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Double Input Z-Source DC-DC Converter

SARAB JWAID MOUSA AL-CHLAIHAWI
PG Scholar, Dept of EEE, JNTU College of Engineering, Kukatpally, Hyderabad, A.P-India,
E-mail: sarab.haedar@yahoo.com.

Abstract: This paper proposes a double input dc-dc converter based on Z-source converters. In the proposed converter, the input dc voltage can be boosted and also input dc sources can deliver power to the load individually or simultaneously, so combination of a battery with one of the new energy sources such as solar array, wind turbine or fuel cell can be used as input sources. Different states of double input Z-source dc-dc converter are analyzed and then steady state operation of converter is explained in detail. Finally, the simulation results are presented to confirm the theoretical analysis.

Keywords: Z-Source Converter, Double Input, Dc-Dc Converter.

I. INTRODUCTION

The renewable energy such as photovoltaic (PV) and wind has created various electric energy sources with different electrical characteristics for the modern power system. In order to combine more than one energy source, such as the solar array, wind turbine, fuel cell (FC) and commercial ac line to get the regulated output voltage, the different topologies of multi input converters (MICs) have been proposed in recent years. Traditionally, two dc voltage sources are connected to two independent dc-dc power converters to obtain two stable and equivalent output voltages, which are then connected to the dc bus, to provide the electric energy demanded by the load. Another approach for the double-input dc-dc converter is to put two dc sources in series to form a single voltage source where traditional dc-dc power converters can be used to transfer power to the load. In order to transfer power individually, each dc voltage source needs a controllable switch to provide a bypass short circuit for the input current of the other dc voltage source to deliver electric energy continuously. Another approach is to put PWM converters in parallel with or without electrical isolation using the coupled transformer. Control schemes for these MICs with paralleled dc sources are based on the time-sharing concept because of the clamped voltage. Because of the voltage amplitude differences between two dc sources, only one of them can be connected to the input terminal of the dc-dc converter and transfer power to the load at a time. The general form of a MIC consists of several input sources and a single load, conceptually shown in Fig. 1. 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. In other words, 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.

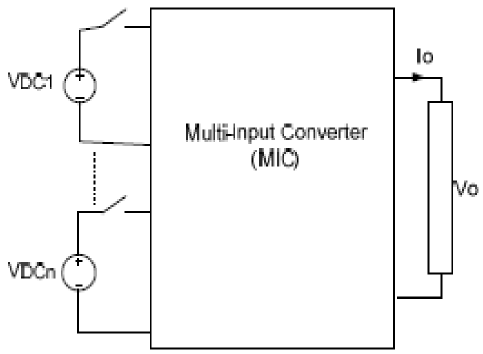

Figure 1: General form of multi input converter

The objective of this paper is to propose a double-input dc-dc converter which has the following advantages: The dc sources can deliver power to the load individually or simultaneously; the multi winding transformer is not needed; the magnitude of the input dc voltage can be higher or lower than the one with a regulated output; minimum switching devices are used in the converter circuit. The proposed double input dc-dc converter is proper for renewable-energy applications and combination of two different sources (such as battery and photovoltaic or fuel cell).

II. CIRCUIT CONFIGURATION AND OPERATION PRINCIPLE OF THE PROPOSED CONVERTER

A. Z-Source Converters

Z-source converters are modern group of power electronic converters which can overcome problems with traditional converters. The Z-source inverter is a novel topology [6] that overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter. The concept of Z-source was used in direct ac-ac power conversion [7]. Similarly, the concept of Z-source also was extended to dc-dc power conversion [8].

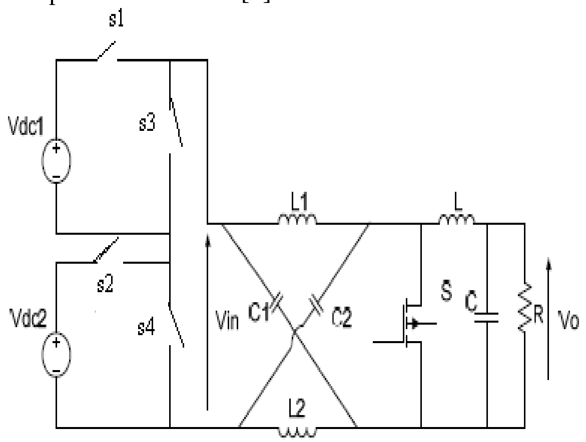

Figure 2: double input z source converter

B. Circuit Configuration of Proposed Converter

The schematic circuit diagram of the proposed double-input Z-source dc-dc converter with two different voltage sources is shown in Fig. 2. It consists of two different input sources, Vdc1 and Vdc2, and four diodes, S1-S4, applied to provide current path in different states. In this paper, permanent connection of input dc sources is considered, so S1 and S2 can be replaced with active switches if it's required to connect and disconnect each of sources to input side of converter frequently. Energy receiver, converter and transmitter sections are situated in the middle side of the converter. This section is a two-port network that consists of a split-inductor L1 and L2 and capacitors C1 and C2 connected in x-shape which is named "Z-network". An active switch, S, is situated in output port of Z-network to control input and output power of converter. The final section of converter is a LC filter beside the load in order to reject output signal ripple.

$$Vin = Vdc1 + Vdc2 \tag{1}$$

1. State 1, source 1 and source 2 is active

In this state, because both two sources are active, S1 and S2 are forward biased and S3 and D4 are reverse biased. Thus, the sources current enters in Z-network through S1 and S2 and after passing load impedance, comes back into sources through negative polarity.

2. State 2, source 1 is active and source 2 is inactive

The equivalent circuit of this state is shown in Fig. 4. In this state, source 1 is active, so only this source provides converter (consequently load) energy. Because of source 1 is active then S1 is forward biased and S3 is reverse biased, so current follows from S1 to Z-network to load. In reverse path from load to the source, current can't pass through source 2 and S2, so S4 is forcedly turned on and conduct current to source 1. In this state, converter input dc voltage is only provided by source (1), as (2) shows.

$$Vin = Vdc1 \tag{2}$$

TABLE 1
STATES OF DOUBLE INPUT DC-DC CONVERTER

state	Sources States		Switches States				V_{in}
	V_{dc1}	V_{dc2}	s1	s2	s3	s4	
1	Active	Active	On	On	Off	Off	$V_{dc1}+V_{dc2}$
2	Active	inactive	On	Off	Off	On	V_{dc1}
3	inactive	Active	Off	On	On	Off	V_{dc2}
4	inactive	inactive	Off	Off	On	On	0

3. State 3, source 1 is inactive and source 2 is active

If source 1 is eliminated for each reason and source 2 is active, the converter can operate normally without effect of source 1 elimination. Fig. 5 shows the equivalent circuit for this state. In state 3, it's only source 2 that supplies converter and load. Source 2 activation causes forward bias of S2 and Reverse bias of S4. Because of source 1 disconnection, current Passes through S3 and indeed, current turns it on forcedly to complete current path. In this state, converter input dc voltage is only provided by source 2, as (3) shows.

$$Vin = Vdc2 \tag{3}$$

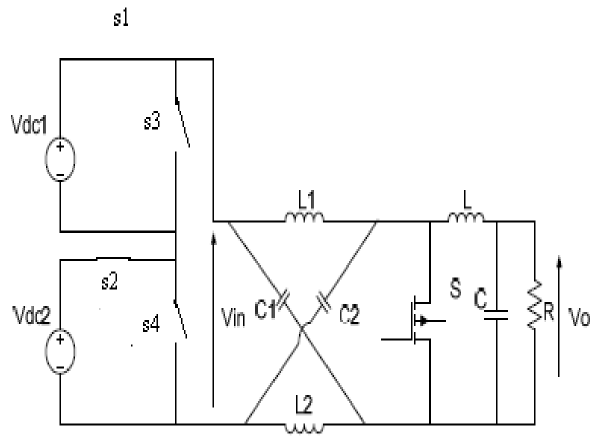

Figure 3: state 1 equivalent circuit

4. State 4, both source 1 and source 2 are inactive

Basically, this state is only following of one of the previously mentioned three states. Because in this state both dc sources are inactive and disconnected from converter, D1 and D2 are forcedly turned off and consequently, the only existing path for remain current, from previous state, is provided by D3 and D4. Thereupon, in state4 D3 and D4 are turned on. Fig. 6 shows equivalent circuit of this state. Input voltage is zero in this state as shown in (4).

$$Vin = 0 \tag{4}$$

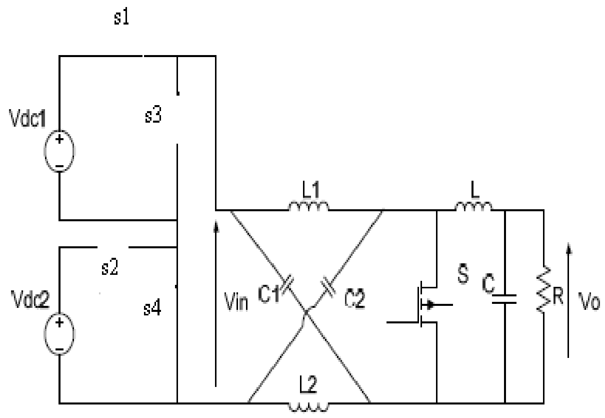

Figure 4: State 2 Equivalent circuit

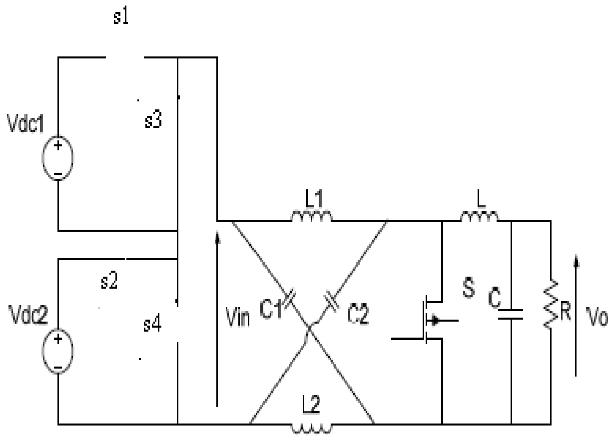

Figure 5: State 3 Equivalent circuit

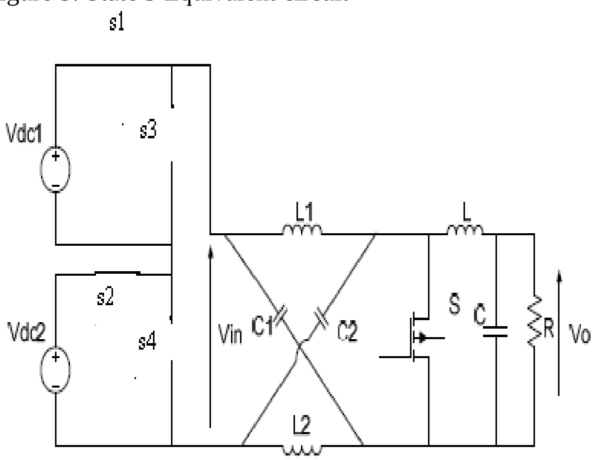

Figure 6: State 4 Equivalent circuit

Obviously, because both dc sources disconnect from converter, duration of this state is very short and when current descends to zero, whole of converter will be inactive.

III. STEADY STATE ANALYSIS OF DOUBLE INPUT Z-SOURCE DC-DC CONVERTER

Assuming that the inductors L1 and L2 and capacitors C1 and C2 have the same inductance(L) and capacitance (C), respectively, the Z-source network becomes symmetrical. From the symmetry and the equivalent circuits, we have

$$V_{C1} = V_{C2} = V_C \quad v_{L1} = v_{L2} = v_L. \tag{5}$$

Given that the inverter bridge is in the shoot-through zero state for an interval of, during a switching cycle T_0, and from the equivalent circuit, Fig. 6, one has

$$v_L = V_C \quad v_d = 2V_C \quad v_i = 0. \tag{6}$$

Now consider that the inverter bridge is in one of the eight non shoots- through states for an interval of T_1, during the switching cycle. From the equivalent circuit, Fig. 7, one has

$$v_L = V_0 - V_C \quad v_d = V_0 \quad v_i = V_C - v_L = 2V_C - V_0 \tag{7}$$

Where V_0 is the dc source voltage and $T=T_0+T_1$. The average voltage of the inductors over one switching period(5) should be zero in steady state, from (6) and (7), thus, we have

$$V_L = \overline{v_L} = \frac{T_0 \cdot V_C + T_1 \cdot (V_0 - V_C)}{T} = 0 \tag{8}$$

or

$$\frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0}. \tag{9}$$

Similarly, the average dc-link voltage across the inverter bridge can be found as follows:

$$V_i = \overline{v_i} = \frac{T_0 \cdot 0 + T_1 \cdot (2V_C - V_0)}{T} = \frac{T_1}{T_1 - T_0} V_0 = V_C. \tag{10}$$

The peak dc-link voltage across the inverter bridge is expressed in (7) and can be rewritten as

$$\hat{v}_i = V_C - v_L = 2V_c - V_0 = \frac{T}{T_1 - T_0} V_0 = B \cdot V_0 \tag{11}$$

Where,

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} \geq 1 \tag{12}$$

is the boost factor resulting from the shoot-through zero state. The peak dc-link voltage v_i is the equivalent dc-link voltage of the inverter. On the other side, the output peak phase voltage from the inverter can be expressed as

$$\hat{v}_{ac} = M \cdot \frac{\hat{v}_i}{2} \tag{13}$$

where is the modulation index. M Using (11), (13) can be further expressed as

$$\hat{v}_{ac} = M \cdot B \cdot \frac{V_0}{2}. \tag{14}$$

For the traditional V-source PWM inverter, we have the well-known relationship: .v_{ac}=M.V/2 .Equation (14) shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor,

$$B_B = M \cdot B = (0 \sim \infty). \tag{15}$$

From (5), (9) and (12), the capacitor voltage can express as

$$V_{C1} = V_{C2} = V_C = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} V_0. \tag{16}$$

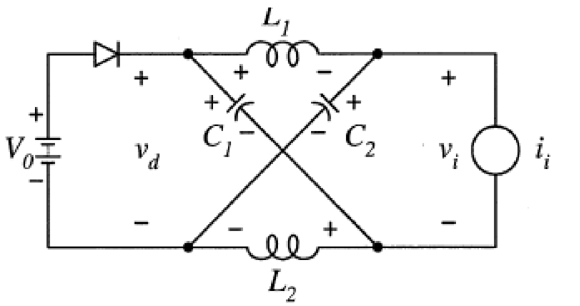

Figure 7: Equivalent circuit of the Z-source inverter viewed from the dc link

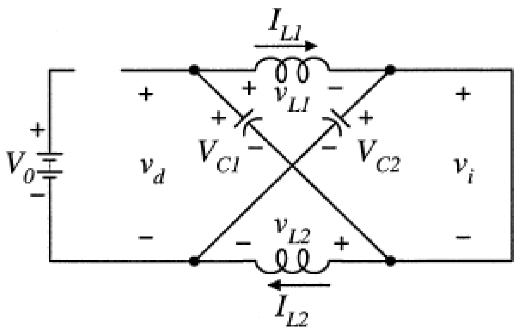

Figure 8: Equivalent circuit of the Z-source converter viewed from the dc link when the inverter bridge is in the shoot-through zero state

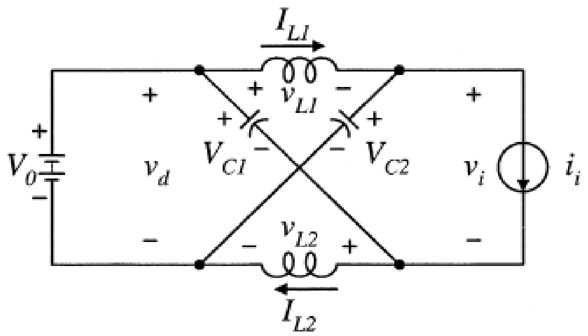

Figure 9: Equivalent circuit of the Z-source converter viewed from the dc link

The buck–boost factor B_B is determined by the modulation Index M and boost factor B. The boost factor B as expressed in (12) can be controlled by duty cycle (i.e., interval ratio) of the shoot-through zero state over the non shoot-through states of the inverter PWM. Note that the shoot-through zero state does not affect the PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal. The available shoot through period is limited by the zero-state period that is determined by the modulation index.

VI. PULSE-WIDTH MODULATION (PWM)

PWM is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load. The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. Typically switching's have to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies. The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel. Using digital pulses to create some analog value other than, just 'high' and 'low' signal levels. Many digital systems are powered by a 5-Volt power supply, so if you filter a signal that has a 50% duty cycle you get an average voltage of 2.5 Volts. Other duty cycles produce any voltage in the range of 0 to 100% of the 'high' voltage, depending upon the PWM resolution. The duty cycle is defined as the percentage of digital 'high' to digital 'low' signals present during a PWM period. The PWM resolution is defined as the maximum number of pulses that you can pack into a PWM period. The PWM period is an arbitrarily time period in which PWM takes place. It is chosen to give best results for your particular use.

1. Why the PWM frequency is important

The PWM is a large amplitude digital signal that swings from one voltage extreme to the other and this wide voltage swing takes a lot of filtering to smooth out. When the PWM frequency is close to the frequency of the waveform that you are generating, then any PWM filter will also smooth out your generated waveform and drastically reduce its amplitude. So, a good rule of thumb is to keep the PWM frequency much higher than the frequency of any waveform you generate.

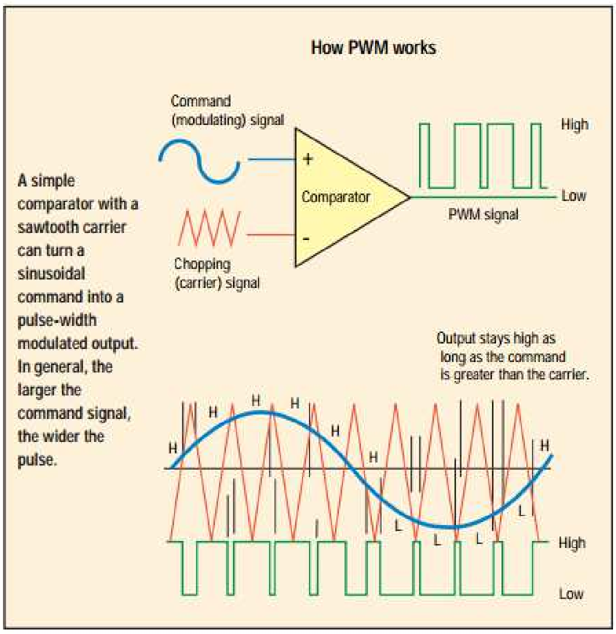

Figure10: PWM Technique diagram

Finally, filtering pulses is not just about the pulse frequency but about the duty cycle and how much energy is in the pulse. The same filter will do better on a low or high duty cycle pulse compared to a 50% duty cycle pulse. Because the wider pulse has more time to integrate to a stable filter voltage and the smaller pulse has less time to disturb it. Traditional solenoid driver electronics rely on linear control, which is the application of a constant voltage across a resistance to produce an output current that is directly proportional to the voltage. Feedback can be used to achieve an output that matches exactly the control signal. However, this scheme dissipates a lot of power as heat, and it is therefore very inefficient. The more efficient technique employs pulse width modulation (PWM) to produce the constant current through the coil. A PWM signal is not constant. Rather, the signal is on for part of its period, and off for the rest. The duty cycle, D, refers to the percentage of the period for which the signal is on. The duty cycle can be anywhere from 0, the signal is always off, to 1, where the signal is constantly on. A 50% D results in a perfect square wave.

V .SIMULATION RESULTS

Simulation of double input Z-source dc-dc converter was performed using MATLAB/SIMULINK to confirm above analysis. Simulation consists of double input circuit with PWM control technique by using z source inverter in this the z source inverter output depends upon the PWM design the because of this reason there is only one operation will be performed which best for the output voltage Converter parameters in the simulation were as in Table II.

TABLE II: SIMULATION PARAMETERS

Parameter	Value
V_{dc1}	40 V
V_{dc2}	100 V
R	Ω 15
C1=C2	1000μF
C	500μF
L1=L2=L	0.5 mH
Switching frequency	10 KHz
Duty Ratio (D)	30%

Here the input of double input z source converter are taken as wind and solar energies .for solar input maximum power is achieved by using MPPT algorithm. For wind without MPPT supply is produced to the z source inverter .based upon the output voltage of load the two inputs are produced for z source converter. The input of the solar panels as shown infig.13.In that circuit w are going to apply PWM.

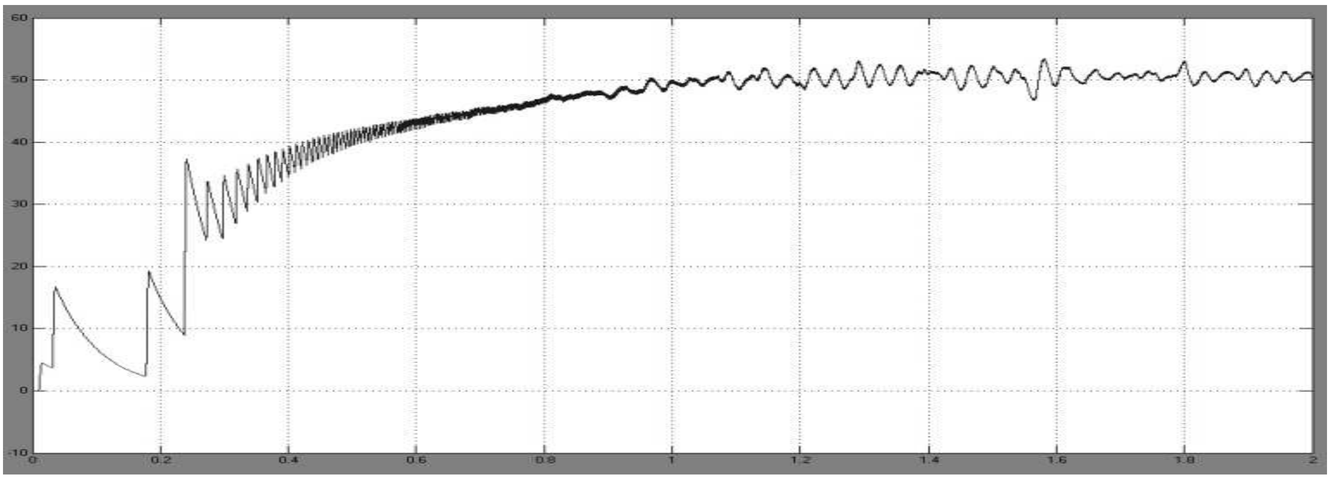

Figure11: Output voltage of the z-source converter

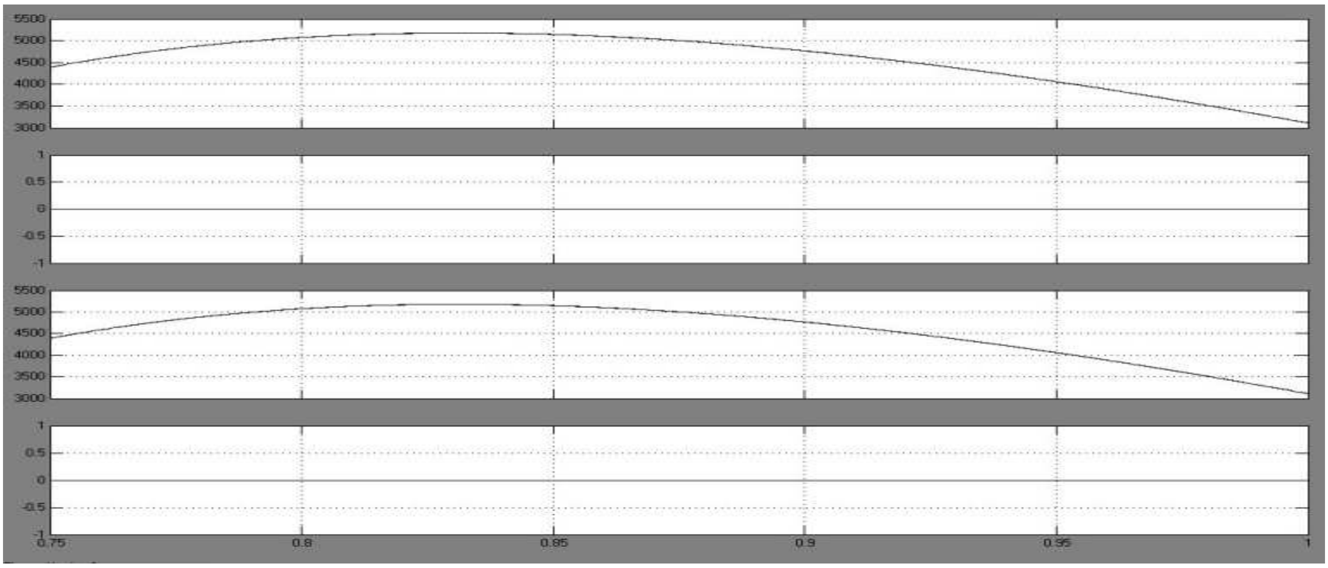

Figure12: I/P volyage and i/p current

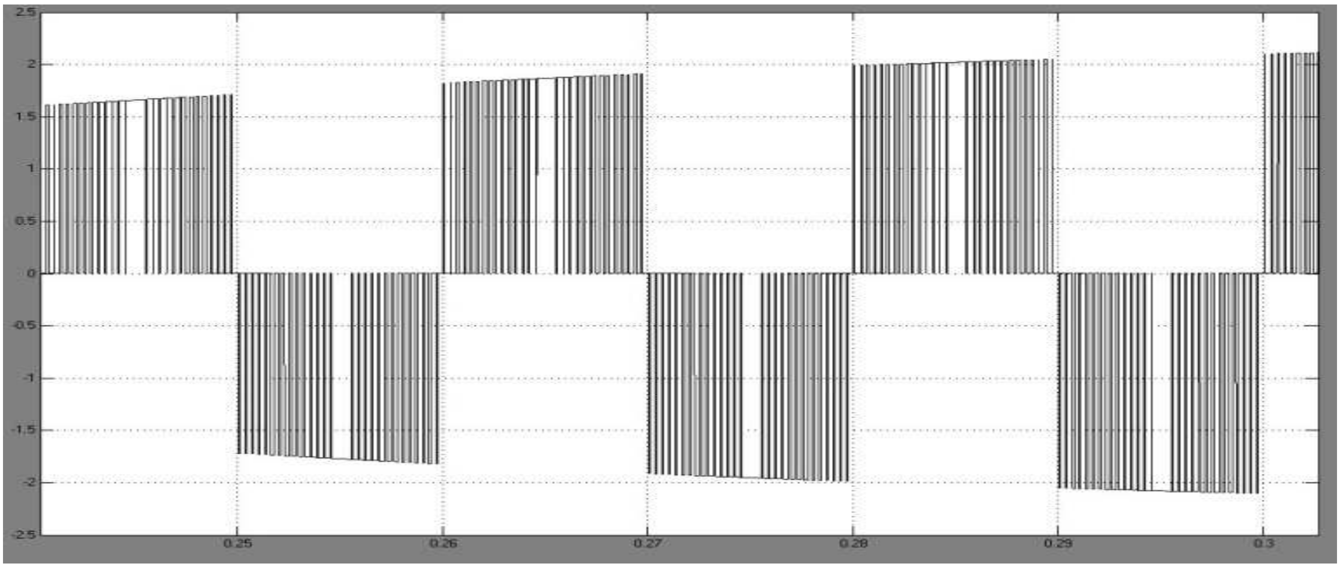

Figure 13: Satate -1 out put voltage

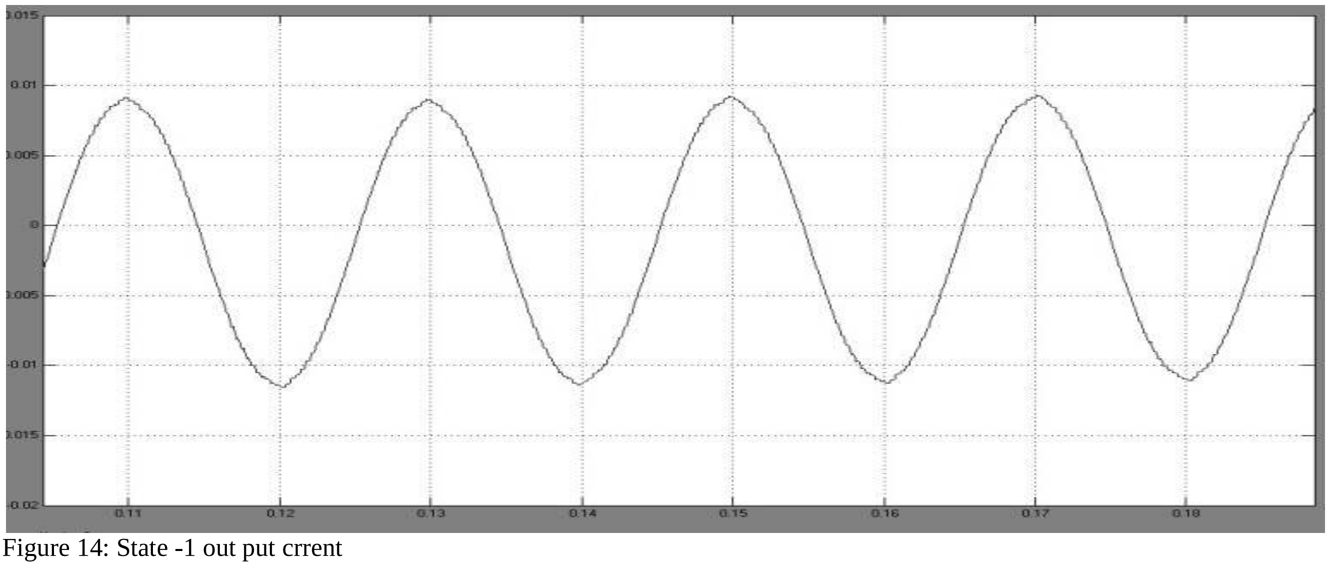

Figure 14: State -1 out put crrent

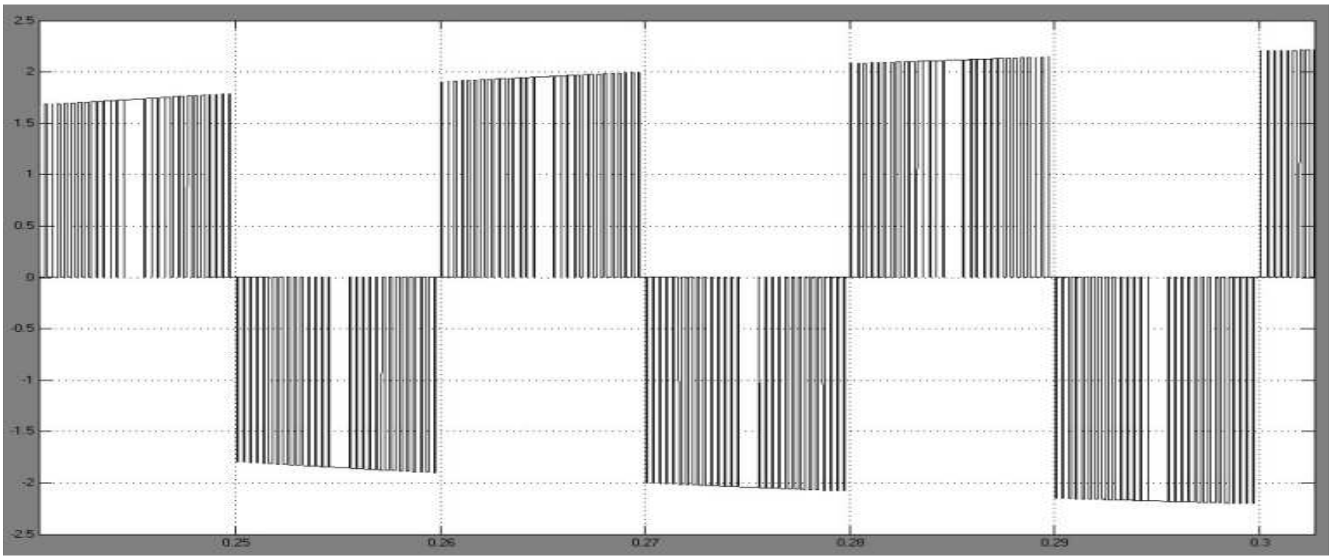

Figure 15: State -2 output voltage

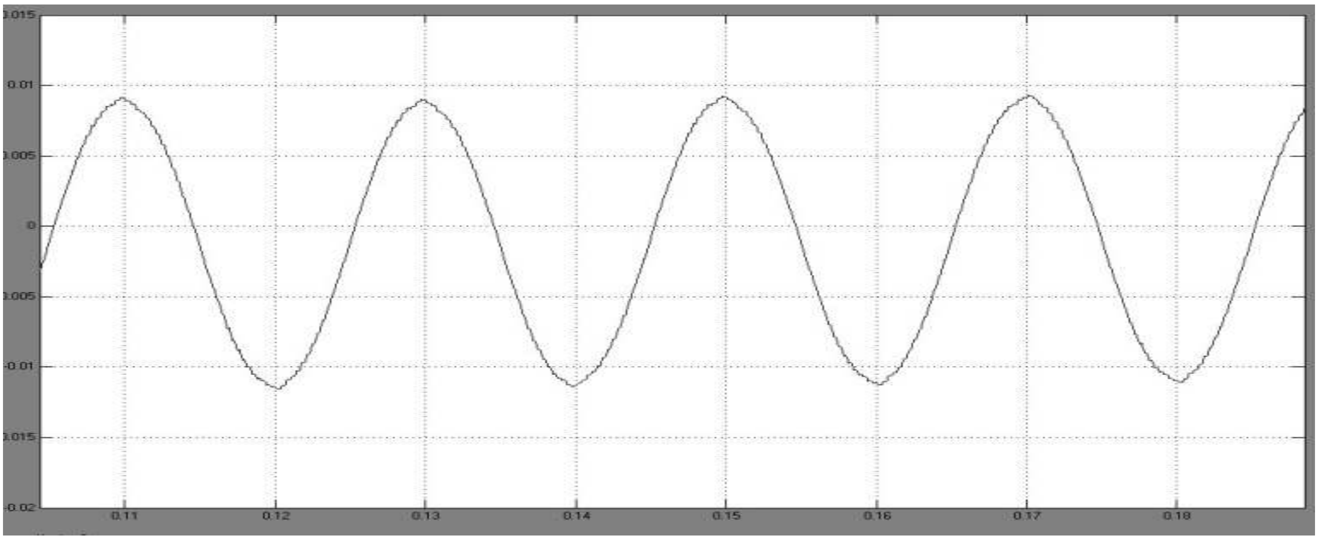

Figure 16: State 2 outputs current

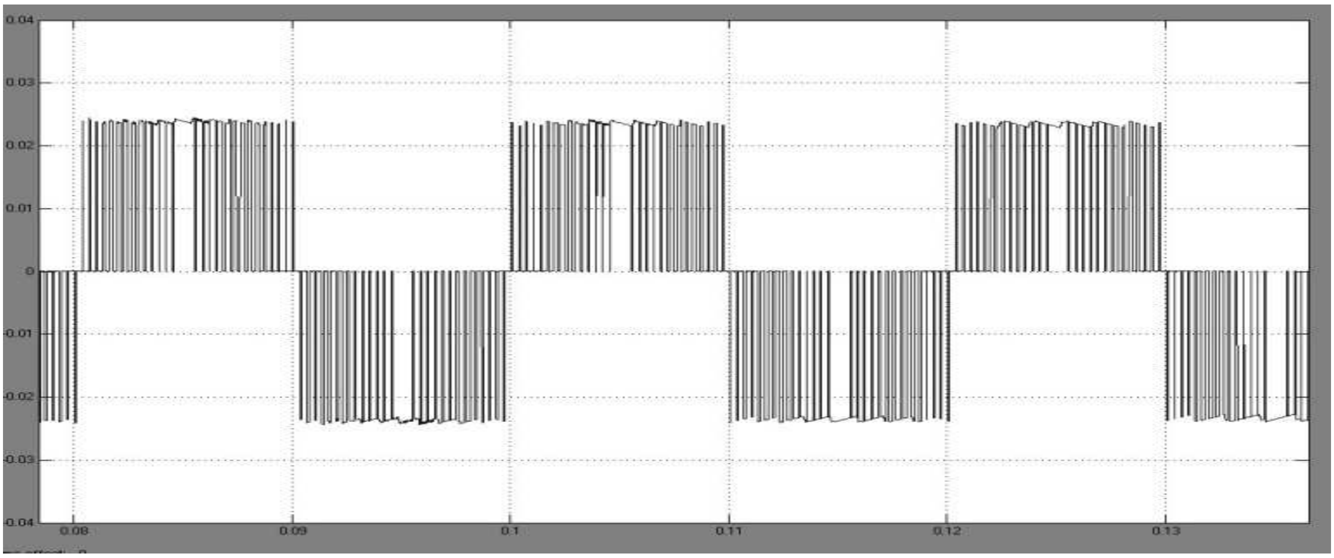

Figure 17: State -3 output voltage

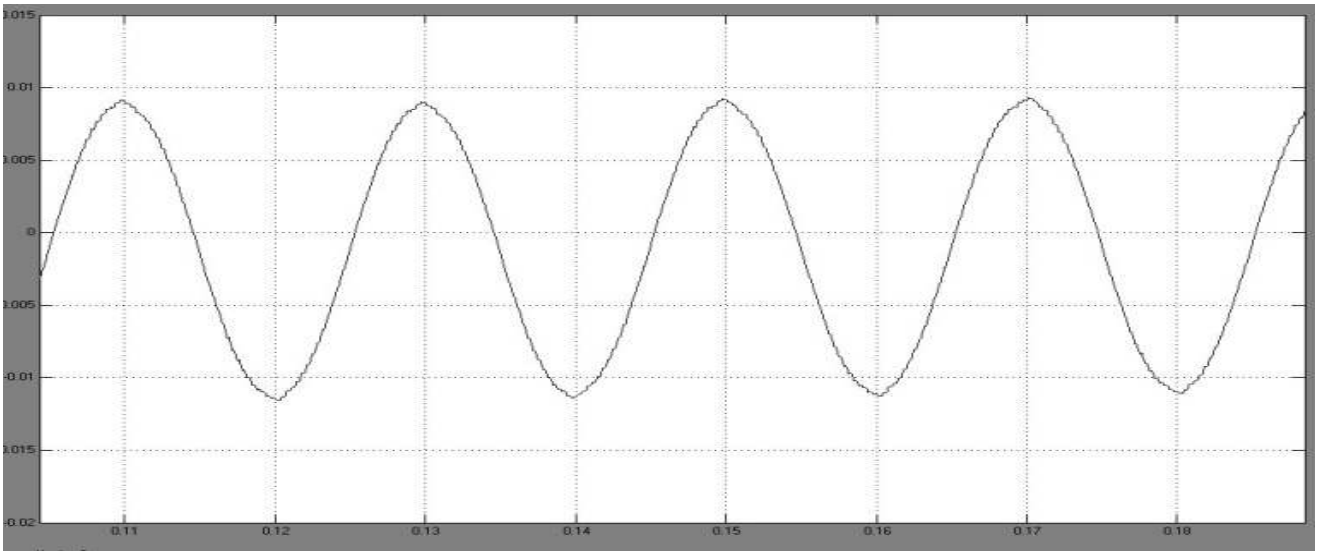

Figure 18: State-3 output current

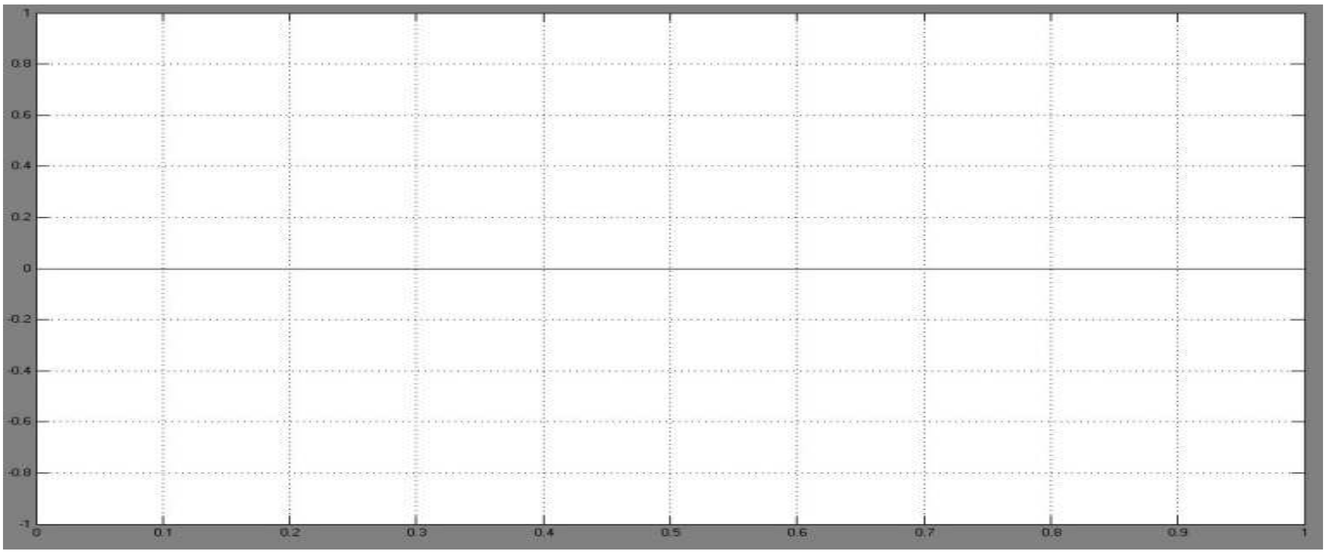

Figure 19: State-4 voltage

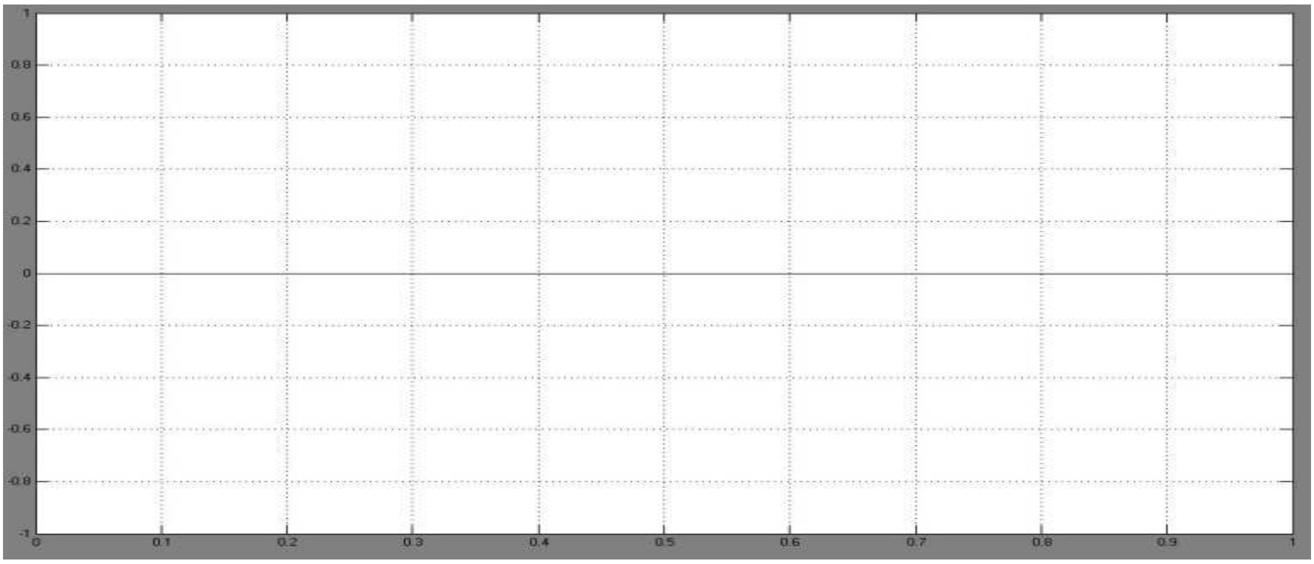

Figure 20: State output current

V. CONCLUSION

In this paper, double input Z-source dc-dc converter is proposed. The operation principle, including the operation modes and steady-state analysis is explained in detail. 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. Two input sources can have different characteristics and voltage. Also, converter controls output power with only one active switch which can reduce cost and improve the reliability. Boosting feature of converter makes it proper for new energy applications.

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Author's Profile:

Sarab Jwaid Mousa Al-Chlaihawi, Lecturer in Najaf Technical Institute, Foundation of Technical Education/Baghdad, Received her Bachelor Degree in Electrical Engineering & Education from Baghdad University of Technology /Baghdad, Iraq. Presently she finished her Master of Technology in Power Electronics Engineering, Collage of Engineering, Jawaharlal Nehru Technological University, Hyderabad, INDIA.