MULTI-INPUT DC-DC CONVERTER FOR RENEWABLE ENERGY SOURCES

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Abstract

A multi-input DC-DC boost converter is proposed to obtain power from several input sources and to supply the regulated output voltage to the load from the sources. The structure of Multiple-Input Converter (MIC) is simpler compared to the use of several single-input converters for each source. As the conventional source of energy is rapidly depleting and the cost of energy is rising, we turn towards renewable energy sources. Reason to choose renewable energy is because of its abundance and distribution throughout the earth. Input sources include renewable energy sources like Photovoltaic (PV) source and Wind source. As the power from renewable energy sources is intermittent, a storage element battery is used to provide uninterrupted supply to the load. The battery utilized is bidirectional in its power flow hence the converter topology enables the charging and discharging of the storage element through input power sources. MIC can deliver power either simultaneously from all of the input sources to the load or individually. MICs reduce the system size and cost by reducing the number of components. In addition some other advantages are the system is reliable and its dynamic performance due to centralized control. Three different operating modes of MIC are analyzed based on the power from the input sources and the battery operation. The closed loop operation of MIC is performed using PI controller. The system is suitable for applications such as hybrid automobile charging and in residential buildings. The performance of different operating modes and its control are simulated using MATLAB.

Keywords: Renewable energy sources, DC-DC converter and PI controller.

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1. INTRODUCTION

In recent days, the number of applications which require more than one power source is increasing. Distributed generating systems or micro-grid systems normally use more than one power source or more than one kind of energy source. Also, to increase the utilization of renewable energy sources, diversified energy source combination is recommended. The combination of more power sources and diversified power sources make it possible to obtain higher availability in a power system. A parallel connection of converters has been used to integrate more than one input energy source in a power system. However, a MIC [1]-[4] can generally have the following advantages compare to a combination of several individual converters like cost reduction, compactness, more expandability and greater manageability. MICs are being used in aerospace, electric and hybrid vehicles, sustainable energy sources and microgrid applications.

India has tremendous energy requirements and increasing intricacy in meeting those needs through conventional means of power generating system. Consumption of electricity has been rising at fastest rates in the world owing to growing population and economic development. Our economy has been put forth to increasing challenges since energy supply is struggling to meet the demand and there are energy shortages almost many places in the country. Such continual lack of energy and unreliable supplies warn our economic growth.

Renewable Energy Sources (RES) [5] such as solar and wind, produce power intermittently according to the weather conditions rather than to the power demanded. Energy Storage Systems may be used to mitigate the intermittent generation from RES and to increase the quality of power supply. This makes it difficult to integrate the power generated from these RES into the electric network. One major benefit with the use of renewable sources is that as it is renewable and so will never run out. Their fuel being obtained from natural and readily available resources reduces the operation cost and maintenance. Even more significantly, renewable energy produces little or no waste products such as carbon dioxide or other chemical pollutants, so has negligible impact on the environment. Human activity is overfilling our atmosphere with carbon dioxide and other global warming emissions, which trap heat, steadily drive up earth's temperature, and create harmful impacts on our health, surroundings and climate. Electricity production is majorly generated by coal-fired power plants which emits global warming gases. The air and water pollutants emitted by coal and natural gas plants are avoided by using RES. Hence, Solar and Wind energy [6]-[9] sources are considered as the input sources for MIC.

2. DC-DC CONVERTER

A DC-DC converter [11] is an electronic circuit that converts a DC source from one level of voltage to another. An unregulated DC voltage is given as input to these converters and therefore it will be fluctuated. In these

converters regulated DC output voltage is obtained although the input voltage is changing. The regulation of output voltage in a DC-DC converter is based on the on-time of the switch, pulse width and the switching frequency. The control of output voltage depends on the duty cycle D. The duty ratio is defined as the ratio of the on-time of the switch and the total switching period. Duty cycle is given by the Equation -1.

$$D = \frac{T_{on}}{T_s} \qquad (1)$$

Where,
D is the duty cycle
T_{ON} is the on period of the switch
T_S is the total time period ($T_{ON} + T_{OFF}$)

2.1 DC-DC Boost Converter

A converter that produces an output voltage higher than that of the input voltage is called Boost converter [12] or step-up converter. The fundamental for a boost converter consists of an inductor, diode, capacitor and switch. The input to a boost converter can be from any kind of sources as well as batteries. The DC input voltage is in series with a large inductor acting as a current source. A switch connected in parallel with the current source and the output is turned off periodically, providing energy from the inductor and source to raise the output voltage. The circuit diagram of DC-DC boost converter is shown in Fig -1.
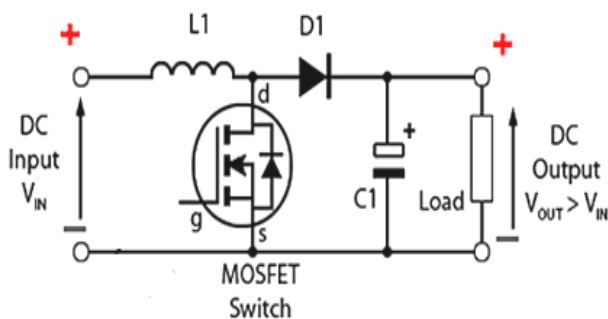

Fig -1: Circuit diagram of DC-DC boost converter

The average output voltage is given by Equation -2.

$$v_o = \frac{v_{IN}}{1-D} \qquad (2)$$

Where,
V_O is the output voltage
V_{IN} is the input voltage
D is the duty cycle

The charging and discharging operation of the DC-DC boost converter depends on switching condition of the switch in the circuit.

3. MULTI-INPUT DC-DC CONVERTER

Multiple-Input DC-DC converters are the sole key to combine numerous input power sources whose voltage levels are different and to get regulated output voltage for the load from them.
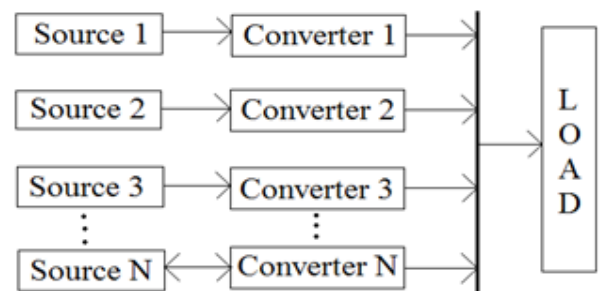

Fig -2: Separate converters for each source

In many applications, there is a requirement for multiple power sources to be connected together, providing the power for a single loads. Fig -2 shows the separate converter for different sources. Source 1 to Source N-1 can be composed of any kind of energy source combinations, such as wind turbines, PV modules, FC, micro turbines and/or electric grid, and Source N could be a storage unit, such as a battery, ultra-capacitor, flywheel or superconducting magnetic energy storage system. All the energy sources are unidirectional where the storage element is bidirectional which can perform both charging and discharging operations.
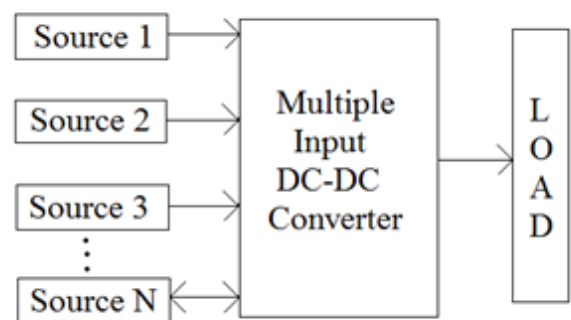

Fig -3: An MIC for all sources

A single Multi-Input DC-DC Converter [13]-[15] replaces several number of parallel connected single converters is shown in Fig -3. Fig -4 shows the structure of the four-input DC–DC boost converter. The converter interfaces voltages from four input power sources V_1, V_2, V_3 and V_4 and the storage element battery.
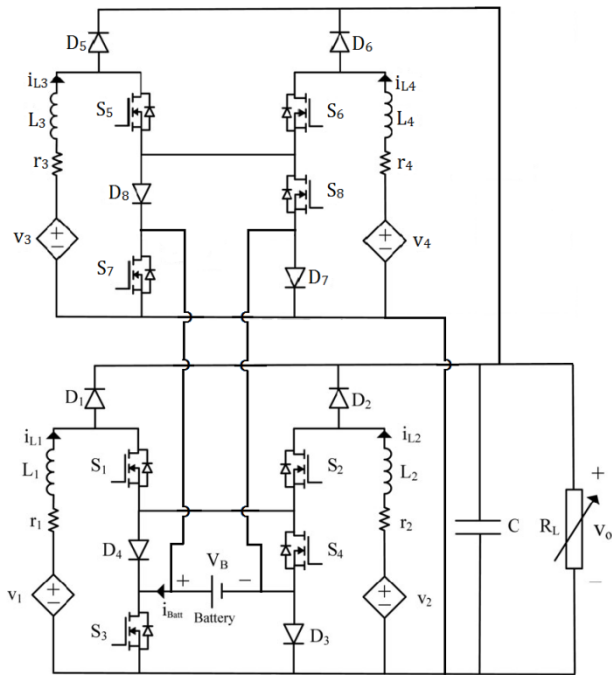
Fig -4: Circuit topology of four-input DC-DC converter

Therefore, V_1, V_2, V_3 and V_4 are shown as four dependent power sources and the determination of their output characteristics are based on the type of input power sources. Four inductors L_1, L_2, L_3 and L_4 make the input power ports as two current type sources, which result in obtaining even dc currents from the input power sources.

The major controlling elements that control the power flow of the MIC system are the eight power switches S_1, S_2, S_3, S_4, S_5, S_6, S_7 and S_8 in the converter. Like the conventional boost converters, diodes D_1 and D_2, D_5 and D_6, conduct in complementary manner with switches S_1 and S_2, S_5 and S_6. The converter structure shows that when switches S_3 and S_4, S_7 and S_8 are turned ON, their corresponding diodes D_3 and D_4, D_7 and D_8 are reversely biased by the battery voltage and then blocked. On the other hand, turn-OFF state of these switches makes diodes D_3 and D_4 able to conduct input currents i_{L1} and i_{L2}, D_7 and D_8 able to conduct input currents i_{L3} and i_{L4}.

4. MODES OF OPERATION

The proposed four-input DC-DC converter is operated in three different modes based on the performance of the storage element.

- Mode 1
  Supplying the load with sources V_1, V_2, V_3 and V_4 without battery
- Mode 2
  Supplying the load with sources V1, V2, V3 and V4 and the battery
- Mode 3
  Supplying the load with sources V1, V2, V3 and V4 and battery charging performance

The various switching condition for the operating modes of four-input DC-DC converter is shown in Table -1.

Table -1: Switching states of four-input DC-DC converter

Mode 1				Mode 2				Mode 3			
$P_{PV} + P_{WT} = P_L$				$P_{PV} + P_{WT} < P_L$				$P_{PV} + P_{WT} > P_L$			
S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
on	on	off	on	on	on	on	on	on	on	off	Off
S_5	S_6	S_7	S_8	S_5	S_6	S_7	S_8	S_5	S_6	S_7	S_8
on	on	off	on	on	on	on	on	on	on	off	Off

4.1 Mode 1

The first operation mode is shown in Fig -5. In this operation mode, four input power sources V_1, V_2, V_3 and V_4 are in charge for supplying voltage to the load, and battery charging or discharging is not done. This operation mode is considered as the basic operation mode of the converter. As clearly seen from the converter structure, there are two options to conduct input power sources currents i_{L1}, i_{L2}, i_{L3} and i_{L4} without passing through the battery; path 1:S_4-D_3 and S_8-D_7, path 2:S_3-D_4 and S_7-D_8. In this operation mode, the first path is chosen; therefore, switch S_3 and S_7 are turned OFF while switch S_4 and S_8 are turned ON entirely in the switching period. Switches S_1, S_2, S_5 and S_6 are turned ON and inductors L_1, L_2, L_3 and L_4 are charged with voltages across V_1, V_2, V_3 and V_4 respectively. In this mode, voltage from the input sources is directly fed to the load and the battery remains unused.
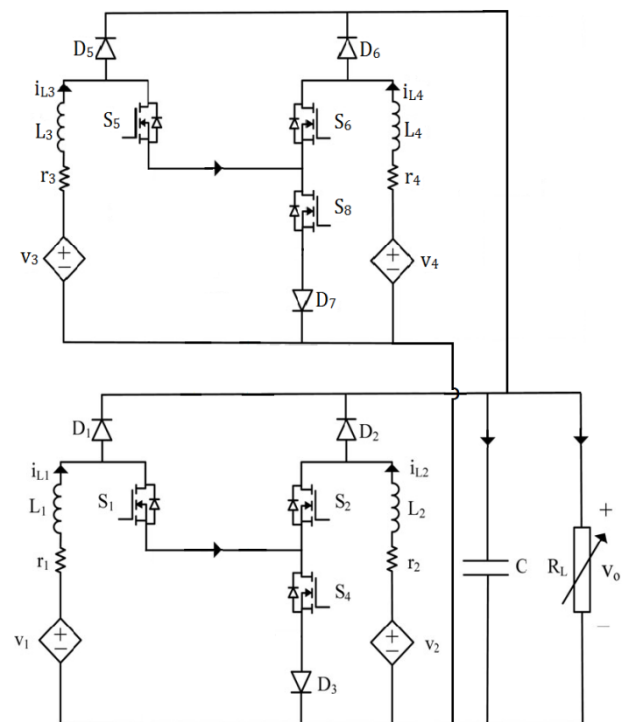
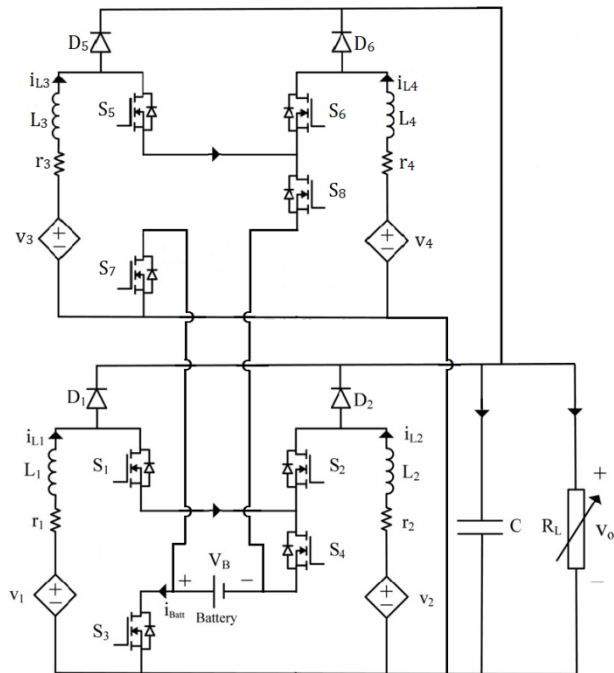**Fig -5**: Mode 1 of four-input DC-DC converter

4.2 Mode 2

Fig -6: Mode 2 of four-input DC-DC converter

Second operation mode is shown in Fig -6. In this operation mode, four input power sources V_1, V_2, V_3 and V_4 along with the battery are accountable for supplying the load voltage. Therefore, discharging operation of the battery is performed in this operation mode. Referring to the converter topology, when switches S_3, S_4, S_7 and S_8 are turned ON simultaneously, currents i_{L1}, i_{L2}, i_{L3} and i_{L4} are conducted through the path of switch S_4 and S_8, the battery, and switch S_3 and S_7 which results in battery discharging. However, discharging operations of the battery can only last until switches S_1, S_5 and/or S_2, S_6 are conducting. As a result, the maximum discharge power of the battery depends on inductor currents i_{L1}, i_{L2}, i_{L3} and i_{L4}. Therefore, in order to acquire a maximum charge power of the battery, the input power sources should be designed in proper current and voltage values. On the other hand, regulate the discharging power of the battery below the maximum discharging power.

4.3 Mode 3

Fig -7 shows the third operation mode. In this operation mode, four input power sources V_1, V_2, V_3 and V_4 are responsible for supplying the load while the battery charging action is accomplished. Therefore, the charging state of the battery should be provided in this operation mode. Referring to the converter topology, when switches S_3, S_4, S_7 and S_8 are turned OFF, by turning ON switches S_1, S_2, S_3 and S_4, inductor currents i_{L1}, i_{L2}, i_{L3} and i_{L4} are conducted through

the path of diode D_4 and D_8, the battery, and diode D_3 and D_7; therefore, the condition of battery charging is provided.
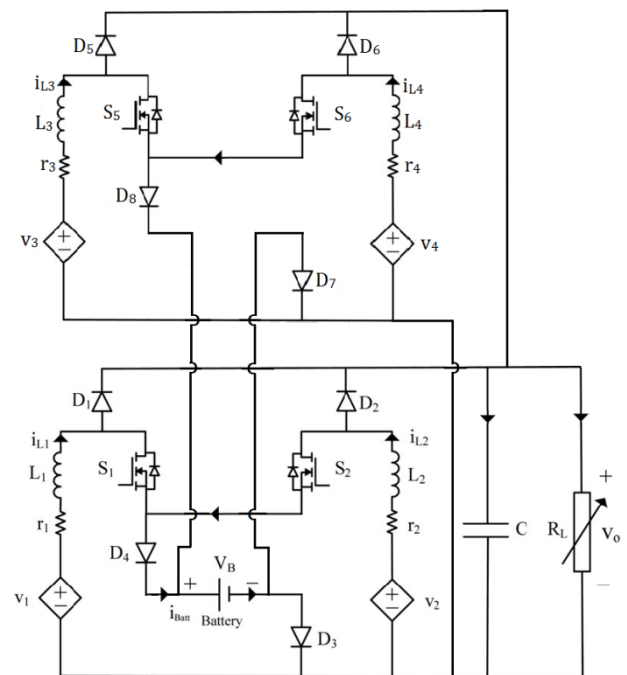

Fig -7: Mode 3 of four-input DC-DC converter

However, the charging operation of the battery can only last until switches S_1, S_5 and/or S_2, S_6 are conducting. As a result, the maximum charge power of the battery depends on inductor currents i_{L1}, i_{L2}, i_{L3} and i_{L4}.

5. SIMULATION RESULTS

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy to use environment. MATLAB is an excellent tool for teaching and research. In this, the MATLAB simulink model for Multi-Input DC-DC Converter is modeled and simulated with PI controller. The results are studied based on the performance of DC-DC converter and battery in obtaining a continuous regulated output voltage. The parameters of MIC with four input sources are listed below in Table -2.

Table -2: Simulation parameters

Parameters	Ratings
Input voltage (V_1,V_2,V_3,V_4)	0-15 V
Output voltage (V_o)	24 V
Inductor (L_1,L_2,L_3,L_4)	1.90985e-5 H
Capacitor (C)	100000e-6 F
Frequency (f)	2000 Hz
Resistive load (L)	4.8 Ω
Battery	6 V

5.1 Mode 1

In this operation mode, four input power sources V_1, V_2, V_3 and V_4 are responsible for supplying the load, and battery charging or discharging is not done. The operation is performed under the condition that one of the input voltages should be greater than or equal to 8v. Fig -8 shows the first mode of operation with input voltages V_1 as 2V, V_2 as 8V, V_3 as 0V and V_4 as 3V.
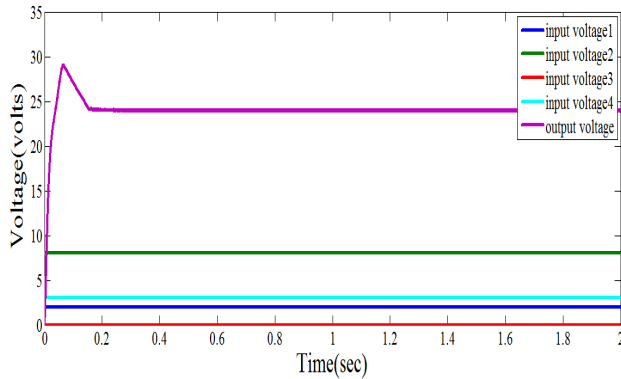

Fig -8 Mode 1 waveform with V_1 as 2V, V_2 as 8V, V_3 as 0V and V_4 as 3V

5.2 Mode 2

Four input power sources V_1, V_2, V_3 and V_4 along with the battery are responsible for supplying the load in this operation mode. One of the input voltages should be greater than or equal to 6v in battery discharging condition. Fig -9 shows the second mode of operation with input voltages V_1 as 6V, V_2 as 2V, V_3 as 1V and V_4 as 0V.
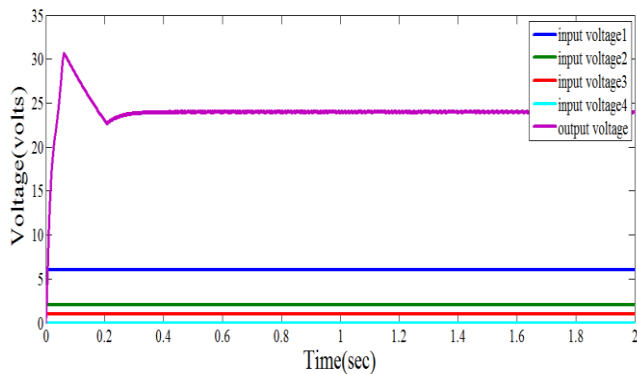

Fig -9 Mode 2 waveform with V_1 as 6V, V_2 as 2V, V_3 as 1V and V_4 as 0V

5.3 Mode 3

In this operation mode, four input power sources V_1, V_2, V_3 and V_4 are responsible for supplying the load while the battery charging is performed. Battery charging is performed under the condition that one of the input voltages should be greater than or equal to 11v. Fig -10 shows the third mode of operation with input voltages V_1 as 2V, V_2 as 8V, V_3 as 11V and V_4 as 1V.
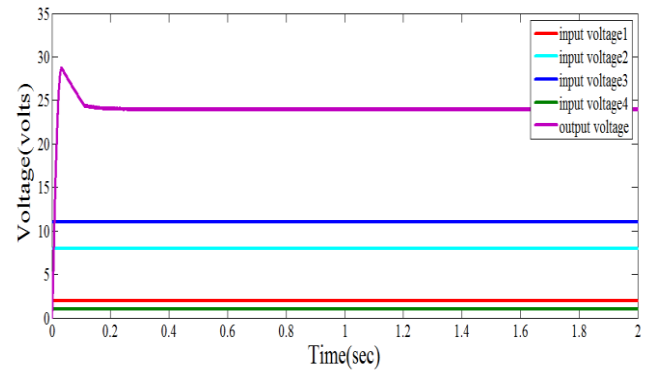

Fig -10 Mode 3 waveform with V_1 as 2V, V_2 as 8V, V_3 as 11V and V_4 as 1V

6. CONCLUSIONS

The proposed Multi-Input DC-DC converter produces regulated output voltage to the load from the different input sources. MIC supplies power to the load either individually or simultaneously from the input sources. As the power delivered by the renewable energy sources like solar and wind which are discontinuous due to change in weather conditions, a storage element battery is provided. Battery starts discharging, when the power delivered by the input sources is not as much of to the load voltage to provide a continuous supply to the load. Instead of using individual converter for each source in hybrid system, MIC is used which reduces the system size and cost.

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