Design of Four Input Buck-Boost DC-DC Converter for Renewable Energy Application

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Abstract

Nowadays, electricity along with power electronics have become essential part of our life. Power consumptions are increasing every year due to industrialization in our country. DC-DC converter topologies such as buck, boost, buck-boost, cuk converters provide us with ability to step up and step down the input DC voltage precisely. DC-DC converter is needed to convert directly to the desired voltage from the renewable energy sources such as solar cell and Fuel cell. In this paper, we proposed four input buck-boost DC-DC converter which is used in such system to improve efficiency, performance and also to reduce cost and component count. Four input buck-boost dc-dc converter is designed through derivation by using five Single pole Single Throw (SPST) switches as a building block. Switch realization and operating characteristics of proposed four input buck-boost dc-dc converter is obtained with their voltage transfer ratios in buck and boost modes of operation. The performances of the dc-dc converter are simulated using MATLAB/simulink.

Keywords - *Buck-Boost DC-DC conversion,Single pole Four throw Switch,modes of operation,MATLAB/simulink.*

I. INTRODUCTION

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 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.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. 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 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. In this Paper, only four inputs are used. So it is named as four input dc-dc 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 five Single pole Single Throw (SPST) switch as building block. The Fig.1 shows the block diagram of multi input dc-dc converters with four input voltage sources

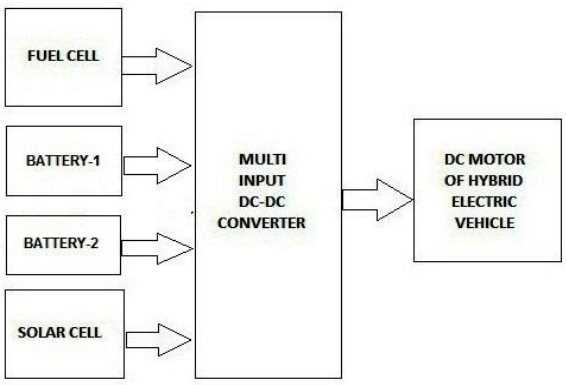

Fig.1 Block diagram of Multi input dc-dc buck-boost converter for Hybrid Electric Vehicle

In this paper, design of dc-dc converters using five 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 converter are presented in part IV.

II. DESIGN OF FOUR INPUT DC-DC BOOST CONVERTER USING SINGLE POLE FOUT THROW SWITCH

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

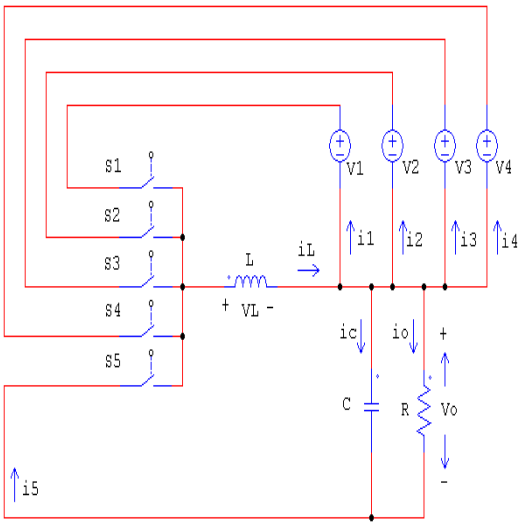

Fig.2 A Basic circuit diagram of of four input buck-boost dc-dc converter using Five Single Pole Single Throw switch

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 five SPST switches S1, S2, S3, S4, S5 which can be turned ON and OFF individually. The switching patterns of the five switches are shown in Fig.3

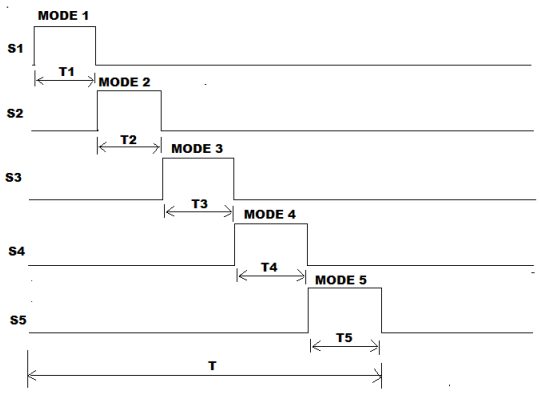

Fig.3 Switching patterns of four input buck-boost dc-dc converter using Five Single Pole Single Throw switch

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

Table I : Modes of Operation at Different Modes of Operation of Four Input Buck – Boost DC-Dc Converter

Modes	ON condition switches	OFF condition switches	Voltage across Inductor(V_L)
1	S1	S2,S3,S4,S5	V_1
2	S2	S3,S4,S5,S1	V_2
3	S3	S4,S5,S1,S2	V_3
4	S4	S5,S1,S2,S3	V_4
5	S5	S1,S2,S3,S4	$-V_0$

In mode 1, V1 gives energy to the inductor and load resistor R. In mode 2, V_2 gives energy to the inductor and load resistor R .In mode 3, V_3 gives energy to the inductor and load resistor R. In mode 4, V_4 gives energy to the inductor and load resistor R. In mode 5, 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.

$$T_1 = (d_1) * T$$
$$T_2 = (d_2) * T$$
$$T_3 = (d_3) * T$$
$$T_4 = (d_4) * T$$
$$T_5 = (d_5) * T$$
$$T_1 + T_2 + T_3 + T_4 + T_5 = T$$

Where,

T is the total time period of the switching patterns.

d_1, d_2 , d_3 ,d_4 and d_5 are the duty ratios of the switches

S_1 , S_2 ,S_3 ,S_4 and S_5 respectively.

V_1 V_2 V_3 V_4 and V_5 is the input voltage of the converter.

V_0 is the output voltage of the converter.

T_1,T_2 ,T_3 ,T_4 and T_5 are the On time of the switches S_1 ,S_2 ,S_3 ,S_4 and S_5 respectively.

Voltage second balance equation of the inductor is given by

$$T_1 * (V_1) + T_2 * (V_2) + T_3 * (V_3) + T_4 * (V_4) + T_5 * (-V_0) = 0$$

$$T_1 * (V_1) + T_2 * (V_2) + T_3 * (V_3) + T_4 * (V_4) = T_5 * (V_0)$$

$$V_1 * (d_1) + V_2 * (d_2) + V_3 * (d_3) + V_4 * (d_4) = V_0 * (1 - d_1 - d_2 - d_3 - d_4)$$

By combining the equations (1), (2), (3), (4), (5) and (6), we can get the voltage transfer ratio of the following equation (10) which gives the relation between the input and output of four input buck-boost dc-dc converter.

$$V_0 = \frac{d_1 * V_1}{(1 - d_1 - d_2 - d_3 - d_4)} + \frac{d_2 * V_2}{(1 - d_1 - d_2 - d_3 - d_4)} + \frac{d_3 * V_3}{(1 - d_1 - d_2 - d_3 - d_4)} + \frac{d_4 * V_4}{(1 - d_1 - d_2 - d_3 - d_4)} \quad (10)$$

It is applicable only if sum of duty ratios are equal to 0.9 for all the switches [3]. The sum of duty ratio should not be greater than 90%.

III. SWITCH REALIZATION OF FOUR INPUT BUCK-BOOST DC-DC CONVERTER

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

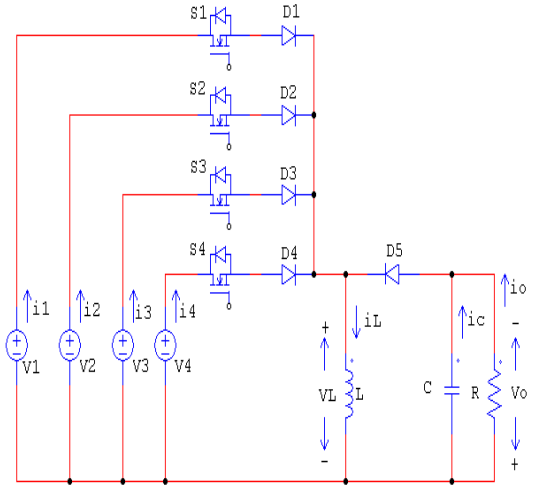

Fig.4 The circuit diagram of four input buck-boost dc-dc converter

Voltage drop across the inductor depends on the switches which are in ON condition.S1, S2, S3 and S4 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 S5 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 four 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].

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

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

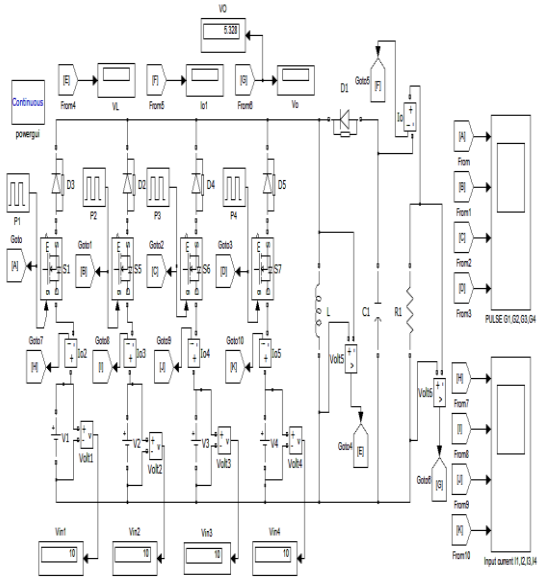

Fig.5 Simulation model of four input buck-boost dc-dc converter using MATLAB

The values of inductance and capacitance are L=500 mH and C=200 µF were used for the converters. The converter operates in continuous conduction mode (CCM). 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. 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 four input buck-boost dc-dc converter in boost mode is shown in the Fig.6.

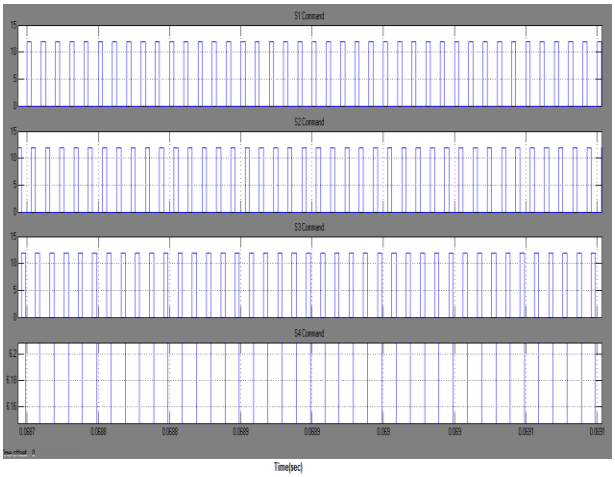

Fig.6 Switching signals of four input buck-boost dc-dc converter (Boost mode) using MATLAB

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

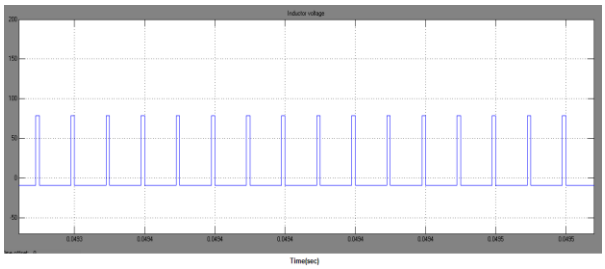

Fig.7 Inductor voltage of four input buck-boost dc-dc converter (Boost mode) using MATLAB

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

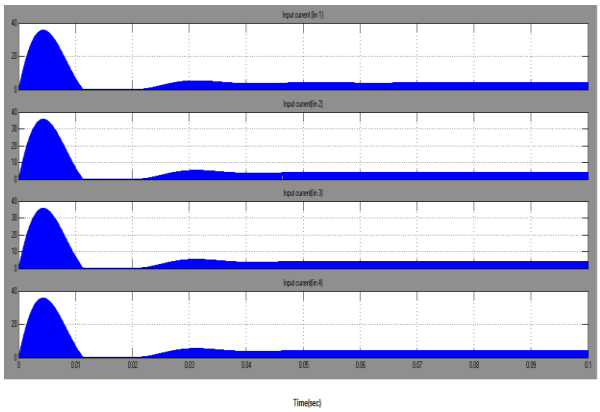

Fig.8 Input current of four input buck-boost dc-dc converter (Boost mode) using MATLAB

The simulation result of Output current in boost mode is shown in Fig.9

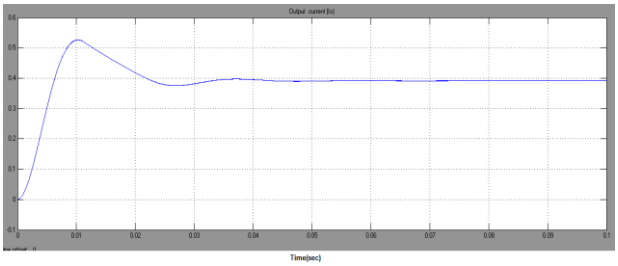

Fig.9 Output current of four input buck-boost dc-dc converter (Boost mode) using MATLAB

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

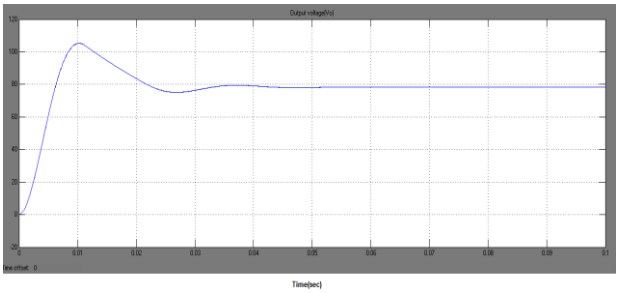

Fig.10 Output voltage of four input buck-boost dc-dc converter (Boost mode)using MATLAB

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

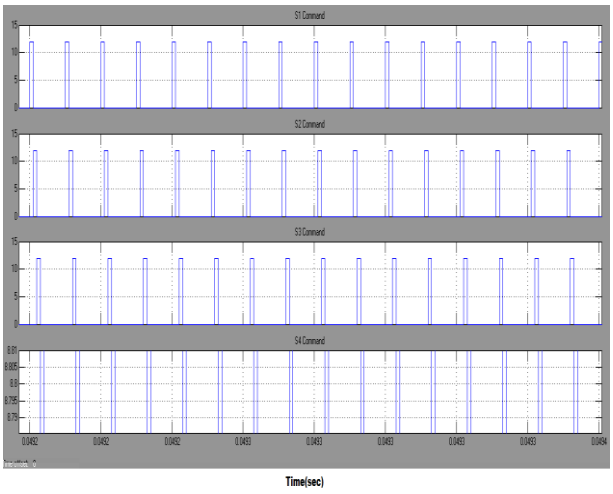

Fig.11 Switching signals of four input buck-boost dc-dc converter (Buck mode) using MATLAB

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

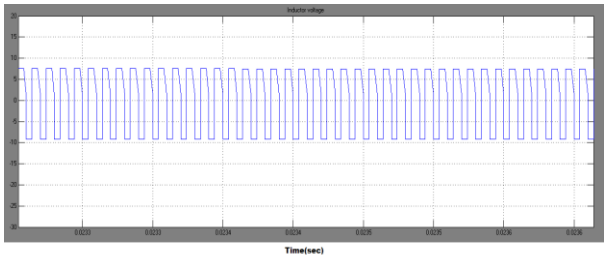

Fig.12 Inductor voltage of four input buck-boost dc-dc converter (Buck mode) using MATLAB

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

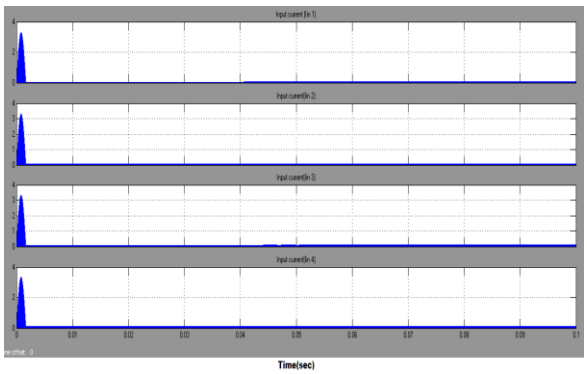

Fig.13 Input current of four input buck-boost dc-dc converter (Buck mode) using MATLAB

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

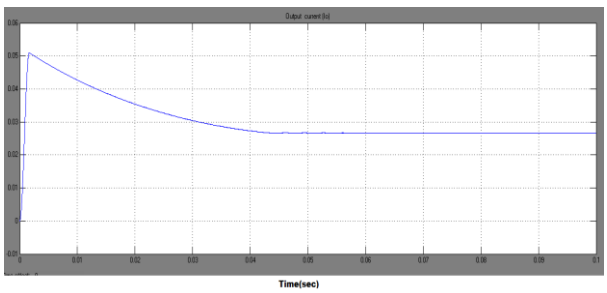

Fig.14 Output current of four input buck-boost dc-dc converter (Buck mode) using MATLAB

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

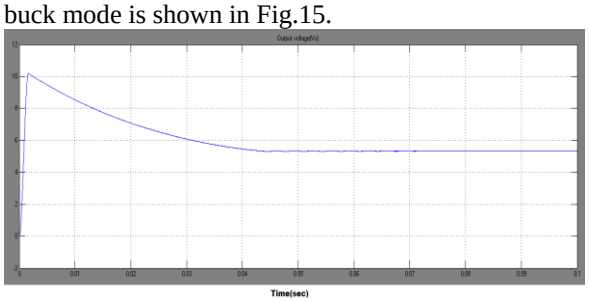

Fig.15 Output voltage of four input dc-dc buck-boost converter (Buck mode) using MATLAB

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

Table III : Output Voltage of Four Input DC – DC Buck Boost Convertor at Various duty Ratios

Duty ratios of switches S_1, S_2, S_3, S_4				Output voltage(Vo)
d_1	d_2	d_3	d_4	
0.1	0.1	0.1	0.1	6.67
0.2	0.2	0.2	0.2	40
0.3	0.3	0.3	0	90
0.4	0.4	0.1	0	90
0.5	0.4	0	0	90
0.6	0.3	0	0	90
0.7	0.2	0	0	90
0.8	0.1	0	0	90
0.9	0	0	0	90

It is observed that, sum of duty ratio must be 0.9 for all switches. The performance of the converter is simulated under constant input voltages (V_1=V_2=V_3=V_4=10V).If the duty ratio is 0.1 for all the switches (sum of duty ratio is 0.4), the converter operates in buck mode. It provides Output voltage Vo = 5.33V. If sum of the duty ratio is 0.9 or above 0.5 for all the switches, the converter operates in boost mode. It provides Output voltage Vo = 90V.

V. CONCLUSION

The four input buck-boost dc-dc converter topologies were designed through derivation by using five 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 four input buck-boost dc-dc converter were simulated with constant input voltages with variable duty ratios. The proposed converter provides efficient output voltage in buck and boost modes. It can be used with Ultra Capacitor, Battery, Photovoltaic system, Fuel cell system for renewable energy applications.

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