A Multi-Input Dc/Dc Converter For Zero-Emission Electric Power Generation System

Anjana S
M.tech student
M. A.College of Engineering
Kothamangalam, Kerala,

Kavitha Issac
Assistant Professor
M. A.College of Engineering
Kothamangalam, Kerala

Alias M V
Professor
M.A.College of Engineering
Kothamangalam,Kerala

***Abstract* — Alternate energy sources such as solar array, fuel cell (FC), wind etc. have a wide voltage change range due to the nature of the sources. The traditional converters cannot cope with this wide voltage change nature and often requires additional voltage boost by additional dc/dc converter. In this paper a double input dc-dc converter based on Z-source converters is developed. Here, the input dc voltage can be bucked or boosted and also input dc sources can deliver power to the load individually/simultaneously, so a combination of battery with one of the alternate energy sources such as solar array, wind turbine or fuel cell can be used as input sources. Various stages of double input Z-source dc-dc converter are investigated and analysed using MATLAB/Simulink. Finally, the experimental results are presented to confirm the theoretical analysis.**

***Index Terms* — multi input converter (MIC), Z-source converter, dc-dc converter.**

I. INTRODUCTION

RECENTLY, the zero-emission electric power generation system has been developed to exploit clean energy resources such as the solar array, wind generator, fuel cell, and so forth. Alternate energy sources such as solar, fuel cell, and wind have a wide voltage change range due to the nature of the sources. Photovoltaic cell's voltage varies with temperature and irradiation. Fuel cell stack voltage drops greatly with current. And wind generator voltage varies with wind speed and control. Thus the renewable energy such as photovoltaic (PV), fuel cell (FC) and wind has created various electric energy sources with different electrical characteristics for the modern power system. In order to supply load continuously, more than one energy sources are combined and to get the regulated output voltage, the different topologies of multi input converters (MICs) have been proposed in recent years [2]-[4].

In order to combine more than one source, either two independent converters or a single double input (DI) converter is needed. The advantages of using a DI converter include reduced component count, lower cost, and control simplicity [4].

Traditionally, a double-input dc/dc converter with two dc voltage sources connected either in parallel or in series to form an input voltage source for the dc/dc converter has been proposed to transfer the desired power to the load [3]. Also a multiple input dc/dc converter using a multi input winding is proposed [2].

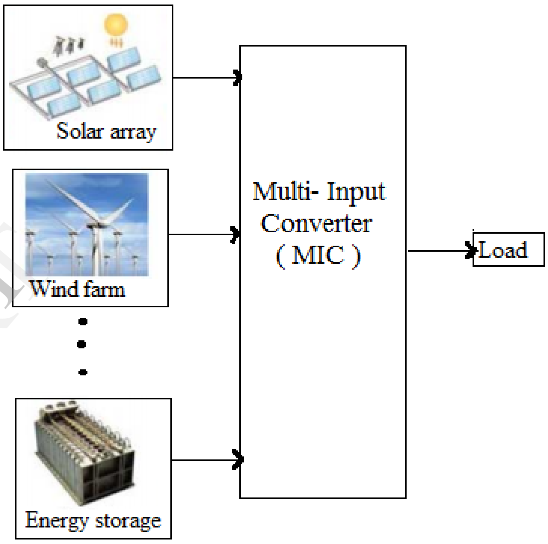

Fig. 1. Block diagram of Multi-Input Converter (MIC).

The general block diagram of a MIC consists of several input sources and a single load, as shown in Fig. 1. The energy storage systems may be a battery or a super capacitor. In general, all of the input sources can deliver power to the load either individually or simultaneously through the MIC. When only one of the input sources feeds the MIC, it will transfer power to the load individually and the MIC will operate as a PWM converter. And when more than one input sources are supplied to the MIC, all input sources will deliver power to the load simultaneously without disturbing each other's operation [1].

In this paper, a two-input dc–dc converter using based on Z-source converter, as shown in Fig. 2, is examined because a general discussion of multiple-input converter is too complicated. In this converter, the input dc voltage can be bucked or boosted and also input dc sources can deliver power to the load individually or simultaneously. So a combination of battery with one of the alternate energy sources such as solar array, wind turbine or fuel cell can be used as input sources. Section II deals with Z-source converters. In Section

III, the Circuit configuration and operating principle of the converter is discussed. Simulation and experimental results to verify the converters' characteristics are presented in Sections IV and V, respectively. Finally, Section VI draws the concluding remarks.

II. Z-SOURCE CONVERTERS

The two traditional converters: voltage-source and current-source converters have the following common problems: Operates either as a boost or a buck converter; main circuits cannot be interchangeable; vulnerable to EMI noise. To overcome the above problems of the traditional V-source and I-source converters, an impedance-source (or impedance-fed) power converter (abbreviated as Z-source converter) is implemented for dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. Fig. 2 shows the general Z-source converter structure. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters, respectively.

In Fig. 2, a two-port network that consists of a split-inductor L_1 and L_2 and capacitors C_1 and C_2 connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter. The dc source/or load can be either a voltage or a current source/or load. Therefore, the dc source can be a battery, fuel cell, a capacitor, or a combination of those. The inductance L_1 and L_2 can be provided through a split inductor or two separate inductors.

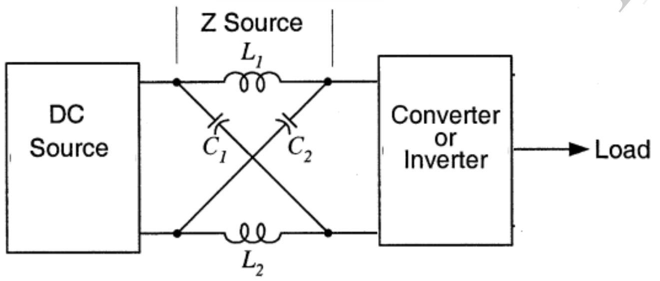

Fig. 2. Double input Z-source DC-DC converter

Major features of Z-source converters includes: Single power stage for buck and boost; minimum number of switching devices; more reliable and lower cost; high immunity to EMI noise and high efficiency.

The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. In this paper a double input dc-dc converter based on Z-source converters is studied. This topology is proper for renewable-energy applications and combination of two different sources.

III. CIRCUIT CONFIGURATION

The circuit diagram of the double-input Z-source dc-dc converter with two different voltage sources is shown in Fig. 3. The circuit consists of two different input sources, V_1 and V_2, and four diodes, D_1- D_4, to provide current path in different states and a Z-network that consists of a split-inductor L_1 and L_2 and capacitors C_1 and C_2 connected in X shape. A switch S, is situated in output port of Z-network to control input and output power of converter. The last section of the converter is a LC filter besides the load in order to suppress output signal ripple.

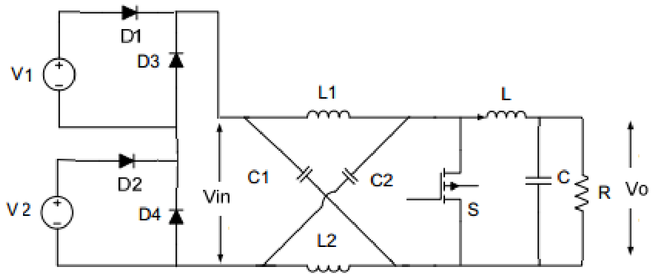

Fig. 3. Double input Z-source DC-DC converter

In a multi- input converter (MIC), all of the input sources can deliver power to the load either individually or simultaneously. A double input Z-source dc-dc converter operates in four stages depending on the presence or absence of input sources, as shown in table 1.

TABLE 1. STAGES OF DOUBLE INPUT DC-DC CONVERTER

STAGE	SOURCES		DIODES				V_{in}
	V_1	V_2	D_1	D_2	D_3	D_4	
1	ON	ON	F.B	F.B	R.B	R.B	$V_1 + V_2$
2	ON	OFF	F.B	R.B	R.B	F.B	V_1
3	OFF	ON	R.B	F.B	F.B	R.B	V_2
4	OFF	OFF	R.B	R.B	F.B	F.B	0

F.B – Forward biased; R.B – Reverse biased

a. ***Stage 1 :***

In stage 1, both of the input sources are present. That is, both of the input sources deliver power to the load simultaneously through the MIC. Equivalent circuit of this stage is shown in Fig. 4. When both sources are present, the converter input dc voltage is sum of voltage of two series dc sources. The input voltage is given by:

$$V_{in} = V_1 + V_2$$

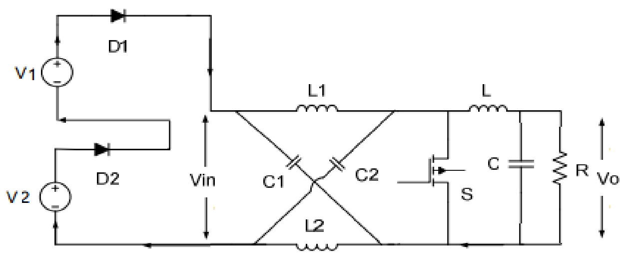

Fig. 4. Equivalent circuit of stage 1

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b. ***Stage 2 :***

In stage 2, only one of the input sources is present. When only one of the input sources feeds the MIC, it transfers power to the load individually and the MIC will operate as a PWM converter. Equivalent circuit of this stage is shown in Fig. 5. In this stage, source 1 is present and source 2 is absent, so only this source provides energy to load. The input voltage is given by:

$$V_{in} = V_1$$

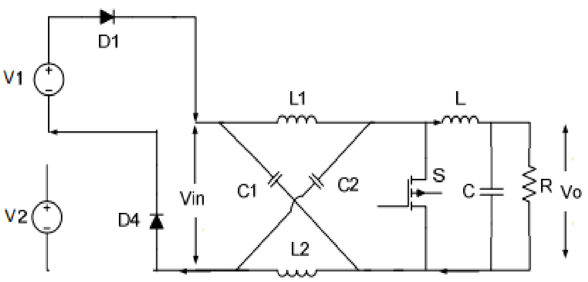

Fig. 5. Equivalent circuit of stage 2

c. ***Stage 3 :***

In stage 3, only one of the input sources is present. When only one of the input sources feeds the MIC, it transfers power to the load individually and the MIC will operate as a PWM converter. Equivalent circuit of this stage is shown in Fig. 6. In this stage, source 1 is absent and source 2 is present, so only this source provides energy to load. The input voltage is given by:

$$V_{in} = V_2$$

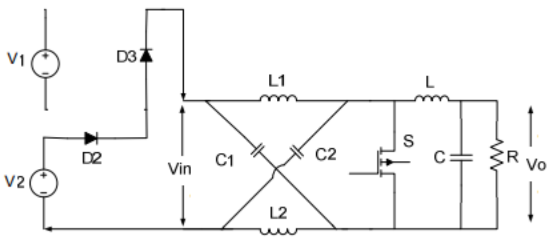

Fig. 6. Equivalent circuit of stage 3

d. ***Stage 4 :***

In stage 4, both of the input sources are present. Equivalent circuit of this stage is shown in Fig. 7. When both sources are absent, the converter input voltage is zero.

$$V_{in} = 0$$

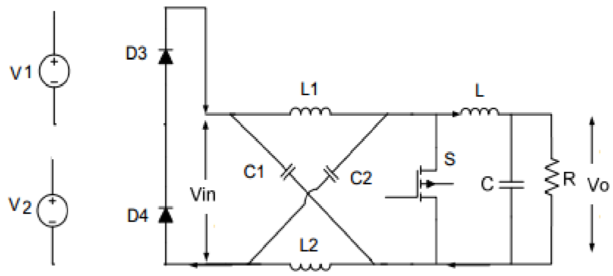

Fig. 7. Equivalent circuit of stage 4

IV. CIRCUIT ANALYSIS

Similar to the other Z-source inverter/converter topologies, Z-network of the Z-source dc-dc converter is also symmetrical. Assuming that the inductors L_1 and L_2 and capacitors C_1 and C_2 have the same inductance (L) and capacitance (C), respectively, the Z-source network becomes symmetrical. From the symmetry and the equivalent circuits [6]:

$$V_{L1} = V_{L2} = V_L$$

$$V_{C1} = V_{C2} = V_C$$

A double input Z-source dc-dc converter operates in four stages as shown in table 1. All the stages can be analysed in similar way. All the four stages operate in two modes depending upon the condition of the diodes and the switch S.

In mode 1 of stage 1, diodes D_1 and D_2 are ON and the switch S is OFF. The dc sources charge Z-network capacitors, while Z-network inductors discharge and transfer energy to the load. In mode 2, switch S is ON and D_1 and D_2 are OFF. The Z-network capacitors discharge, while inductors charge and store energy to release and transfer to the load in the next interval. In all the stages, the dc sources charge Z-network capacitors, while Z-network inductors discharge and transfer energy to the load in mode 1 and capacitors discharge, while inductors charge and store energy in mode 2.

Thus for mode 1, we have:

$$V_C = V_{in} - V_L$$

$$V_0 = V_{in} - 2V_L$$

For mode 2, we have:

$$V_C = V_L$$

$$V_0 = 0$$

Equating the average voltage of the inductors over one switching period to zero, the average output voltage V_0 can be expressed as:

$$V_0 = \frac{(1-D)}{(1-2D)} V_{in}$$

By varying the duty cycle D, the output voltage of the double input dc-dc converter can be bucked or boosted. When the duty cycle is greater than 0.5, the converter enters negative gain region, and it operates in the buck or boost mode. When the duty cycle is less than 0.5, the converter operates in the boost mode.

Considerations on Inductor and Capacitor:

The Z-source network is a combination of two inductors and two capacitors. For the Z-source converter, the Z-source network is the energy storage or filtering element. This network provides a second-order filter and is more effective to suppress voltage and current ripples than capacitor or inductor used alone in the traditional converters. Therefore, the inductor and capacitor requirement should be smaller than the traditional inverters. Therefore a traditional V-source converter's capacitor requirements and physical size and a traditional I-source converter's inductor requirements and physical size are the worst case requirement for the Z-source network [6].

V. SIMULATION RESULTS

In this section, simulation of double input Z-source dc-dc converter was performed using MATLAB/SIMULINK to confirm above analysis. Simulation consists of four sections which describes each stage of the converter, as in Table 3. Converter parameters in the simulation were as in Table 2. In this simulation, independence of dc sources from each other is shown in four different states.

TABLE 2. CONVERTER PARAMETERS

PARAMETER	VALUE
V_1	15 V
V_2	15 V
$C_1 = C_2 = C$	1000µF
$L_1 = L_2$	1.5mH
R	15Ω
Switching Frequency	25kHz
Duty Ratio (D)	25%
MOSFET,S	IRF840
DIODES	1N4001

TABLE 3. OUTPUT VOLTAGE FOR DIFFERENT STAGES

STAGE	*V_1 (V)*	*V_2 (V)*	*V_0 (V) Theoritical*	*V_0 (V) Simulated output*
1	*15*	*15*	*45*	*42.35*
2	*15*	*0*	*22.5*	*19.95*
3	*0*	*15*	*22.5*	*19.95*
4	*0*	*0*	*0*	*0*

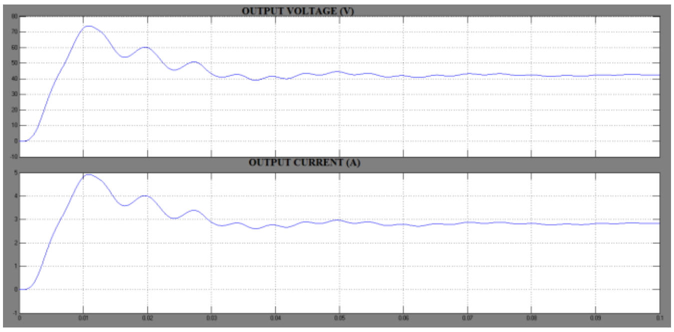

Fig .8 Output voltage and current waveforms for Stage 1

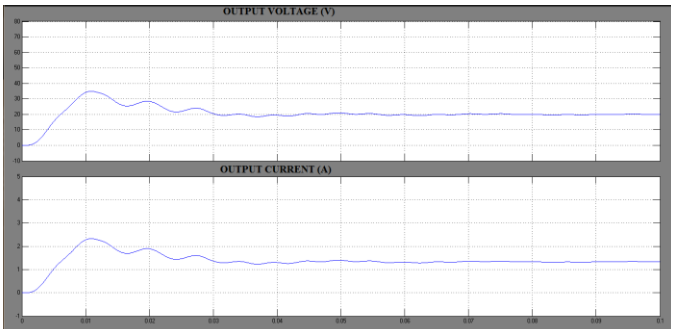

Fig .9 Output voltage and current waveforms for Stage 2 & 3

Fig. 8 to Fig. 10 shows the simulated output voltage and load current for stage 1, stage 2 & 3,stage 4 respectively. Fig. 11 shows the simulated waveforms of output voltage and load current for all the four stages.

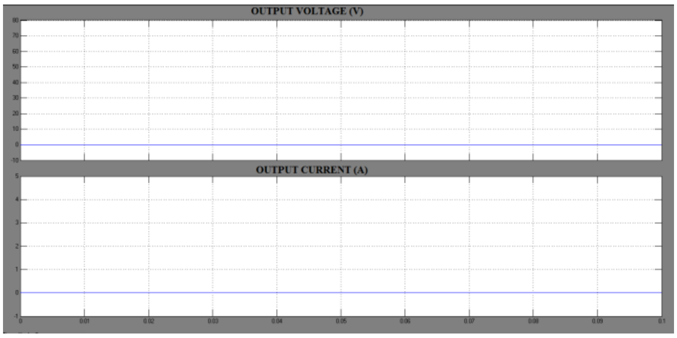

Fig .10 Output voltage and current waveforms for Stage 4

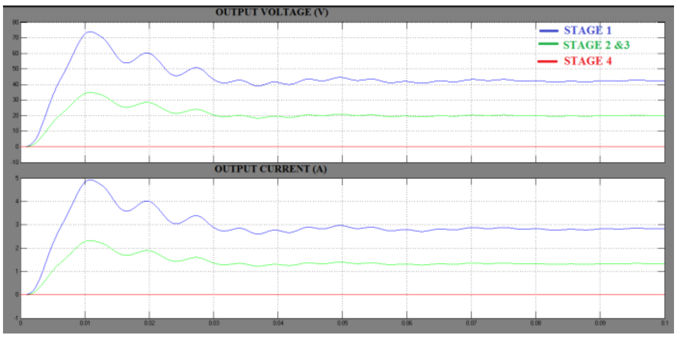

Fig .11 Output voltage and current waveforms for different Stages (a) Stage 1, (b) Stage 2 & 3, (c) Stage 4

V. HARDWARE RESULTS

To verify the performance of the double-input Z source dc/dc converter shown in Fig. 8, a prototype circuit is implemented with the specifications and component values as in Table 2. Block diagram of the hardware is shown in Fig. 12 and the experimental setup is shown in Fig. 13.

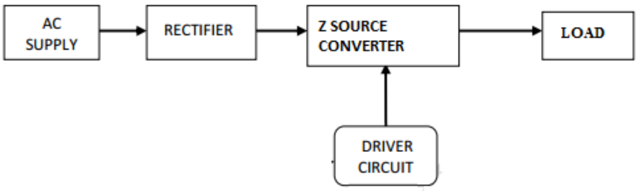

Fig.12. Block diagram of the hardware

Experimental setup is done for the specifications shown in table 2. The ac supply is converted to dc by a rectifier, which is in turn given as the input to the Z source converter. The Z source converter has one switch which driven using a driver circuit. When , both of the input sources are present. Then both of the input sources deliver power to the load simultaneously through the MIC and when only one source is present, it deliver power to the load individually. A double input Z-source dc-dc converter operates in four stages depending on the presence or absence of input sources.

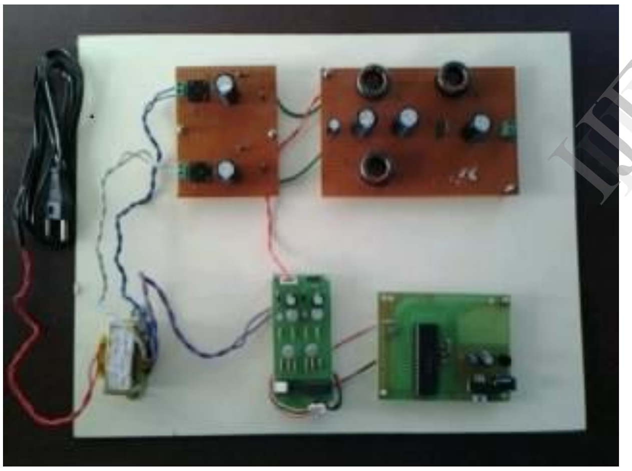

Fig.13. Experimental setup

V. CONCLUSION

In this paper, a double-input dc-dc converter in which the dc sources can deliver power to the load individually or simultaneously is analysed. The advantages of this topology include: the magnitude of the input dc voltage can be higher or lower than the one with a regulated output; the multi winding transformer is not needed; minimum switching devices are used in the circuit. Thus, the double-input dc-dc converter is proper for renewable-energy applications and zero-emission electric power generation systems which uses a combination of two or more different sources (such as battery and photovoltaic or fuel cell).

The analysis and simulation results show the input dc sources can deliver power to the load individually or simultaneously, as failure of each input sources doesn't disturb the other's operation. To verify the performance of the proposed double-input dc/dc converter, a prototype circuit is implemented and the results agree with the analytical results.

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