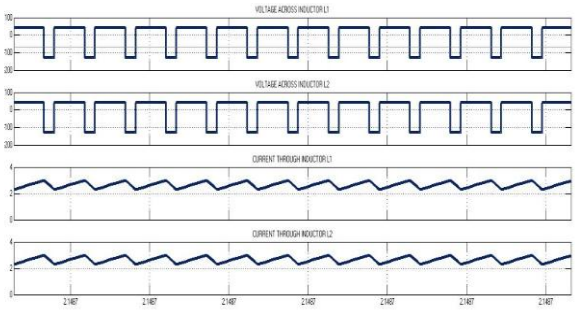

Fig. 11.Voltage and current through inductors L_1 and L_2

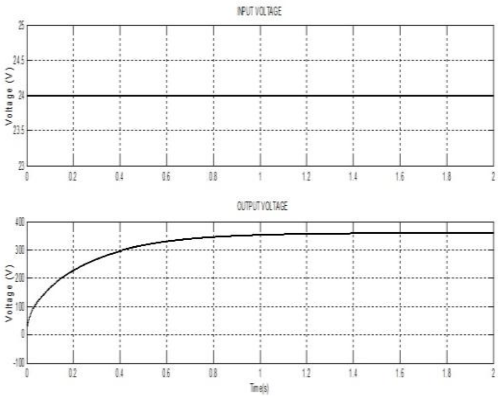

Fig. 12.Simulation waveforms of input and output voltage waveforms of high step up converter

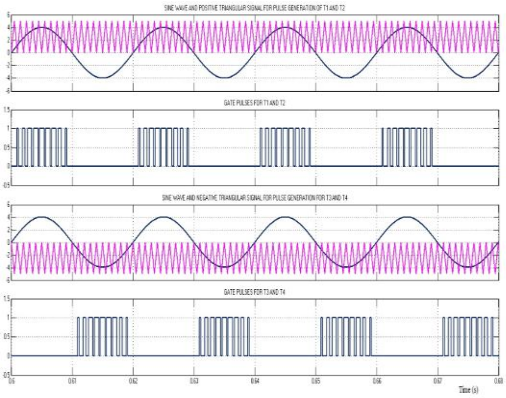

Fig. 13. PWM gate driving signals for switches of inverter unit

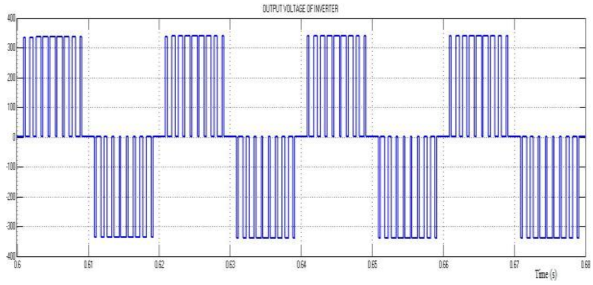

Fig. 14.Simulation waveforms of inverter output voltage

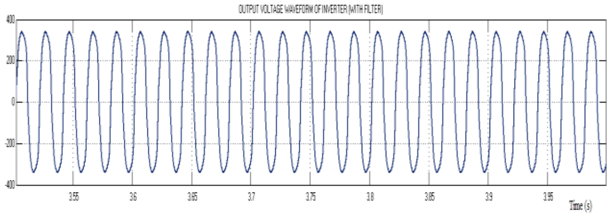

Fig. 15.Simulation waveforms of inverter output voltage (with filter)

Fig. 15 shows output voltage waveform of inverter with LC filter. Thus voltage of 240 V (RMS) and 50Hz frequency is obtained which can be used for feeding residential loads.

V. CONCLUSION

A high voltage-boosting converter with inverter topology is presented here, in which converter is based on inductors connected in series with charge pump capacitors and high conversion ratio is obtained by this method. The output of converter is given to a single phase inverter. The modes of operation of the overall circuit and simulation results are presented. From the simulation results, the converter exhibit good performance with different inductor values and hence suitable for industrial applications and this converter can be used for powering residential loads.

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