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Modeling of Multi-Input DC-DC Converter for Renewable Energy Sources

Nithya. K[1], M. Ramasamy[2]

PG Scholar, Department of EEE, K.S.R College of Engineering, Tiruchengode, Tamilnadu, India[1]

Assistant Professor, Department of EEE, K.S.R College of Engineering, Tiruchengode, Tamilnadu, India[2]

Abstract— A multi-input DC-DC boost converter is proposed to draw power from several input sources and to supply the regulated output voltage for the load from the power sources. 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. 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 storage element to be charged or discharged through input power sources. Multi-Input Converter (MIC) can deliver power from all of the input sources to the load either individually or simultaneously. MICs reduce the system size and cost by reducing the number of components. Three different operation modes are discussed based on the consumption of the battery. A PI controller is used for the closed loop performance of MIC. The different operating modes of the proposed converter are simulated using MATLAB.

Index Terms—Renewable energy sources, DC-DC converter, PI controller.

I. 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 energy source in a power system. However, a MIC[7] 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 needs and increasing difficulty in meeting those needs through traditional means of power generation. Electricity consumption has been increasing at one of the fastest rates in the world due to population growth and economic development. Our economy faces increasing challenges because energy supply is struggling to keep pace with demand and there are energy shortages almost everywhere in the country. Such chronic lack of energy and unreliable supplies threaten our economic growth.

Renewable Energy Sources (RES)[4] such as wind and solar, 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 advantage with the use of renewable energy is that as it is renewable and so will never run out. Their fuel being derived from natural and available resources reduces the costs of operation. It facilities generally require less maintenance.

Even more importantly, renewable energy produces little or no waste products such as carbon dioxide or other chemical pollutants, so has minimal impact on the environment. Renewable energy also has the advantage of allowing decentralized distribution of energy particularly for meeting rural energy needs. Human activity is overloading our atmosphere with carbon dioxide and other global warming emissions, which trap heat, steadily drive up the planet's temperature, and create significant and harmful impacts on our health, environment and climate. Electricity production is majorly generated by coal-fired power plants which emits global warming gases. The air and water pollution emitted by coal and natural gas plants are avoided by using RES. Hence, Solar and Wind energy[13] sources are considered as the input sources for MIC.

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Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use PV panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies. PV cell[8] is a device that converts light into electric current using the photoelectric effect. The most modern systems use a method of sun exposure to generate electricity via semiconductors. Simple, direct exposure to the sun and its heat generate electrons that are then captured into the system and translated into electricity. The design can be used for a variety of things as small as powering a mobile phone to as large of a system as that needed to power the home.

Wind energy is the kinetic energy of air in motion, also called wind. Wind is the movement of air across the surface of the Earth, affected by areas of high pressure and of low pressure. The surface of the Earth is heated unevenly by the Sun, depending on factors such as the angle of incidence of the sun's rays at the surface which differs with latitude and time of day and whether the land is open or covered with vegetation. Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electrical power, windmills for mechanical power, wind pumps for water pumping or drainage, or sails to propel ships. Wind power consumes no fuel, and emits no air pollution, unlike fossil fuel power sources.

II. DC-DC CONVERTER

A DC-DC converter[3] is an electronic circuit which converts a source of DC from one voltage level to another. The DC-DC converters are widely used in regulated switch mode DC power supplies. The input of these converters is an unregulated DC voltage, and therefore it will be fluctuated. In these converters the average DC output voltage must be controlled to be equated to the desired value although the input voltage is changing. The regulation of the average output voltage in a DC-DC converter is a function of the on-time of the switch, the pulse width and the switching frequency. The output voltage control depends on the duty ratio D. The duty ratio is defined as the ratio of the on-time of the switch and the switching period. Duty cycle is given by the Equation 1

$$D = \frac{T_{ON}}{T_S} \quad (1)$$

where,

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

A. DC-DC Boost Converter

A converter that outputs a voltage higher than the input voltage is called Boost converter[11]. For this reason boost converter is often referred to as a step-up converter or regulator. The fundamental for a boost converter consists of an inductor, diode, capacitor and switch. The DC input to a boost converter can be from many sources as well as batteries, such as rectified AC from the mains supply, or DC from solar panels, fuel cells, dynamos and DC generators. The DC input voltage is in series with a large inductor acting as a current source. A switch in parallel with the current source and the output is turned off periodically, providing energy from the inductor and source to increase the average output voltage.

The circuit diagram of DC-DC boost converter is shown in Figure 1.

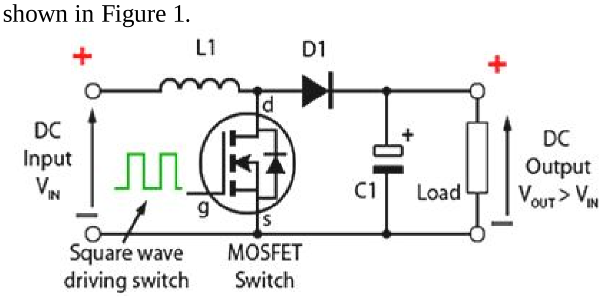

Fig. 1. Circuit diagram of DC-DC boost converter

The average output voltage is given by Equation 2.

$$V_O = \frac{V_{IN}}{1 - D} \quad (2)$$

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 is based on the on and off condition of the switch in the circuit.

III. MULTI-INPUT DC-DC CONVERTER

Multiple-Input DC-DC converters are the unique solution to combine several input power sources whose voltage levels and/or power capacity are different and to get regulated output voltage for the load from them. In

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many applications, there is a requirement for multiple power sources to be connected together, providing the power for a single loads. Figure 2 shows the separate converter for different sources.

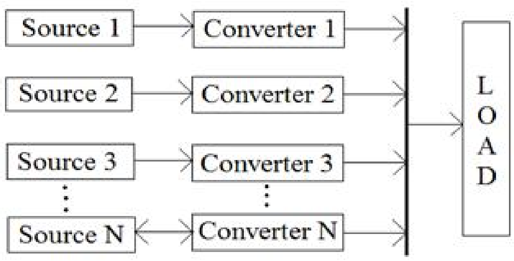

Fig. 2. Separate converters for each source

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. A single Multi-Input DC-DC Converter[18] replaces several number of parallel connected single converters is shown in Figure 3.

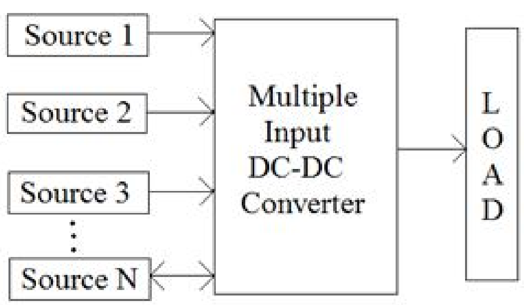

Fig. 3. An MIC for all sources

The structure of the two-input DC-DC boost converter is represented in Figure 4. The converter interfaces two input power sources V_1 and V_2, and a battery as the storage element. This converter is suitable alternative for hybrid power systems of PV, FC, and wind sources. Therefore, V_1 and V_2 are shown as two dependent power sources that their output characteristics are determined by the type of input power sources. In the converter structure, two inductors L_1 and L_2 make the input power ports as two current type sources, which result in drawing smooth DC currents from the input power sources. The R_L is the load resistance, which can represent the equivalent power feeding an inverter.

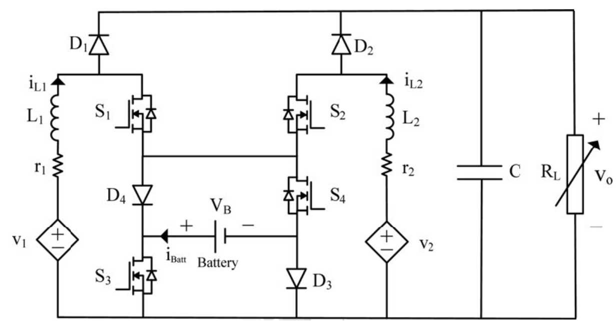

Fig. 4. Circuit topology of two-input DC-DC converter

Four power switches S_1, S_2, S_3 and S_4 in the converter structure are the main controllable elements that control the power flow of the hybrid power system. As like the conventional boost converters, diodes D_1 and D_2 conduct in complementary manner with switches S_1 and S_2. The converter structure shows that when switches S_3 and S_4 are turned ON, their corresponding diodes D_3 and D_4 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}. In hybrid power system applications, the input power sources should be exploited in continuous current mode.

IV. MODES OF OPERATION

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

- Mode 1
  Supplying the load with sources V_1 and V_2 without battery.
- Mode 2
  Supplying the load with sources V_1 and V_2 and the battery.
- Mode 3
  Supplying the load with sources V_1 and V_2, and battery charging performance.

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

TABLE I
SWITCHING STATES OF TWO-INPUT DC-DC CONVERTER

Mode 1				Mode 2				Mode 3			
$P_{PV} + P_{WT} = P_{LOAD}$				$P_{PV} + P_{WT} < P_{LOAD}$				$P_{PV} + P_{WT} > P_{LOAD}$			
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

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A. Mode 1

Figure 5 shows the first operation mode. In this operation mode, two input power sources V_1 and V_2 are responsible for supplying 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} and i_{L2} without passing through the battery; path 1:S_4-D_3, path 2:S_3-D_4. In this operation mode, the first path is chosen; therefore, switch S_3 is turned OFF while switch S_4 is turned ON entirely in the switching period. Switches S_1 and S_2 are turned ON and inductors L_1 and L_2 are charged with voltages across V_1 and V_2 respectively. In this mode, voltage from the input sources is directly fed to the load and the battery remains unused.

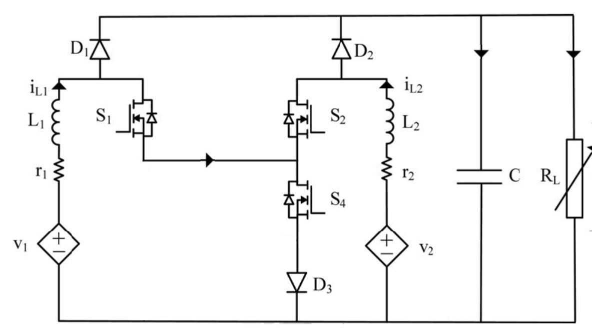

Fig. 5. Mode 1 of two-input DC-DC converter

B. Mode 2

Second operation mode is shown in Figure 6. In this operation mode, two input power sources V_1 and V_2 along with the battery are responsible for supplying the load.

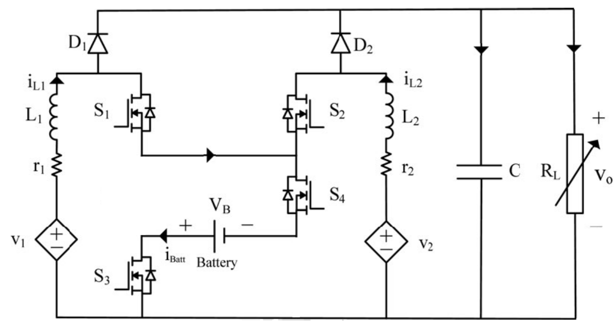

Fig. 6. Mode 2 of two-input DC-DC converter

Therefore, discharging state of the battery should be provided in this operation mode. Referring to the converter topology, when switches S_3 and S_4 are turned ON simultaneously, currents i_{L1} and i_{L2} are conducted through the path of switch S_4, the battery, and switch S_3 which results in battery discharging. However, discharging operations of the battery can only last until switches S_1 and/or S_2 are conducting. As a result, the maximum discharge power of the battery depends on inductor currents i_{L1} and i_{L2}. Therefore, in order to acquire a desired 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.

C. Mode 3

Figure 7 shows the third operation mode. In this operation mode, two input power sources V_1 and V_2 are responsible for supplying the load while the battery charging performance 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 and S_4 are turned OFF, by turning ON switches S_1 and S_2, inductor currents i_{L1} and i_{L2} are conducted through the path of diode D_4, the battery, and diode D_3; therefore, the condition of battery charging is provided.

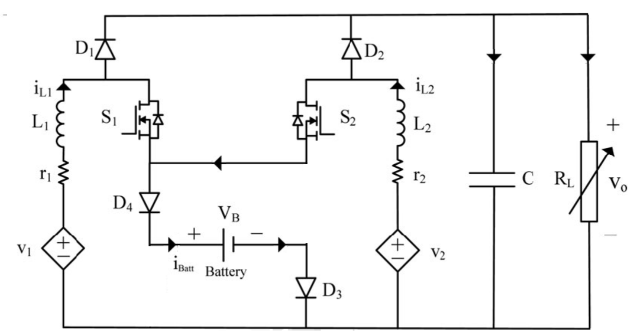

Fig. 7. Mode 3 of two-input DC-DC converter

However, the charging operation of the battery can only last until switches S_1 and/or S_2 are conducting. As a result, the maximum charge power of the battery depends on inductor currents i_{L1} and i_{L2}. Therefore, in order to acquire a desired 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 charging power of the battery below the maximum charging power.

V. SIMULATION RESULTS

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy to use

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environment. MATLAB is an excellent tool for teaching and research. In this, the MATLAB simulink model for Multi-Input DC-DC Converter is modelled 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.

A. Mode 1

In this operation mode, two input power sources V_1 and V_2 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. Figure 8 shows the first mode of operation with input voltages V_1 as 9V and V_2 as 4V.

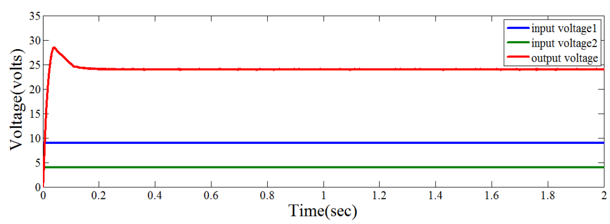

Fig. 8. Mode 1 waveform with V_1 as 9V and V_2 as 4V

B. Mode 2

Two input power sources V_1 and V_2 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 the battery discharging condition. Figure 9 shows the second mode of operation with input voltages V_1 as 7V and V_2 as 3V.

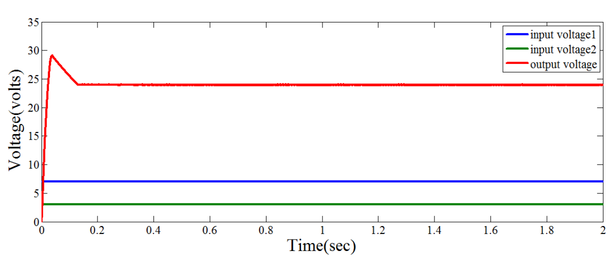

Fig. 9. Mode 2 waveform with V_1 as 7V and V_2 as 3V

C. Mode 3

In this operation mode, two input power sources V_1 and V_2 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. Figure 10 shows the third mode of operation with input voltages V_1 as 15V and V_2 as 0V.

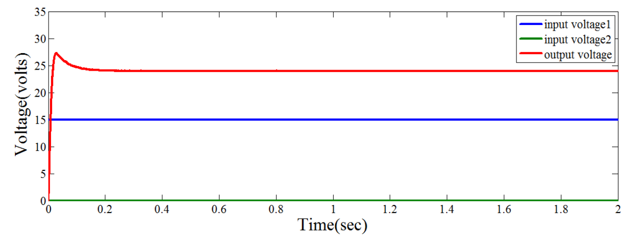

Fig. 10. Mode 3 waveform with V_1 as 15V and V_2 as 0V

VI. CONCLUSION

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 produced by the renewable energy sources like solar and wind which are intermittent due to change in weather conditions, a storage element battery is provided. Battery starts discharging, when the power delivered by the input sources is less than 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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