

A Fuzzy Controlled High Voltage Boosting Converter Based On Boost Inductors and Capacitors

V.V Jayashankar¹, K.P Elby², R Uma³

¹Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kolenchery, Ernakulum, Kerala, India)

²Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kolenchery, Ernakulum, Kerala, India)

³Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kolenchery, Ernakulum, Kerala, India)

Abstract: A novel high voltage-boosting converter topology is explained in this paper. By changing the connection position of the anode of the diode two types of converters are obtained-Type1 and Type2. These converters are constructed based on boost inductors and capacitors and have different voltage conversion ratios. Furthermore, although there are three switches in each converter, only one half-bridge gate driver and one low-side gate driver are needed, but no isolated gate driver would be needed. In this paper, closed loop control of type2 converter using fuzzy logic controller is explained. Some simulated results are provided to verify the effectiveness of the proposed converter.

Keywords: Boost converter, fuzzy logic controller, voltage-boosting converter, voltage conversion ratio.

I. Introduction

As generally recognized, step-up converters have been widely used in many applications, such as battery powering device, uninterruptible power supply (UPS), photovoltaic (PV) system, etc. requiring some circuits transferring low voltages to high voltages used as input voltages for dc-ac converters[2],[3]. For the applications of the power supply using the low voltage battery, analog circuits, such as RF amplifier, audio amplifier, etc., often need high voltage to obtain enough output power and voltage amplitude. This is achieved by boosting the low voltage to the required high voltage. Therefore, in many 3C (consumer, communications, computer) electronics, some converters are needed to supply one boosted voltage or more under a given low voltage, especially for portable communications systems, such as MPEG-3 (MP3) players, Bluetooth devices, personal digital assistant, etc. For such applications, the output voltage ripple must be taken into account seriously. Regarding the conventional nonisolated voltage-boosting converter such as the boost converter and the buck-boost converter, their output currents are pulsating, thereby causing the corresponding output voltage ripples to tend to be large. As generally acknowledged, to overcome this problem, one way is to use the capacitor with large capacitance and low equivalent series resistance (ESR), another way is to add an inductance-capacitance (LC) filter, and the other way is to increase the switching frequency. Recently, some voltage-boosting converter topologies with low output voltage ripples have been derived. In some converters, the voltage-lift technique is utilized to boost the output voltage along with the small output voltage ripple taken into account [4], [5].

However, it is not easy for boost converter or the buck-boost converters to achieve high voltage ratio. In theory, the voltage ratios of these two converters can reach infinity, but in actuality about four or five, limited by parasitic component effect and controller capability. Consequently, if the voltage ratio of the converter is desired to be over five, then two-stage converter based on the boost converter or the buck-boost converter is utilized, or different converter topologies are created[6]-[8]. The boost converter is simple in structure, but the voltage conversion ratio is not so high, whereas the flyback converter possesses a high voltage conversion ratio but the corresponding leakage inductance is large. In certain converter topologies, a method of improving the voltage conversion ratio is proposed, which is based on the fact that the number of inductors is increased, and these inductors are connected in series during the demagnetizing period, thereby pumping the energy created by the input voltage and the energy stored in the inductors into the output terminal to obtain the high voltage conversion ratio [9], [10].

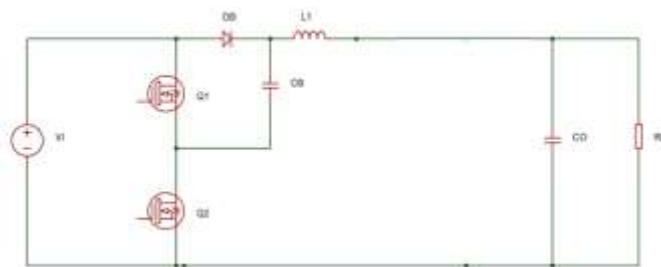


Fig. 1 KY converter

A new voltage-boosting converter, named as KY converter, provides low output voltage ripple and is very suitable for supplying power to devices that must operate under low-ripple conditions[11]-[14]. Unlike the conventional boost converter, it offers very fast load transient responses, similar to the behavior of the buck converter with synchronous rectification (SR). Besides, in order to enlarge the output voltages, additional proposed converters derived from the KY converter are proposed. KY converter always operates in continuous conduction mode (CCM). Besides, the output current is nonpulsating. However, its ratio of the output voltage to the input voltage is one plus D , where D is the duty cycle of the main switch. As a consequence, to further enlarge the output voltage under the same duty cycle, second-order-derived KY converters, 1-plus- $2D$ and 2-plus- D converters, are used under the same structure but different control strategies.

Since the voltage conversion ratios can be upgraded by increasing the number of voltage-boosting cells, two high voltage-boosting circuits, based on two boost capacitors and two inductors, are presented here. The two inductors are connected in series during the demagnetizing period. In addition, based on different diode connections, two voltage-boosting converters with different voltage conversion ratios are generated under similar circuit structure. Under the same condition that two inductors and two capacitors are used except the input capacitor, any one of the proposed voltage conversion ratios is higher than all the other voltage conversion ratios in the conventional converters. On the other hand, under the condition where the same components are used, the proposed converters have higher voltage conversion ratios. In this paper, a brief illustration of the operation of one of the two converters is given along with some simulation results provided to demonstrate the effectiveness of such converters. Here, the closed loop control of the type2 converter, with same value for both inductors, is analyzed using fuzzy logic control [15] which ensures better performance of the converter than using other conventional control strategies.

II. Proposed converter topologies

Two converter topologies can be derived from the proposed high voltage-boosting converter. Each have individual voltage conversion ratios and individual control strategies. Hence, the type 1 converter is described in Fig. 3.1(a), whereas the type 2 converter is shown in Fig. 3.1(b).

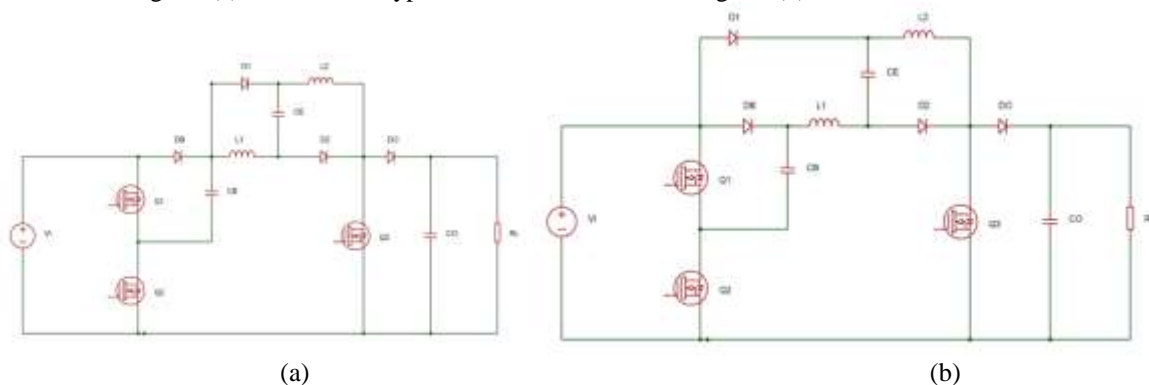


Fig.2 proposed voltage-boosting converters: (a) type 1; (b) type 2.

It is noted that the difference in circuit between Fig. 3.1(a) and (b) is the location of the anode of D_1 . Each converter contains three MOSFET switches Q_1 , Q_2 , and Q_3 , two boost capacitors C_b and C_e , three diodes D_b , D_1 , and D_2 , one output diode D_o , two inductors L_1 and L_2 , one output capacitor C_o , and one output resistor R_L . In

addition, the input voltage is signified by V_1 , the output voltage is represented by V_o , the voltages across C_b , C_e , D_1 , and D_2 are shown by V_{Cb} , V_{Ce} , V_{D1} , and V_{D2} , respectively, and the currents flowing through L_1 , L_2 , and D_o are denoted by I_{L1} , I_{L2} , and I_{D_o} , respectively.

Here, the proposed converters are based on the charge pump of the KY converter and the series boost converter. By doing so, the conversion ratios can be upgraded further. Above all, if the anode of the diode D_1 is connected to the cathode of the diode D_b , the conversion voltage ratio in continuous conduction mode (CCM) is $(3 + D)/(1 - D)$, where D is the duty cycle of the control signal created from the fuzzy logic controller, whereas if the anode of the diode D_1 is connected to the anode of the diode D_b with switch turn-on types different from those of the former, the conversion ratio in CCM is $(3 - D)/(1 - D)$. Therefore, the proposed converters can be used according to industrial applications. In this paper, closed loop control of Type 2 converter using fuzzy logic controller is analyzed. Above all, the converter operated in the CCM under the condition that L_1 is equal to L_2 is analyzed here. The result is also verified by using MATLAB software.

III. Basic operating principles

There are some assumptions about the operation of the proposed converter. They are:

- 1) The blanking times between the switches are omitted.
- 2) The voltage drops across the switches and diodes during the turn-on period are negligible.
- 3) Since the boost capacitors C_b and C_e , operating based on the charge pump principle, are abruptly charged to some voltage within a very short time, which is much less than the switching period T_s , the values of C_b and C_e are large enough to keep the voltages across themselves constant at some values, and hence it is reasonable that the voltages across the capacitors C_b and C_e are both V_1 for type 2.

For these two converters to be considered, the turn on types for three switches and the voltages on the boost capacitors are tabulated in Table.1.

Table.1 Turn-on types for switches and voltages on capacitors

	Q_1	Q_2	Q_3	V_{cb}	V_{ce}
Type 2	$1-D$	D	D	V_1	V_1

There are basically two operating modes for the proposed converter. They are:

- a) Mode 1 [$t_0 < t < t_1$]:

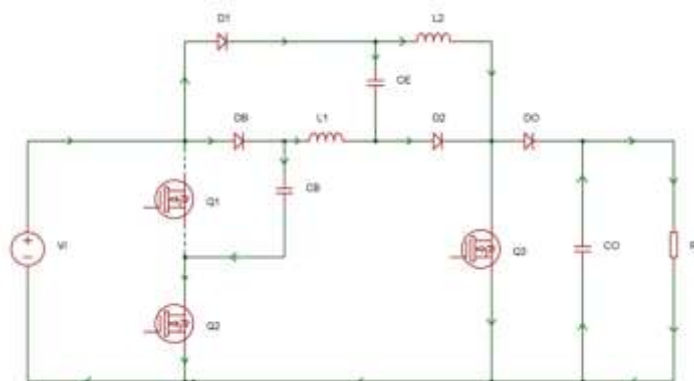


Fig.3 power flow of type 2 operated in CCM with L_1 equal to L_2 in mode 1.

As shown in Fig 3, Q_2 and Q_3 are turned on, but Q_1 is turned off. Due to Q_3 being turned on, D_o is reverse biased, but D_1 and D_2 are forward biased, thereby causing C_e to be abruptly charged to V_1 , whereas due to Q_2 being turned on, D_b is forward biased, thereby causing C_b to be abruptly charged to V_1 . At the same time, the voltages across L_1 and L_2 both are V_1 , thereby causing L_1 and L_2 to be magnetized. Also, C_o releases energy to the output. In this mode, the voltages across L_1 and L_2 , V_{L1-ON} and V_{L2-ON} , can be written as:

$$V_{L1-ON} = V_1 \quad (1)$$

$$V_{L2-ON} = V_1 \quad (2)$$

- b) Mode 2 [$t_1 < t < t_2$]:

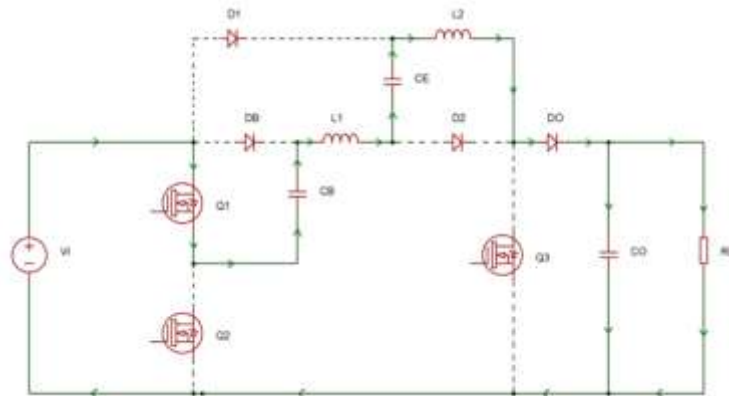


Fig.4 power flow of type 2 operated in CCM with L_1 equal to L_2 in mode 2.

As shown in Fig. 4, Q_2 and Q_3 are turned off, but Q_1 is turned on. At the same time, the input voltage plus the energy stored in C_b and C_e plus the energy stored in L_1 and L_2 supplies the load, thereby causing C_o to be energized, C_b and C_e to be discharged, and L_1 and L_2 to be demagnetized. By doing so, the output voltage is boosted up, and is higher than the input voltage. According to the voltage-second balance, the voltages V_{L1-OFF} , V_{L2-OFF} , and V_o can be expressed as:

$$V_{L1-OFF} = \frac{-D}{1-D} V_{L1-ON} \quad (3)$$

$$V_{L2-OFF} = \frac{-D}{1-D} V_{L2-ON} \quad (4)$$

$$V_o = -V_{L1-OFF} - V_{L2-OFF} + V_1 + V_{Cb} + V_{Ce} \quad (5)$$

Since V_{Cb} and V_{Ce} are equal to V_1 , (1), (2), and (5) can be rewritten to be:

$$V_{L1-ON} = V_{L2-ON} = V_1 \quad (6)$$

$$V_o = -V_{L1-OFF} - V_{L2-OFF} + 3V_1 \quad (7)$$

By substituting (6) into (3) and (4), V_{L1-OFF} and V_{L2-OFF} can be rewritten to be:

$$V_{L1-OFF} = V_{L2-OFF} = \frac{-D}{1-D} * V_1 \quad (8)$$

Substituting (8) into (7) yields the following CCM voltage conversion ratio:

$$\frac{V_o}{V_1} = \frac{3-D}{1-D} \quad (9)$$

Key waveforms for type 2 converter operated in CCM with L_1 equal to L_2 are shown in the figure below.

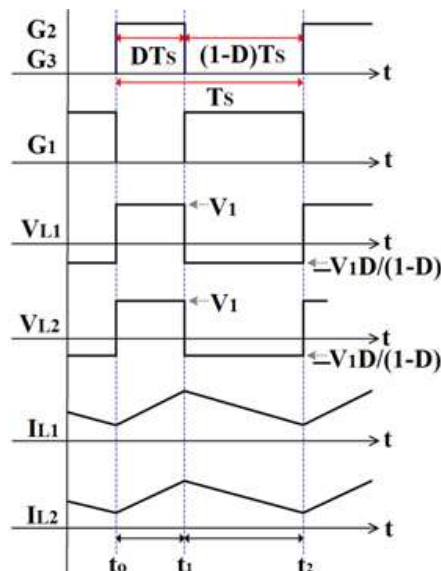


Fig.5 waveforms for type 2 operated in CCM with L_1 equal to L_2 .

IV. Fuzzy logic control

Fuzzy Logic (FL) is a multivalued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. Here, Mamdani type Fuzzy Inference System (FIS) is used.

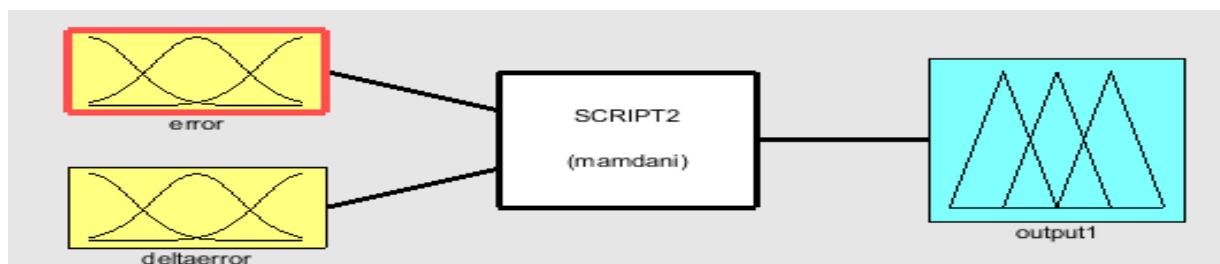


Fig.6 fuzzy Inference System

The two inputs error and deltaerror are fed to the FIS. Fuzzification, Application of rules, Implication, Aggregation and Defuzzification are the major process taking place in the fuzzy inference system. After these processes a crisp output is obtained. The membership functions used here are negative big (NB), negative medium (NM), negative small (NS), zero (Z), medium (M), positive small (PS), positive medium (PM) and positive big (PB).

Fig. 7 shows the membership functions of input variable error. Here, seven membership functions are used. They are NB, NM, NS, Z, PS, PM and PB.

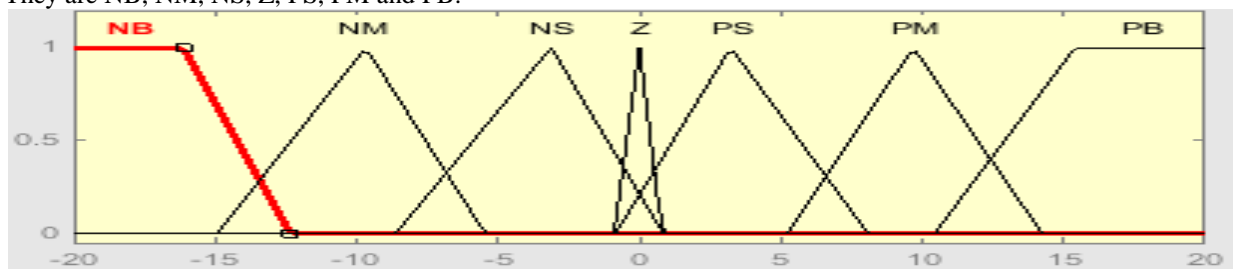


Fig.7 membership functions of the variable error

The five membership functions used for the input variable deltaerror are shown in the fig.8.They are NB, NS, M, PS and PB.

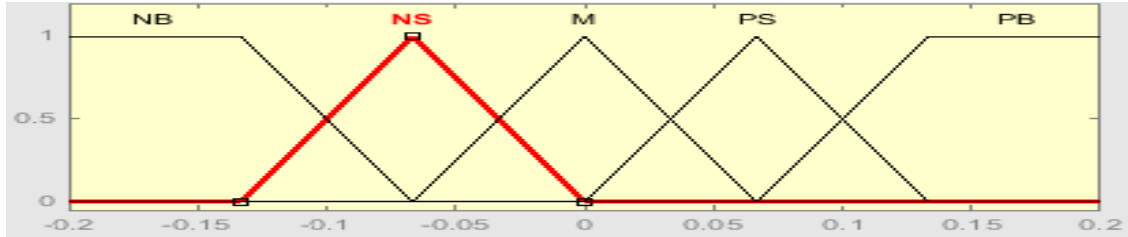


Fig.8 membership functions of the variable deltaerror

For the output variable seven membership functions, NB, NM, NS, Z, PS, PM, PB, are used. They are shown in the fig.9.

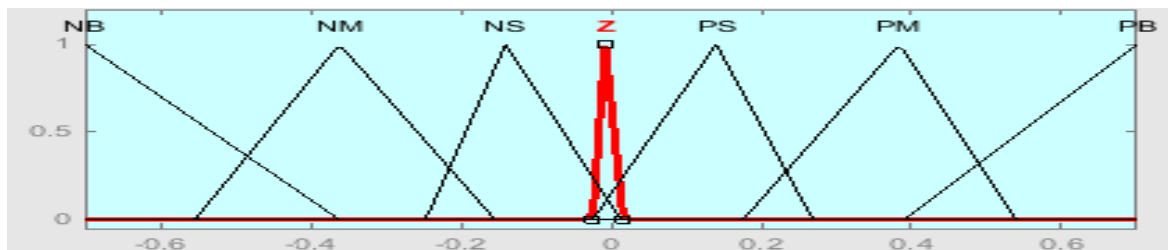


Fig.9 membership functions of the output variable

In this paper, eleven rules are used to control the output variable. The weightage for all the rules are set to one. The rules are:

- Rule 1: If error is (Z) then output1 is (Z).
- Rule 2: If error is (PB) then output1 is (PB).
- Rule 3: If error is (NB) then output1 is (NB).
- Rule 4: If error is (NS) then output1 is (NS).
- Rule 5: If error is (PS) then output1 is (PS).
- Rule 6: If error is (NM) then output1 is (NM).
- Rule 7: If error is (PM) then output1 is (PM).
- Rule 8: If error is (PS) and deltaerror is (PS) then output1 is (PS).
- Rule 9: If error is (PS) and deltaerror is (PB) then output1 is (PM).
- Rule 10: If error is (NS) and deltaerror is (NS) then output1 is (NS).
- Rule 11: If error is (NS) and deltaerror is (NB) then output1 is (NM).

V. Simulink model

In order to verify the performance of the proposed converter, simulations have been done using Matlab/Simulink software. The duty cycle of the converter is set as 50%.An input voltage of 12V is applied to the type2 high voltage boosting converter which boosts the input voltage. The simulation parameters are shown in Table 2.

Table.2 Simulation parameters

COMPONENTS	SPECIFICATION
V_I	12V
L_1, L_2	80mH
C_b, C_e	330 μ F
C_o	1000 μ F
R_L	470 Ω

The simulink block diagram of the converter in closed loop is shown below. Here, fuzzy logic control is used. The terminal voltage of the converter is compared with the reference voltage, here, 60V. This error voltage along with the change in error serves as the two inputs of the fuzzy logic controller. The output of the fuzzy logic controller is compared with a repeating sequence having frequency 10 kHz to obtain the pulses. These pulses switch the multiinput multioutput dc-dc boost converter. So the converter switching frequency is 10 kHz.

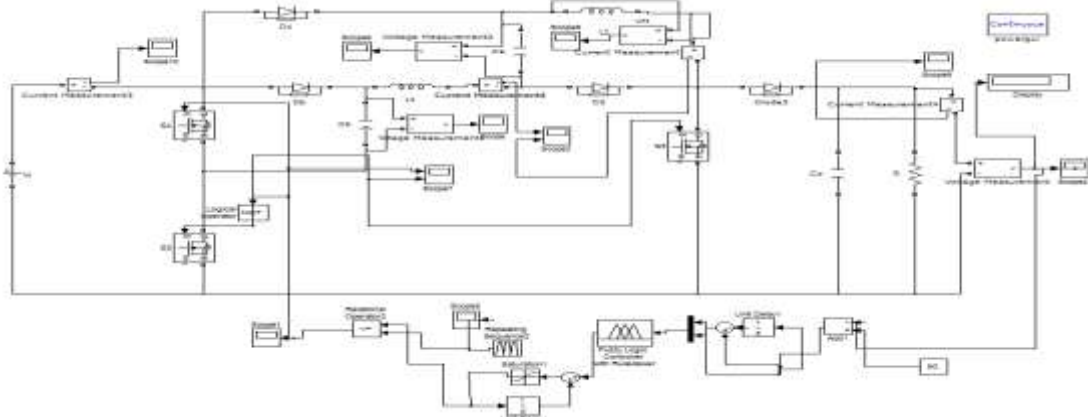


Fig.10 simulink model of the proposed converter

A 12V DC is given to the input of the converter. It is shown in the figure below.

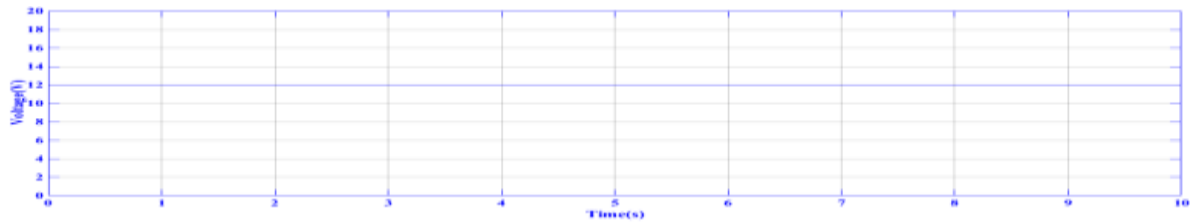


Fig.11 input voltage waveform

Gating signals for the switches Q_2 and Q_3 is shown below. Q_2 and Q_3 are operated together. The complement of this signal is fed to switch Q_1 . The duty cycle of the switches is 50% of time period. The switching frequency is 10 kHz.



Fig.12 gating signals for switches Q_2 and Q_3

The figure below shows the current through the inductors L_1 and L_2 .

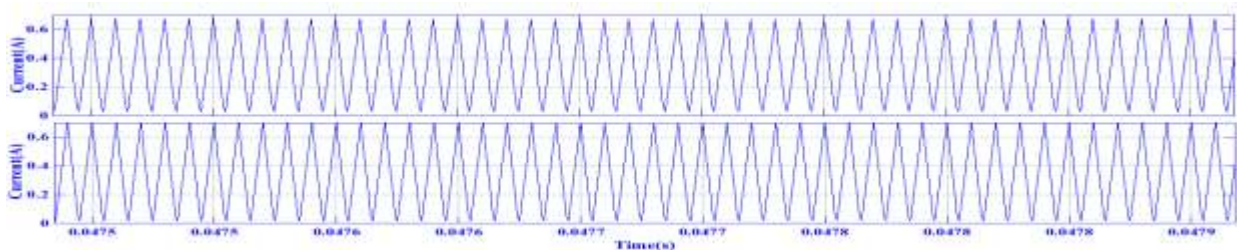


Fig.13 inductor current through L_1 and L_2

Fig.14 shows the voltage across the capacitors C_b and C_e .The magnitude of voltages are same and equal to the input supply voltage, which is 12V.

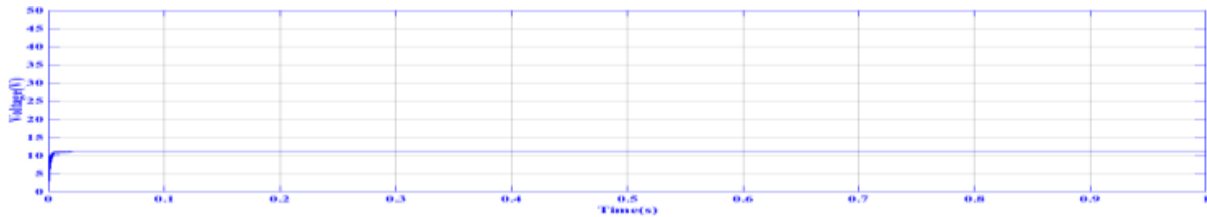


Fig.14 waveforms of voltage across the capacitors C_b and C_e

The output voltage of the high voltage boosting converter with fuzzy logic control strategy is shown below. The output voltage is 60V DC. It is clear that the terminal voltage tracked the reference value well.

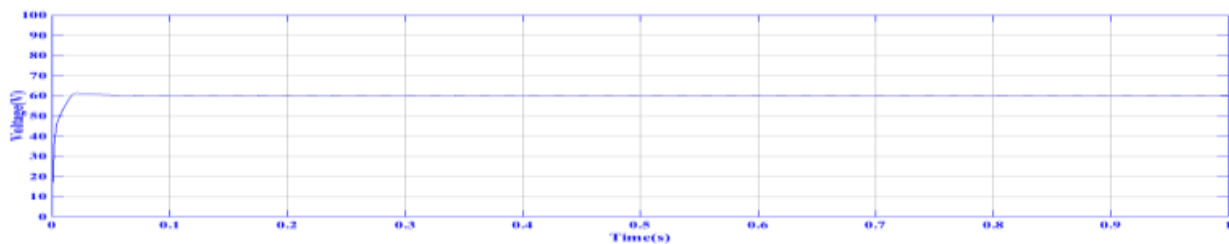


Fig.15 output voltage waveform

The waveform with FLC has lesser oscillations. The peak overshoot and the settling time of the converter is much reduced when closed loop control is done using fuzzy logic controller than other conventional controllers. Also the response time is much better when FLC is used.

VI. Conclusion

In this paper, a fuzzy controlled high voltage-boosting converter is addressed, which is based on inductors connected in series with boost capacitors. It is noted that the proposed converter is based on the charge pump of the KY converter and the series boost converter. By doing so, the conversion ratios can be upgraded further. If the anode of the diode D_1 is connected to the anode of the diode D_b , the conversion ratio in continuous conduction mode is $(3 - D)/(1 - D)$ where D is the duty cycle of the control signal created from the fuzzy controller. The fuzzy logic controller provides fast response, better settling time and reduced overshoot than conventional controllers. From the simulation results, it is seen that such converter exhibit good performances and hence are suitable for industrial applications, such as the energy-recycling burn-in test of the buck-type converter, isolated or nonisolated.

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