

# Design of Three Input Buck-Boost DC-DC Converter with Constant input voltage and Variable duty ratio using MATLAB/Simulink

A.Thiyagarajan, B.Gokulavasan

**Abstract**—Nowadays DC-DC converter is mostly used as power electronics interface in renewable energy source applications such as photovoltaic cell. There are many topologies of converters are available such as buck, boost, buck-boost, cuk converters which provide us with ability to step up and step down the input DC voltage. In this paper, we proposed three input buck-boost DC-DC converter which is used to improve efficiency, performance and also to reduce cost and component count. The dc-dc converter is designed through derivation by using four Single pole Single Throw (SPST) switches as a building block. Switch realization and operating characteristics of the proposed three input buck-boost dc-dc converter is obtained with their voltage transfer ratios in buck and boost modes of operation with constant input voltage and variable duty ratio. The performances of the dc-dc converter are simulated using MATLAB/simulink.

**Index Terms**—Buck-Boost DC-DC converter, Single pole single throw Switch, modes of operation, MATLAB/simulink..

## I. INTRODUCTION

The dc-dc converter has become a promising Option for many power systems applications such as hybrid vehicle, fuel cell vehicle, and all renewable energy systems. It not only reduces the cost and improves Efficiency, but also improves the performance of the system [11],[12]. In the electric vehicle applications, an auxiliary energy storage battery absorbs the Regenerated energy fed back by the electric machine. Recently, clean energy resources such as photovoltaic arrays and wind turbines have been exploited for developing renewable electric power generation systems [9]. The bidirectional dc-dc converter is often used to transfer the solar energy to the capacitive energy source during the sunny time, while to deliver energy to the load when the dc bus voltage is low [10]. Electrical energy can be transferred to any place with the use of transmission lines and also it can be converted to other forms of energy such as light, heat and kinetic energy.

Since power electronic circuits are controllable and

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relatively small compared with vacuum circuits, they have been widely adopted. Solar power, wind power and Hydro power are abundant and unlimited in many areas in this world. Lots of research has been conducted to improve the converter efficiency for renewable energy sources.[4] Most of the renewable energy sources are connected to the power grid or generators as auxiliary backup power source. In our country most of the isolated areas lack the supply from the power grid [13]. Hence; dependence on one renewable energy source is not a reliable method to maintain a stable power in these areas. So connecting all kind of the renewable energy sources to generate electricity is a best solution in the rural areas [14]. The focus of this paper is to design a multi input dc-dc converter to provide an interface between multiple DC sources and a single DC output. The conventional approach of connecting the energy storage unit is by using independent converter has many problems [5]. The Fig.1 shows the block diagram of three input dc-dc buck-boost converters with three input voltage sources.

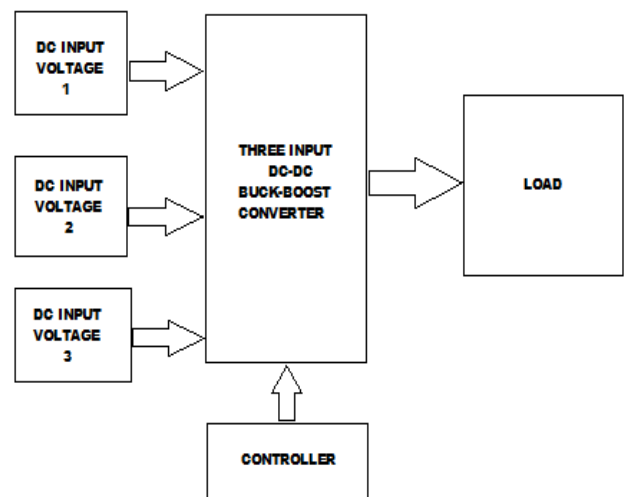


Fig.1 Block diagram of Three input dc-dc buck-boost converter

The independent converter with energy sources can be connected either in series or parallel in multiple input converters. If the sources are connected in series it has to conduct the same current and if the converters are connected in parallel it should have same Voltage levels [6]-[8]. Both the conditions are practically undesirable. Instead of this, multi input converter is used to connect multi voltage Sources in a single system to give required load demand an also to improve efficiency, reduce overall cost, reduce component count, more stability and simple control [15]. In this Paper, only three inputs are used. So it is named as three input dc-dc buck

boost converter. Multi input converters can be constructed using either flux additivity or by combining the structure of the converters. There is not a systematic approach to design multi input converters through derivation [1].

Design of new converters from existing converters is complicated task [2]. Hence in this paper, a systematic approach is given to design a proposed converter through derivation by using four Single pole Single Throw (SPST) switch as building block [1]. In this paper, design of dc-dc converters using four Single pole Single Throw (SPST) switch along with various modes of operation and Voltage transfer ratios are presented in part II. Switch realization of proposed converter is obtained in part III. Simulation model and results of the dc-dc converter are presented in part IV.

## II. DESIGN OF THREE INPUT DC-DC BUCK –BOOST CONVERTER USING FOUR SINGLE POLE SINGLE THROW SWITCH

The basic circuit diagram of the proposed three input buck-boost dc-dc converter using four single pole single throw switch as a building block is shown in Fig.2.

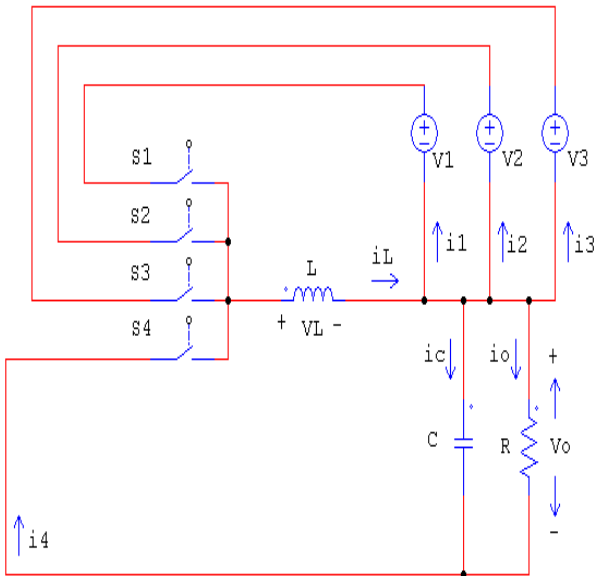


Fig.2 A Basic circuit diagram of of three input buck-boost dc-dc converter using Four Single Pole Single Throw switch

Voltage source V1 delivers power to load when the switch is ON. Voltage source V2 delivers power to load when the switch is ON. Similarly N-number of voltage sources delivers power to the load when the particular channel switch is ON. It consists of four SPST switches S1, S2, S3, and S4 which can be turned ON and OFF individually.  $i_1$ ,  $i_2$ , and  $i_3$  are the currents supplied by the voltage sources V1, V2, V3 respectively.  $i_4$  is the current flowing through the switch S4.  $i_c$  is the current flowing through the capacitor.  $i_o$  is the output load current. The switching patterns of the four switches are shown in Fig.3

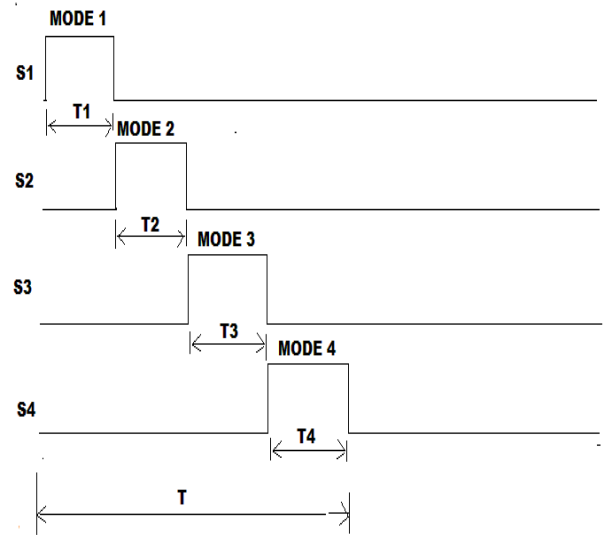


Fig.3 Switching patterns of three input buck-boost dc-dc converter using four Single Pole Single Throw switch

Voltage across the inductor in different modes is shown in the Table. I

TABLE I  
MODES OF OPERATION AT DIFFERENT MODES OF OPERATION OF THREE INPUT BUCK-BOOST DC-DC CONVERTER

Modes	ON condition switches	OFF condition switches	Voltage across Inductor( $V_L$ )
1	S1	S2,S3,S4	$V_1$
2	S2	S3,S4,S1	$V_2$
3	S3	S4,S1,S2	$V_3$
4	S4	S1,S2,S3	$-V_0$

In mode 1, V1 gives energy to the inductor and load resistor R. In mode 2, V2 gives energy to the inductor and load resistor R. In mode 3, V3 gives energy to the inductor and load resistor R. In mode 4, all the input voltage sources are disconnected from the circuit. The energy stored in the inductor is being released to the load. The energy stored in the inductor is reenergized during this mode.

### a) Voltage transfer ratio

It can be formed by taking the product of individual switch duty ratios and total time from the switching patterns.

$$T_1 = (d_1) * T \quad (1)$$

$$T_2 = (d_2) * T \quad (2)$$

$$T_3 = (d_3) * T \quad (3)$$

$$T_4 = (d_4) * T \quad (4)$$

$$T_1 + T_2 + T_3 + T_4 = T \quad (5)$$

Where,

T is the total time period of the switching patterns.

$d_1$ ,  $d_2$ ,  $d_3$  and  $d_4$  are the duty ratios of the switches  $S_1$ ,  $S_2$ ,  $S_3$  and  $S_4$  respectively.

$V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  is the input voltage of the converter.

$V_0$  is the output voltage of the converter.

$T_1$ ,  $T_2$ ,  $T_3$  and  $T_4$  are the On time of the switches

$S_1, S_2, S_3$  and  $S_4$  respectively.

Voltage second balance equation of the inductor is given by

$$T_1 * (V_1) + T_2 * (V_2) + T_3 * (V_3) + T_4 * (-V_0) = 0 \quad (6)$$

$$T_1 * (V_1) + T_2 * (V_2) + T_3 * (V_3) = T_4 * (V_0) \quad (7)$$

$$V_1 * (d_1) + V_2 * (d_2) + V_3 * (d_3) = V_0 * (1 - d_1 - d_2 - d_3) \quad (8)$$

By combining the equations (1), (2), (3), (4), and (5), we can get the voltage transfer ratio of the following equation (9) which gives the relation between the input and output of three input buck-boost dc-dc converter[1],[2].

$$V_0 = \frac{d_1 * V_1}{(1 - d_1 - d_2 - d_3)} + \frac{d_2 * V_2}{(1 - d_1 - d_2 - d_3)} + \frac{d_3 * V_3}{(1 - d_1 - d_2 - d_3)} \quad (9)$$

The sum of duty ratio should not be greater than 90%. To operate a converter in buck and boost modes the following conditions to be satisfied. In buck mode the duty cycle for the individual channel switches should not be greater than 0.5. In boost mode the duty cycle for the individual channel switches should not be less than 0.5. The converters are tested with constant equal input voltage and variable duty ratio for the switches.

### III. REALIZATION OF SWITCH FOR THREE INPUT BUCK-BOOST DC-DC CONVERTER

The circuit diagram of the proposed three input dc-dc buck-boost converter is shown in Fig.4.

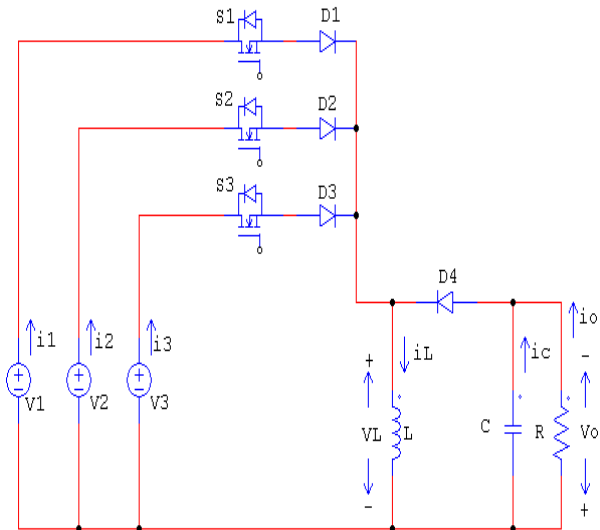


Fig.4 The circuit diagram of three input buck-boost dc-dc converter

Voltage drop across the inductor depends on the switches which are in ON condition.  $S_1, S_2,$  and  $S_3$  conducts positive current and opposes either positive or negative voltage depending on the magnitude of input voltages. For this purpose, the switches are replaced by diode is connected series with MOSFET. It is necessary to commutate the switches with each other depending upon the modes. In this converter, it uses only one Inductor. Switch  $S_4$  which

conducts positive current and opposes negative voltage, so it can be replaced only by diode.

The basic idea in the synthesis of the proposed three input dc-dc buck-boost converter is to bring a new switching circuit which can be able to connect or disconnect input voltage sources individually or simultaneously. Inductor is used as an energy storage element in this circuit [3], [9]. The modes of operation depend on the voltage drop across the inductor in the converter. The converter is tested with resistive load. The value of the components for the converter are chosen as per requirement [1],[2].

### IV. SIMULATION MODEL AND RESULTS OF THREE INPUT BUCK-BOOST DC-DC CONVERTER

The simulation model and the output results are verified using MATLAB/simulink. The simulation model of three input buck-boost dc-dc converter is shown in the Fig.5.

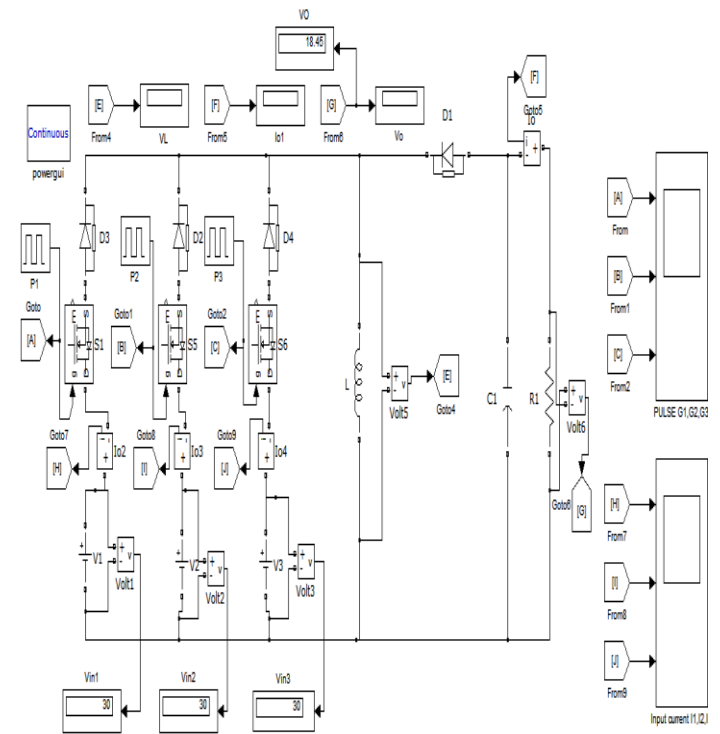


Fig.5 Simulation model of three input buck-boost dc-dc converter using MATLAB

The values of inductance and capacitance are  $L=300$  mH and  $C=200$   $\mu$ F were used for the converters. The converter operates in continuous conduction mode (CCM) [1]. The converter is switched by signal having duty ratio with phase shifted by an angle 90 degrees between each switches at a switching frequency of 100 kHz. Resistive load ( $R=10$ ohms) is used. Pulse width modulation technique is used in this converter. The simulation result of switching signals for Switches  $S_1, S_2, S_3, S_4$  of three input buck-boost dc-dc converter in boost mode is shown in the Fig.6.

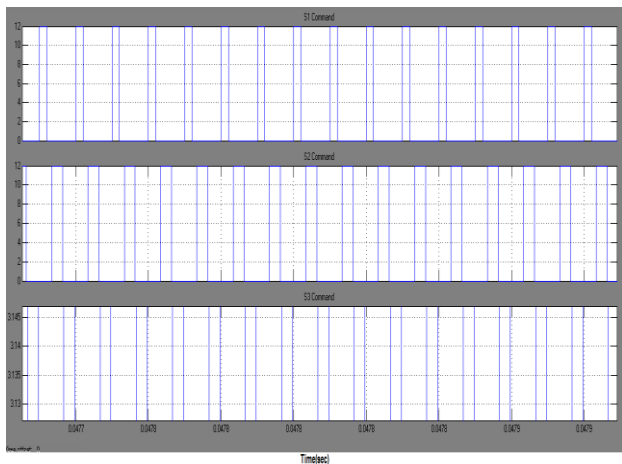


Fig.6 Switching signals of three input buck-boost dc-dc converter (Boost mode) using MATLAB

The simulation result of inductor voltage in boost mode is shown in Fig.7

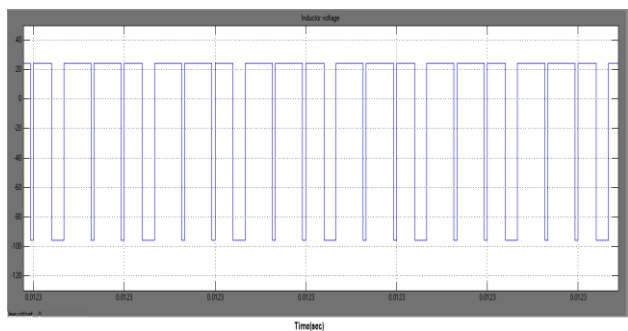


Fig.7 Inductor voltage of three input buck-boost dc-dc converter (Boost mode) using MATLAB

The simulation result of Output current in boost mode is shown in Fig.8. The simulation result of Input current of each input voltage source in boost mode is shown in Fig.9

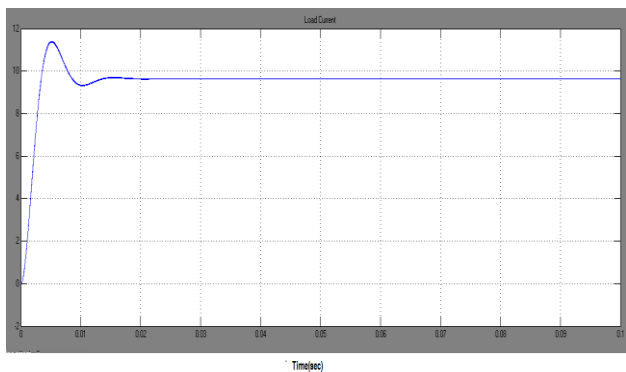


Fig.8 Output current of three input buck-boost dc-dc converter (Boost mode) using MATLAB

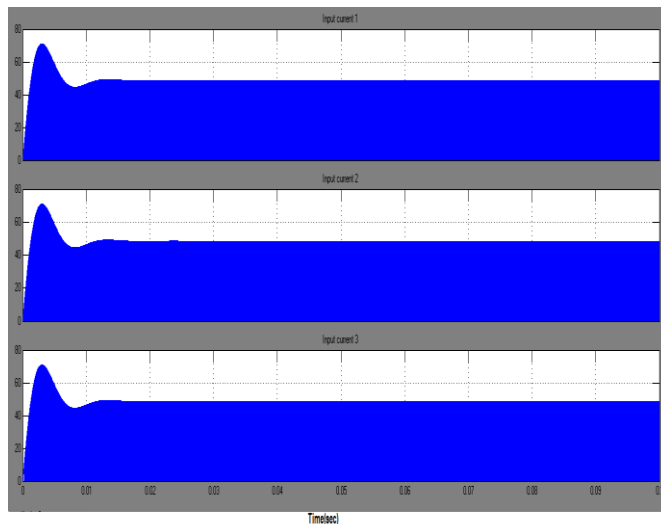


Fig.9 Input current of three input buck-boost dc-dc converter (Boost mode) using MATLAB

The simulation result of Output voltage in boost mode is shown in Fig.10.

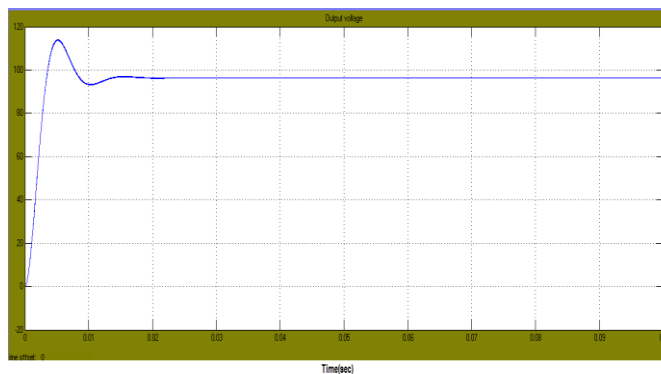


Fig.10 Output voltage of three input buck-boost dc-dc converter (Boost mode) using MATLAB

The simulation result switching signals for Switches  $S_1, S_2, S_3, S_4$  of the three input dc-dc buck-boost converter in buck mode is shown in the Fig.11.

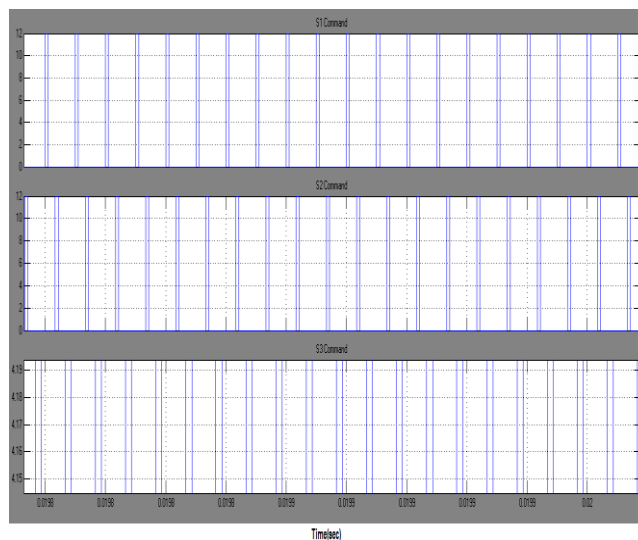


Fig.11 Switching signals of three input buck-boost dc-dc converter (Buck mode) using MATLAB

The simulation result of Inductor voltage in buck mode is shown in Fig.12.

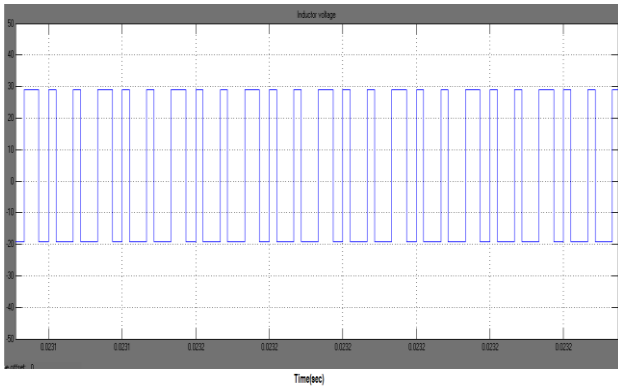


Fig.12 Inductor voltage of three input buck-boost dc-dc converter (Buck mode) using MATLAB

The simulation result of Output voltage in buck mode is shown in Fig.15.

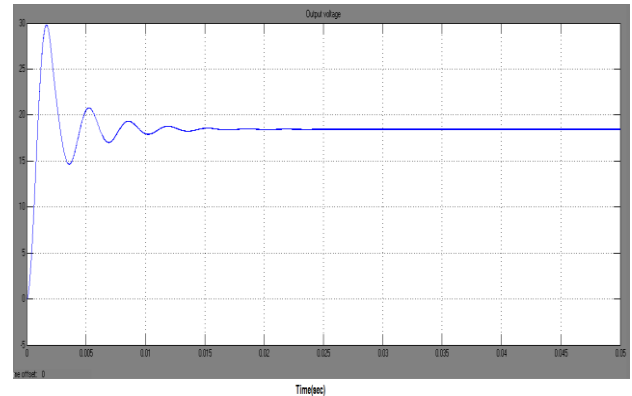


Fig.15 Output voltage of three input dc-dc buck-boost converter (Buck mode) using MATLAB

The simulation result of Input current of each input voltage source in buck mode is shown in Fig.13

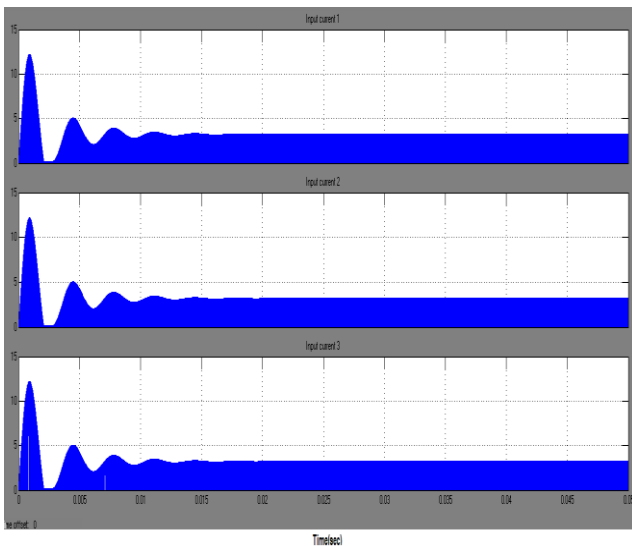


Fig.13 Input current of three input buck-boost dc-dc converter (Buck mode) using MATLAB

An output voltage of three input dc-dc buck-boost converter with constant equal input voltage at various duty ratios is shown in Table.II.

TABLE II  
 COMPARISON OF OUTPUT VOLTAGE OF THREE INPUT DC-DC BUCK-BOOST CONVERTER AT VARIOUS DUTY RATIOS

Duty ratios			Output voltage( $V_o$ )	
$d_1$	$d_2$	$d_3$	Theoretical Value	Simulated Value
0.1	0.1	0.1	12.86	11.64
0.1	0.1	0.2	20	18.45
0.2	0.2	0.1	30	27.84
0.3	0.2	0.1	45	41.39
0.1	0.3	0.3	70	62.33
0.2	0.3	0.3	120	96.36
0.7	0.2	0	270	63.14
0.8	0.1	0	270	104.09
0.9	0	0	270	137.10

The simulation result of Output current in buck mode is shown in Fig.14

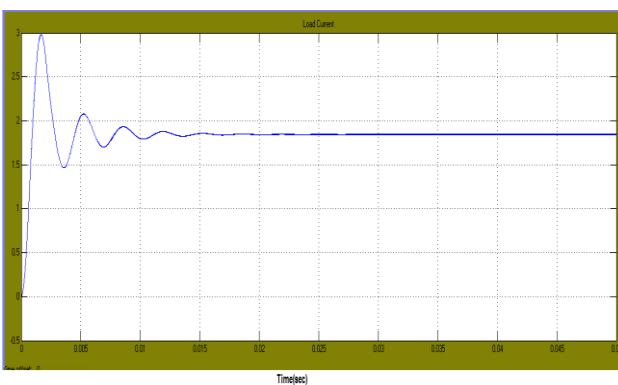


Fig.14 Output current of three input buck-boost dc-dc converter (Buck mode) using MATLAB

The performance of the converter is simulated under constant input voltages ( $V_1=V_2=V_3=30V$ ). If the duty ratio is 0.1 for all the switches (sum of duty ratio is 0.3); the converter operates in buck mode. It provides Output voltage  $V_o = 11.64$  V. If sum of the duty ratio is 0.8 for all the switches, the converter operates in boost mode. It provides Output voltage  $V_o = 96.36V$ . The equation (9) is only applicable until sum of the duty ratio is 0.7. ( $d_1=0.1, d_2=0.3, d_3=0.3$ ). This converter are designed in open loop configuration.

### V. CONCLUSION

The three input buck-boost dc-dc converter topologies were designed through derivation by using four single pole single throw switches as a building block. This converter use only one inductor which reduces the converter size, component count and cost of the converter. The operating performances of the three input buck-boost dc-dc converter were simulated with constant input voltages with variable duty ratios. It is observed that, if sum of the duty ratios are below 0.5, the converter operates in buck mode. If it is above

0.5, the converter operates in boost mode. The proposed converter provides output voltage in both buck and boost modes.

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