Vidhyayana - ISSN 2454-8596
An International Multidisciplinary Peer-Reviewed E-Journal
www.vidhyayanaejournal.org
Indexed in: Crossref, ROAD & Google Scholar

65

Single Phase Z Source Buck-Boost Matrix Converter

Rushikesh Pandya

Assistant Professor,

Department of Electrical Engineering, School of engineering and Technology

Dr. Subhash University, junagadh

Manan M. Desai

Head of Department

Department of Electrical Engineering, School of engineering and Technology

Dr. Subhash University, junagadh

ABSTRACT

A single-phase impedance source buck-boost matrix converter based on a single phase matrix converter that connects directly the single-phase source to the single-phase load. The converter can buck and boost both voltage and frequency. This converter has several attractive features that have been investigated in the last few decades. This converter gives variable output frequency and variable output amplitude. In the last few years, an increase in research work has been observed, bringing this topology closer to the industrial application.

The aim of this Paper is to elimination of voltage spikes on switches without need for a snubbed circuit by providing safe-commutation switching strategy to conduct along a continuous current path. The new modulation strategy keeps the number of switching at a minimum. Implementing this converter requires different switching arrangements based on the desired amplitude and frequency. The amplitude of the output voltage is controlled by the shoot-through period and the frequency of the output voltage depends on the switching strategy. The operating principles of proposed single phase impedance source buck-boost matrix converter are described, To check the performance of proposed converter, Simulink model is provided. simulation result shows the converter can produce an output voltage with different frequencies and that amplitude of the output voltage can be bucked and boosted.

INTRODUCTION

1.1. INTRODUCTION

Impedance source buck-boost matrix converter is combination of two system names as a Z source buck-boost converter and Matrix converter. First a Z source buck boost converter employs a unique LC impedance network for coupling the converter main circuit to the power source, which provides with a way of buck and boosting the input voltage, a condition that cannot be achieved in the traditional inverters and second The Matrix converter consist of four bi-directional switches arranged in a group. A bi-directional switch is capable to control the current flow and voltage blocking in both directions. The single phase Impedance source buck-boost Matrix converter Topology is shown in fig.1.1.

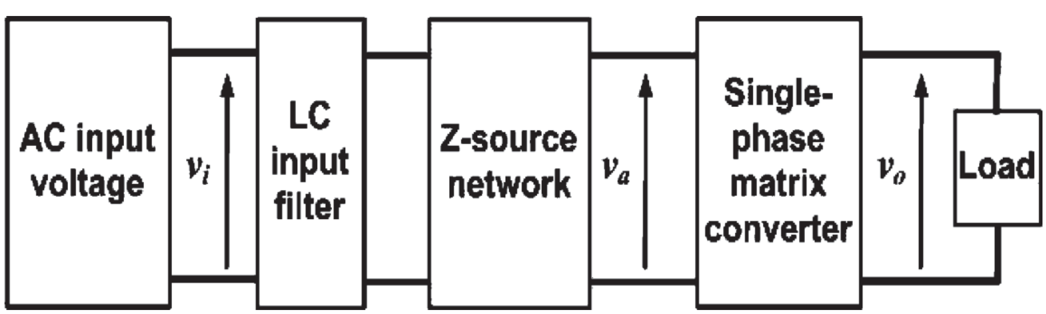


Fig-1.1 - General block diagram of proposed topology.

Vidhyayana - ISSN 2454-8596
An International Multidisciplinary Peer-Reviewed E-Journal
www.vidhyayanaejournal.org
Indexed in: Crossref, ROAD & Google Scholar

The ac voltage across the single-phase matrix converter *va* is bucked or boosted by the ac/ac Z-source converter with ac input voltage *vi*. Then, the single-phase matrix converter modulates the frequency of *va*. The output voltage *vo* is obtained with a step-changed frequency and a variable amplitude.

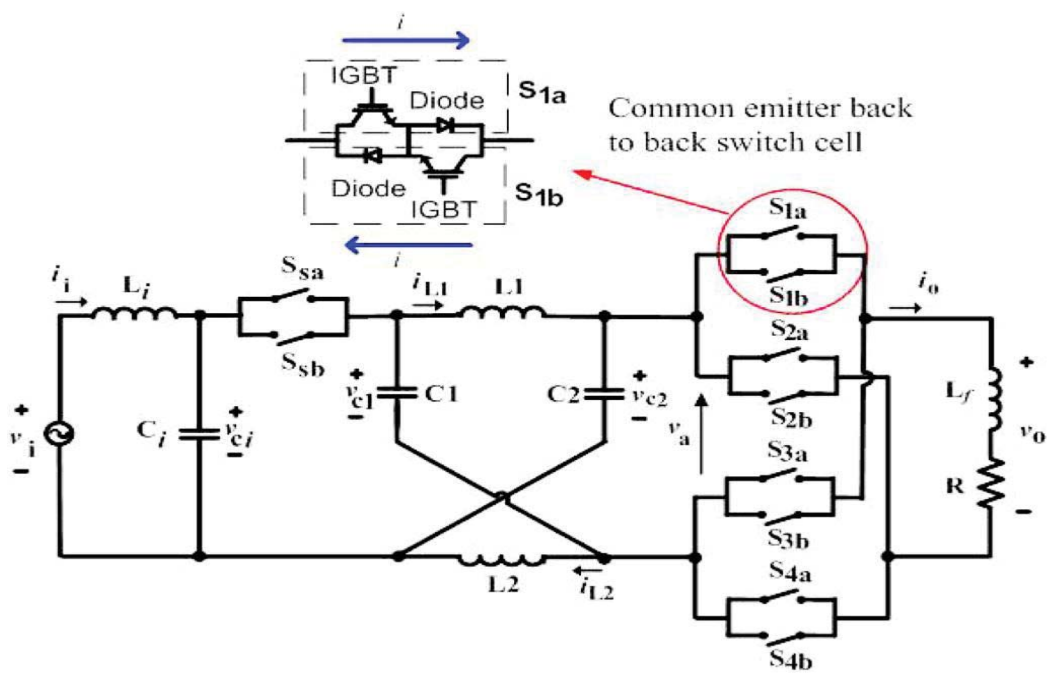


Fig -1.2 Proposed single-phase Z-source buck–boost matrix converter topology.

Fig. 1.2 shows the proposed single-phase Z-source buck–boost matrix converter. It employs an *LC* input filter; a Z-source network, bidirectional switches, and an *RL* load. The *LC* input filter is required to reduce switching ripple included in input current. All the inductors and capacitors are small and are used to filter switching ripples. The symmetrical Z-source network, a combination of two inductors and two capacitors, is the energy storage/filtering element for the single-phase Z-source buck–boost matrix converter. Since the switching frequency is much higher than the ac source (or line) frequency, the requirements for the inductors and capacitors should be low, As shown in Fig.1.2 and here shows the circuit of the Z-source Single-Phase Matrix Converter. It uses four bi-directional switches to serve as a SPMC. This arrangement has the advantage of independent control of the current in both directions. Here IGBTs are used because of its high switching capabilities and high current carrying capabilities leading to high power applications. Diodes are included to provide the reverse voltage blocking capability.

ADVANTAGES

- ✓ Both frequency and voltage can be stepped up or stepped down.
- ✓ Has Safe commutation switching strategy.
- ✓ Switching loss is less compare to conventional rectifier/inverter topology.
- ✓ Small energy-storing elements (L & C) are required

In view of these advantages, this converter topology will provide higher efficiency and higher density with safe commutation as compared with other conventional converter, which is the main aim of the project.

APPLICATIONS

- Adjustment speed drive (ASD)
- Compensation of voltage sags and swells
- Radio-frequency induction heating
- Audio power amplification

CONCEPT OF MATRIX CONVERTER

2.1 INTRODUCTION

The main advantage of matrix converter is elimination of dc link filter. Zero switching loss devices can transfer input power to output power without any power loss. But practically it does not exist. The switching frequency of the device decides the THD of the converter. Maximum power transfer to the load is decided by nature of the control algorithm. Matrix converter has a maximum input output voltage transfer ratio limited to 87% for sinusoidal input and output waveforms, which can be improved. Further, matrix converter requires more semiconductor devices than a conventional AC-AC indirect power frequency converter. Since monolithic bi-directional switches are available they are used for switching purpose.

2.2 BASIC PRINCIPLE OF MATRIX CONVERTER

The matrix converter is AC/AC converter, which uses an array of controlled bidirectional switches to create a variable output voltage system with unrestricted frequency. It does not have any DC-link circuit and does not need any large energy storage elements, which contribute to a compact size and can work with unity power factor. The matrix converter consists of four bi-directional arranged in the group as shown in figure 2.1. A bi-directional switch is able to control the current flow and voltage blocking in both directions. The converter diagram looks like a matrix and hence this type of converter is termed as matrix converter.

The operation of this converter stages is decoupled on an instantaneous basis by the energy storage elements and controlled independently, so long as the average energy flow is equal. Figure 2.1 shows the single phase matrix converter switching arrangement.

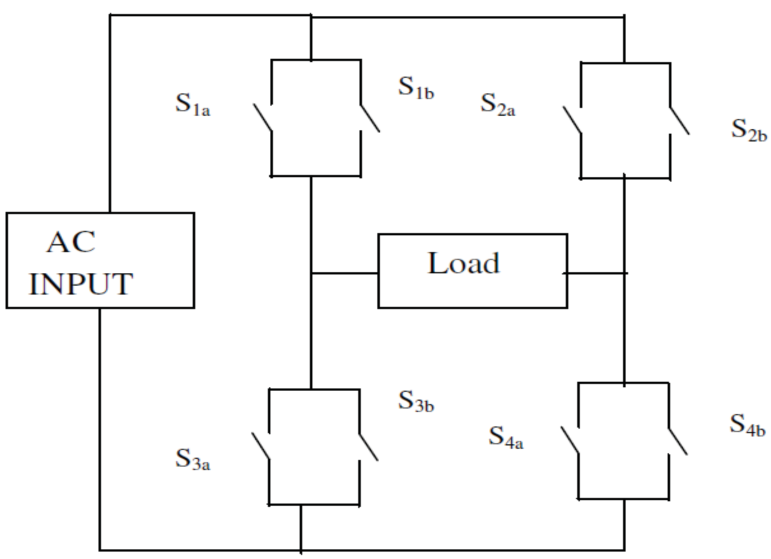


Fig 2.1 Single phase matrix converter

Figure 2.2 to 2.5 shows the operation of the single phase matrix converter in four modes of operation.

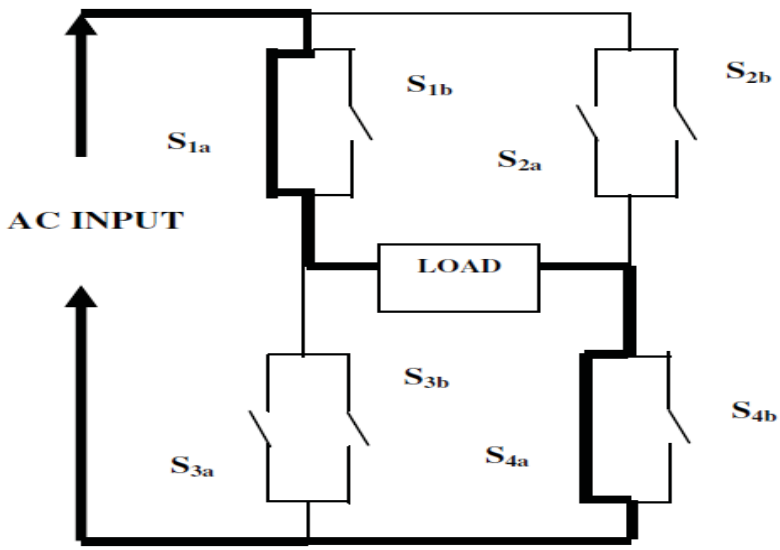


Fig 2.2 S1a and S4a switched on during Positive half cycle

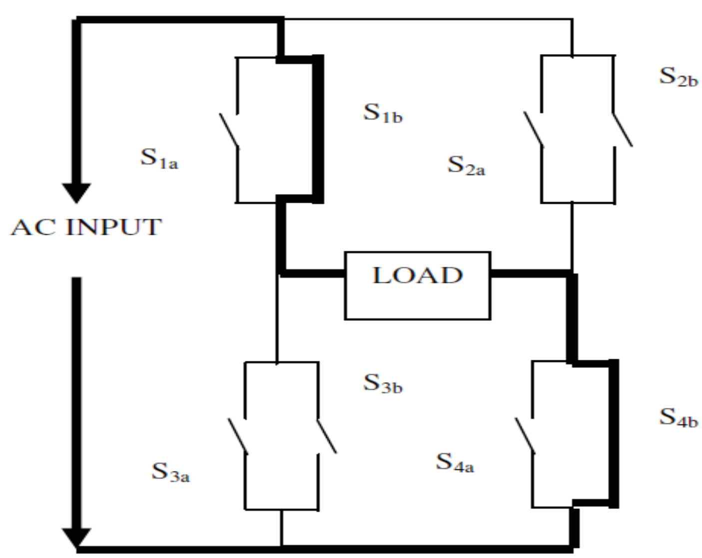


Fig 2.3 S1b and S4b switched on during Negative half cycle

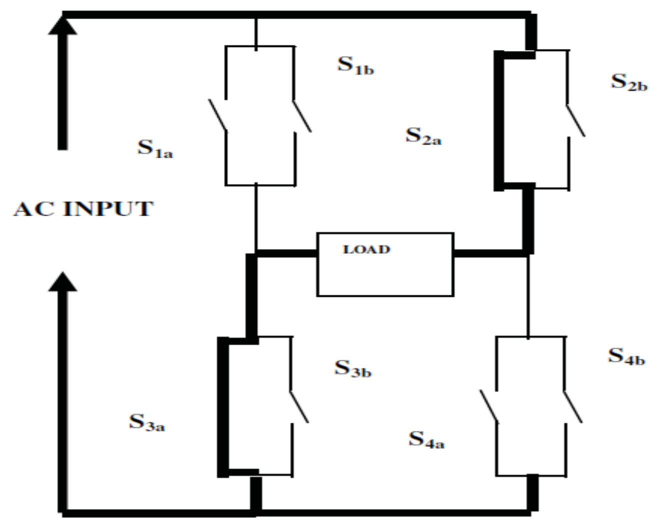


Fig 2.4 S2a and S3a switched on during Positive half cycle

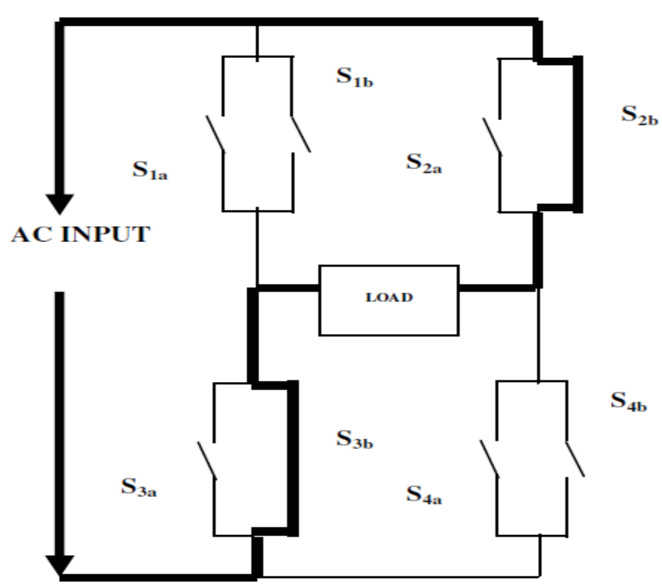


Fig 2.5 S2b and S3b switched on during Negative half cycle

Vidhyayana - ISSN 2454-8596
An International Multidisciplinary Peer-Reviewed E-Journal
www.vidhyayanaejournal.org
Indexed in: Crossref, ROAD & Google Scholar

The matrix converter requires a bidirectional switch capable of blocking voltage and conducting current in both directions. Unfortunately, there is no discrete component that fulfils these needs. To overcome this problem the common emitter anti-parallel IGBT, diode pair is used Diodes are in place to provide reverse blocking capability to the switch module.

2.3 DIFFERENT TYPES OF SWITCHING TOPOLOGY

However at present a true bi-directional switch is still not available in the market and thus it must be realized by the combination of conventional unidirectional semiconductor devices. Figure 2.6 to 2.8 shows the different by directional switch configurations, which have been used in a prototype model.

The unidirectional devices used in the bidirectional switches should have near identical characteristics. Based on the power device and diode combinations three different types of topology as shown in figure 2.6 to 2.8 are used.

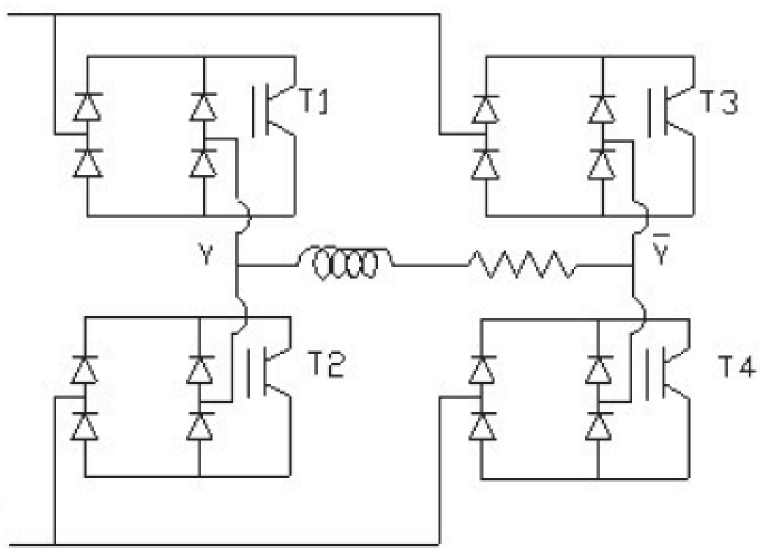


Fig. 2.6 Matrix converter topology 1- Diode and IGBT combination switch (Diode embedded switch)

Figure 2.6 shows the Diode – IGBT combination for single phase matrix converter. In this topology sixteen diodes and 4 IGBT's are used to design the converter. in this figure T1, T2, T3 and T4 are IGBT's. in this Configuration 16 diodes and 4 controlled devices are used. When making this IGBT and gate CMOS bi-polar junction transistor, a mask is used reduce the conduction loss in the bipolar junction. When a poly silicon gate is used, poly silicon is deposited before the gate is formed. The source and drain regions are then doped while keeping the channel doping by different material. This is known as a self-aligned gate, with which the devices can be made smaller and fabricated with precision. Because of the above construction the IGBT switch has faster operation, more stable and current offsets

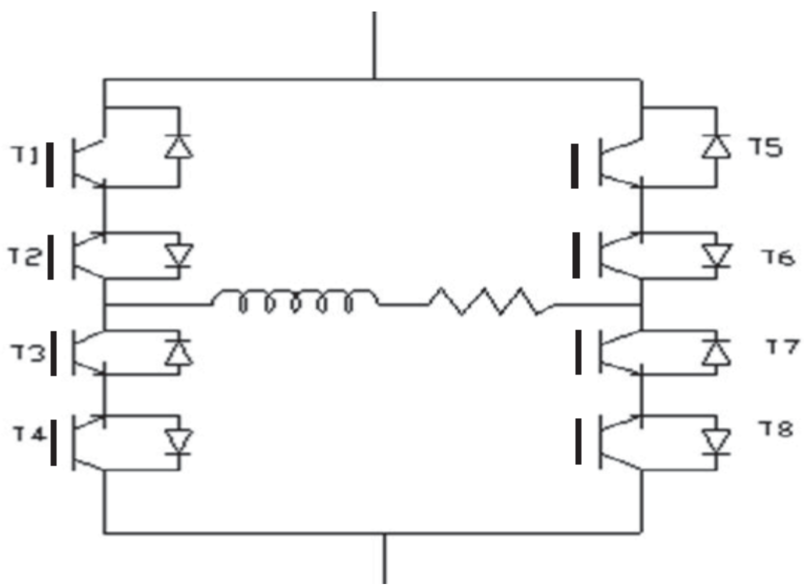


Fig 2.7 Matrix converter topology 2 – Power device combination (Common Emitter configuration)

The second topology is shown in figure 2.7, where T1, T2, T3, T4., T5, T6, T7 and T8 are controlled devices. Eight uncontrolled switches are used for bidirectional power flow. Here two gate switches are connected in anti series as shown in fig.2.7. The advantage of anti – parallel connection of gate device and diode is that the lower conduction loss through the freewheeling diode.

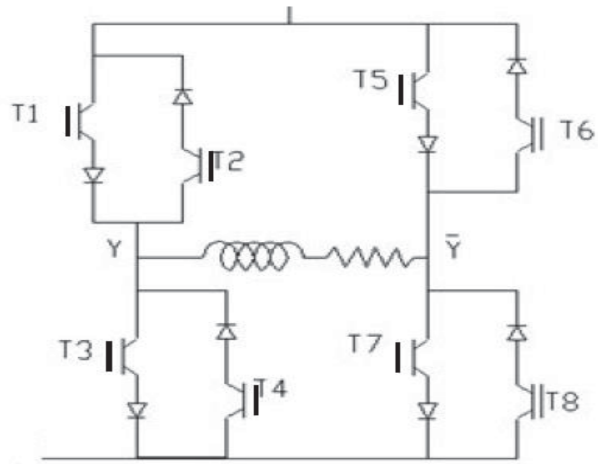


Fig.2.8 Matrix converter topology 3 – Anti parallel Diode and IGBT combinations.

The third topology of the converter is as shown in figure 2.8. The converter uses eight uncontrolled devices (diodes) and eight controlled devices. Here T1, T2, T3, T4., T5, T6, T7 and T8 are controlled devices IGBT's.

The following study has been made about the three topologies as illustrated in Table 2.1. It seems that common emitter configuration is suitable for high power applications. These topologies are used in single phase matrix converter.

Table 2.1 switching topology (single phase matrix converter) and its comparison

Components	**Topology 1 (Diode embedded)**	**Topology 2 (Common emitter)**	**Topology 3 (Anti parallel diode and IGBT)**
Number of diode	16	8	8
Gate controlled devices	4	8	8
Suitable area	Low power applications	Over current protection and high power requirement	High power applications

CONCEPT OF BUCK – BOOST CONVERTER

3.1 What is Z source converter?

The Z source converter (ZSC) is an alternate power conversion topology that can both buck and boost the input voltage using passive components. It uses a unique LC impedance network for coupling the converter main circuit to the power source, which provides a way of boosting the input voltage, a condition that cannot be obtained in the traditional inverters. It also allows the use of the shoot-through switching state, which eliminates the need for dead-times that are used in the traditional inverters to avoid the risk of damaging the inverter circuit.

3.2 Basic Traditional Converters

There exists two traditional converters, voltage-source converter (VSC) and current- source converter (CSC), either rectifier or inverter depending on power flow directions, There is some limitations in those two inverters.

3.2.1 Voltage source inverter (VSI)

VSI is a 3-phase inverter fed from DC voltage source (or) AC voltage source with diode rectifier as shown in fig 3.1. A large capacitor is connected at the input terminals tends make the input DC voltage constant. Six switches are used in main circuit; each composed of power transistor and an anti-parallel diode to provide bidirectional current flow and unidirectional voltage blocking capability. It has eight switching state. In those eight states, six are active states and two are zero states.VSI can be operated as a stepped wave inverter or pulse width modulation (PWM) inverter.

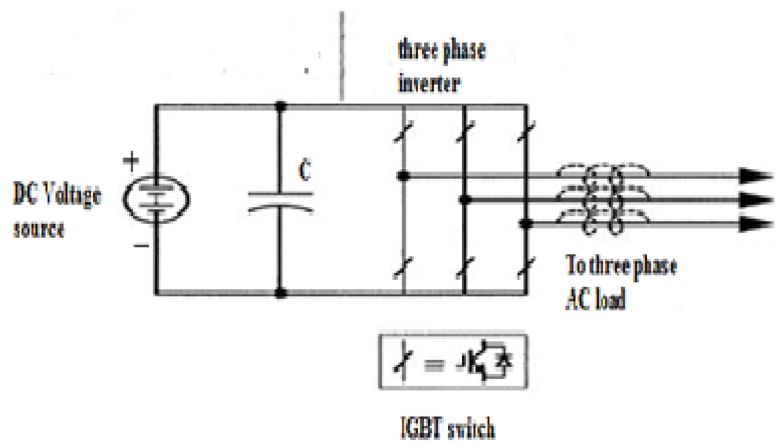


Fig. 3.1 Voltage Source Inverter (VSI)

It has the following conceptual and theoretical barriers.

- The AC output voltage is limited below and cannot exceed the DC input voltage
- External equipment is needed to boost up the voltage, which increases the cost and lowers the overall system efficiency.
- This is a possibility for the occurrence of short through which destroys the devices.
- An output LC filter is needed, which causes additional losses and control complexity.

3.2.2 Current Source Inverter (CSI)

CSI is a 3-phase bridge inverter fed from current source i.e. a voltage source in series with large inductor as shown in fig.3.2. Six switches are used; each composed of IGBT or MOSFET with series diode to provide unidirectional current flow and bidirectional voltage blocking. Unlike VSI, CSI has nine switching states in those six are active states and three are zero states. The AC output voltage is greater than DC input voltage.

Vidhyayana - ISSN 2454-8596
An International Multidisciplinary Peer-Reviewed E-Journal
www.vidhyayanaejournal.org
Indexed in: Crossref, ROAD & Google Scholar

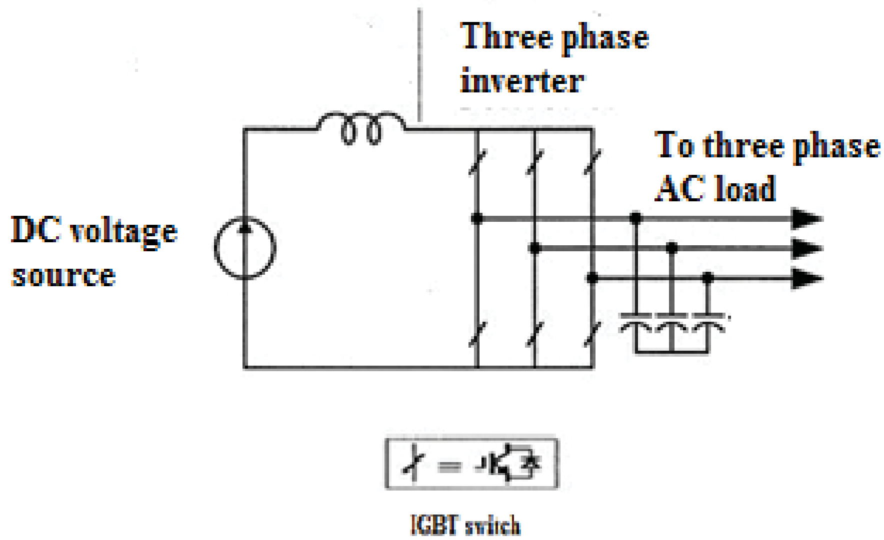


Fig. 3.2 Current Source Inverter (CSI)

However, the current- source inverter has the following conceptual and theoretical limitations:

- It is a boost inverter i.e., the output AC current is greater than the input current; it cannot be used as buck inverter.
- The cost of CSI is high.
- The operating power factor is poor on line side.
- CSI is vulnerable to EMI noise in terms of reliability.
- The dynamic response is slow.

3.3 Limitation of Basic Boost converter

The classic boost converter is not a good choice for the high step-up conversion due to following three reasons

1) An extremely high duty-cycle must be used to obtain the steep conversion ratio, which causes serious losses on the power devices due to their parasitic parameters.

2) Low on-resistance active switches and good performance diodes cannot be adopted due to the high voltage stress.
3) The reverse-recovery problem of the output diode is severe due to its short conduction time.

All these three factors degrade the efficiency and limit the power level.

➢ **VSI and CSI have also some limitation as below:-**

- The two switches of same phase can't be gated on simultaneously which can be damage the inverter
- Buck and Boost both phenomenon can't be take from single topology.

3.4 Advantages of Z - source converter over traditional converter

➢ In VSI and CSI, power loss is high because of additional filter so the efficiency is low but in Z-source Inverter Impedance Network (Z-Source) itself acts as a filter.

➢ The VSI is a buck (down) inverter whereas CSI is a boost (up) inverter. For applications exceeding available voltage range an additional boost (or buck) DC/DC converter is needed. This increases the system cost and decreases the efficiency.

➢ The VSI (CSI) requires dead time (overlap time) to provide safe commutation which causes waveform distortion.

➢ The main circuit is not being interchangeable. In other words, neither the VSI main circuit can be used for the CS I and nor CSI as a VSI.

➢ Vulnerable to EMI noise

➢ In CSI and VSI buck-boost gain are finite but in Z- Source it lies between (0≈∞).

3.5 Basic of Z – source Inverter

The Z-source Inverter (ZSI) is a new topology in power conversion. Fig.3.3 shows the ZSI implemented as a 3- phase DC/AC converter (inverter). Although DC/AC conversion is the most common application of the Z- source topology, it can also be applied to AC/DC and AC/AC power conversions.

The ZSI used to overcome the problems in the traditional source inverters. The ac voltage is rectified to dc voltage by the rectifier. The rectifier output dc voltage fed to the impedance network, which consists of two split inductors and two split capacitors equal in magnitude.

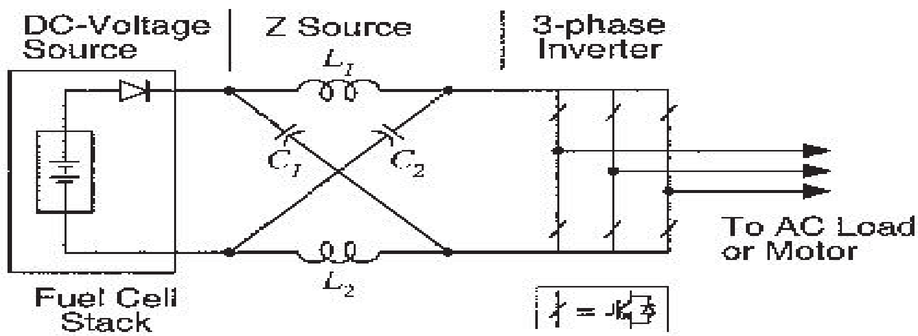


Fig.3.3 Z- Source Inverter

The network inductors are connected in series arms and capacitors are connected in diagonal arms. The impedance network is used to buck or boost the input voltage depend upon buck or boost factor. This network also act as a second order filter and it should required less inductance and less capacitance. The inverter main circuit consists of active switches. These inverters use a unique impedance network, coupled between the power source and converter circuit, which cannot be achieved with conventional VSI and CSI.

The unique feature of the Z- source inverter is that the output ac voltage can be any value between zero and infinity regardless of dc voltage. That is, the Z-source inverter is a buck-boost inverter that has a wide range of voltage.

The traditional three-phase voltage source inverter shown in fig-1 has six active vectors when the DC voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively

However, three phase Z source inverter bridge has one extra zero state when the load terminals are shorted through both the upper and lower devices of any one phase leg, any two phase legs, or all three phase legs. shoot- through zero state is forbidden in the traditional voltage source inverter, because it would cause a shoot-through. The Z- source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique features to the Z-Source Inverter are:

(i) The ZSI provides the buck-boost function by one-stage conversion.

(ii) In this technology unwanted on and off by EMI noise will not destroy the converter.

(iii) The ZSI has the advantages of both VSI and CSI.

(iv) It solves the problems of the traditional converters.

(v) The ZSI has low or no in-rush current as compared to the VSI and CSI.

(vi) Due to low losses efficiency of the system is improved.

3.6 Operating Principle of Z – Source Network

Fig.3.4 shows the basic operating principle of Z source converter in which two switch S1 & S2 is provided for shoot-through zero state and Non shoot- through zero state operation.

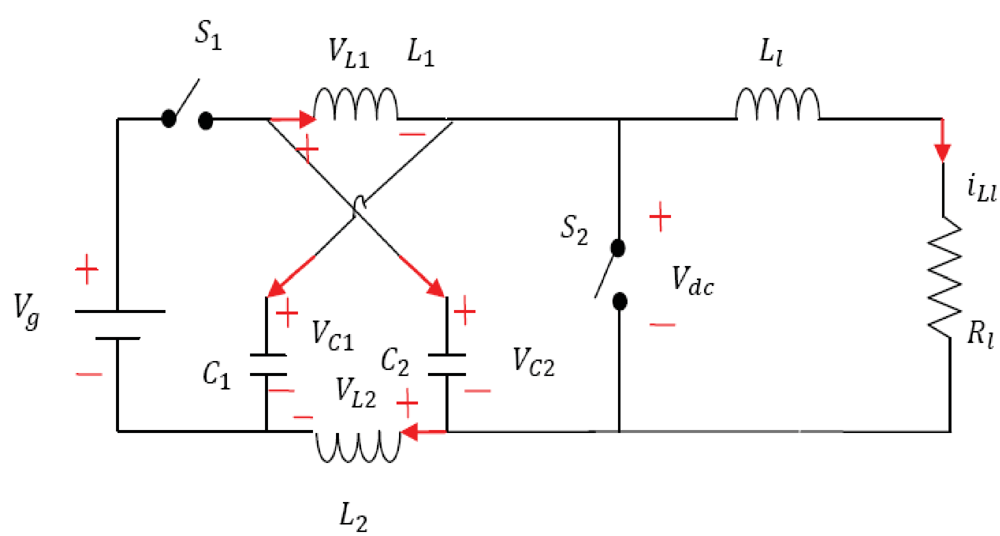


Fig.3.4 Operating principle of ZSC

There are two operating modes of a single phase Z-source converter.

Vidhyayana - ISSN 2454-8596
An International Multidisciplinary Peer-Reviewed E-Journal
www.vidhyayanaejournal.org
Indexed in: Crossref, ROAD & Google Scholar

(1) Normal mode

(2) Boost mode

The normal operation mode is like the traditional inverter. The output voltage is dependent on the voltage across the inverter bridge and on the modulation index. In the boost mode however, the Z-source inverter boosts the voltage of C1 and C2 (see figs 3.5 and 3.6), thereby raising the voltage at the inverter bridge. The capacitor voltage of the Z-source network is a function of shoot- through states.

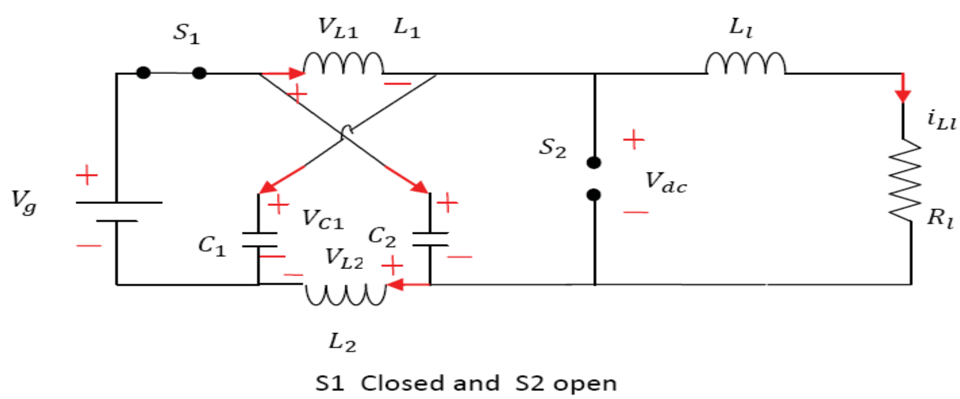


Fig.3.5 non shoot through zero state (Normal mode)

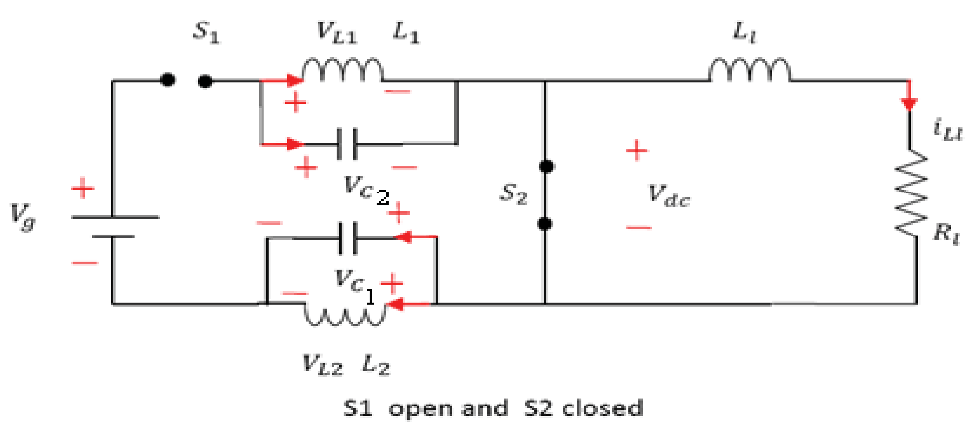


Fig.3.6 Shoot through zero state (Boost mode)

Table 3.1 Switching state of operation of ZSC in continuous current mode

Switching states	S1	S2	Output voltage
Active states	1	0	Finite
Shoot through states	0	1	Zero

Table 3.1 shows, how the shoot- through state of a ZSC can be controlled. It has two switching state: one Active states and when the dc voltage is connected across the load and one shoot through state when the load terminals are shorted through switch S2. Z-source converter utilizes the shoot through zero states to boost voltage in addition to traditional active state.

For Z-source network to be symmetrical

$$L1=L2 \quad \text{and} \quad C1=C2$$

$$V_{C2} = V_{C2} = V \quad \text{and}$$

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

Let the converter is in the shoot- through stste for an interval of To during a switching cycle T, from the equivalent circuit in fig 3.5.

We have

$$V_L=V_C \quad \text{and}$$

$$V_{dc}=0$$

Similarly, if the converter is in active state for an interval of T1,during switching cycle T, from the equivalent circuit in fig.3.4

We have

$$V_L = Vg - Vc$$

$$V_{dc} = Vc - V_L = 2Vc - Vg$$

Voltage across an inductor in steady state

$$\frac{1}{T}\int_0^T VL(t)dt = \frac{T0Vc + T1(Vg - Vc)}{T} = 0$$

Voltage Ratio:

$$\frac{Vc}{Vg} = \frac{T1}{T1 - T0} = \frac{1 - D}{1 - 2D}$$

Where $D = 1 - m = T_0 / T_1$

$$V_{dcn} = 2Vc - Vg = \frac{T}{T1 - T0}Vg = \frac{1}{1 - 2D}Vg = BVg$$

(Where B is Boost factor.)

The boost factor B can be controlled by duty cycle of the shoot through zero state over the non-shoot through states of the PWM inverter. The shoot through zero state does not affect PWM control of the inverter because it equivalently produces the same zero voltage to the load terminal. The available shoot through period is limited by the zero state periods determined by the modulation index(m).

During the design of Z-source inverter the estimation of the reactive components such as impedance network is the most challenging work. The component values should be evaluated for the minimum input voltage of the converter when the boost factor and the current stresses of the components become maximal.

- **Calculation of the average current of an inductor is carried out by using the relation**

$$I_L = \frac{P}{Vdc}$$

Where P is the total power and Vdc is the input voltage.

The maximum current through the inductor occurs when the maximum shoot- through takes place. This causes maximum ripple current. In our design, 30% (60% peak to peak) current ripple through the inductors during maximum power operation is chosen.

Thus we have

$$I_{L\ max} = I_L + I_L .30\%$$
$$I_{L\ min} = I_L - I_L .30\%$$
$$\Delta I_L = I_{L\ max} - I_{L\ min}$$

The capacitor voltage during that condition

$$Vc = \frac{Vdc + Vd_{C1\ max}}{2}$$

Calculation of required inductance of Z-source inductors is carried out by the formula

$$L = \frac{T_0 . Vc}{I_L}$$

Where T_0 - is the shoot-through period per switching cycle and We have

$$T_0 = D\ T$$

The purpose of the capacitor is to absorb the current ripple and maintain a fairly constant voltage so as to keep the output voltage sinusoidal. During shoot-through, the capacitor charges the inductors, and the current through the capacitor equals the current through the inductor. Therefore, the voltage ripple across the capacitor can be roughly calculated by use of required capacitance of Z-source capacitors.

Thus we have

$$\Delta Vc = \frac{I_{av} T_0}{C}$$

Where I_{av} is the average current through the inductor,

T_0 is the shoot-through period per switching cycle, and

C is the capacitance of the capacitor.

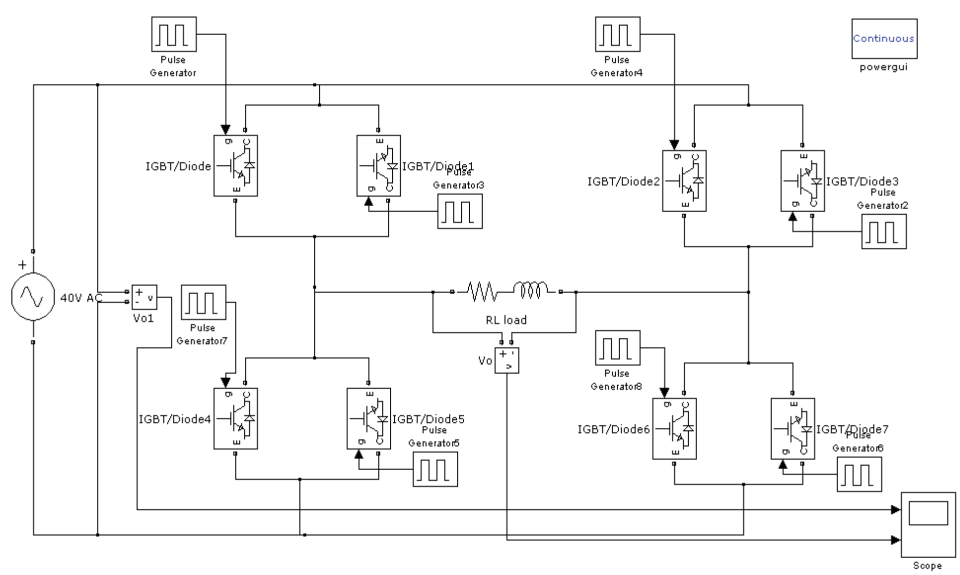
To limit the capacitor voltage ripple to 3% at peak power, the required capacitance is

$$C = \frac{T_0 . I_L}{Vc.3\%}$$

Another function of the capacitor is to absorb the ripple current.

SIMULATION OF Z SOURCE INVERTER

4.1 Simulink model of single-phase matrix converter



Vidhyayana - ISSN 2454-8596
An International Multidisciplinary Peer-Reviewed E-Journal
www.vidhyayanaejournal.org
Indexed in: Crossref, ROAD & Google Scholar

➢ **Simulink Data:**

Input voltage = 40 V

Input frequency = 60 Hz

Load Resistance(R) = 100 Ω

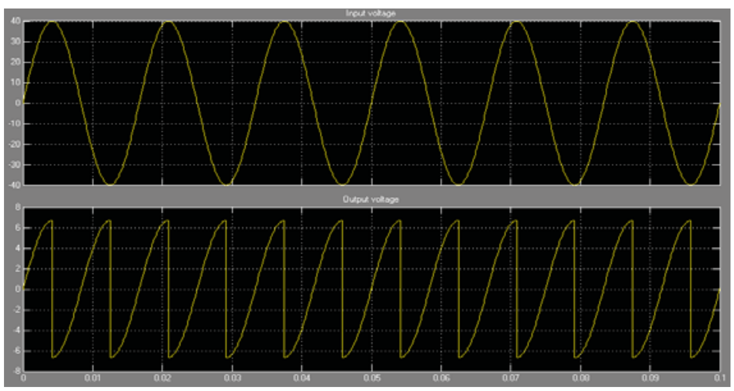
Load inductor (L) = 3 mh

Output voltage = 17 V

Output frequency = 120 Hz

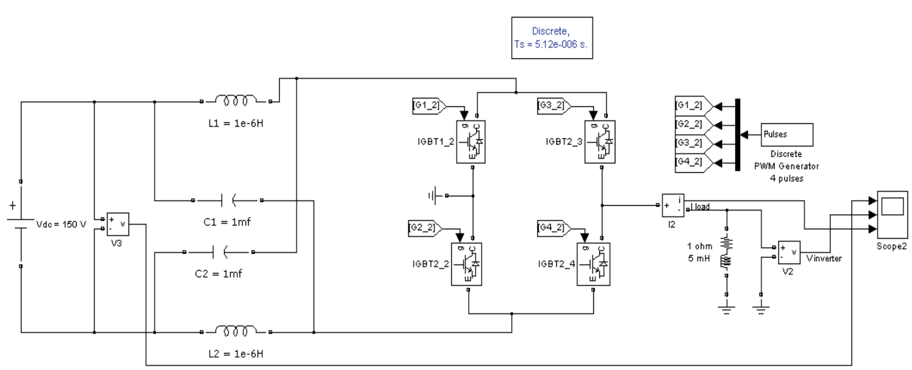
4.2 Results

➢ Waveforms of Input voltage and output voltage



SIMULATION OF PROPOSED SYSTEM

5.1 Simulink model of Z source inverter



Vidhyayana - ISSN 2454-8596
An International Multidisciplinary Peer-Reviewed E-Journal
www.vidhyayanaejournal.org
Indexed in: Crossref, ROAD & Google Scholar

- **Simulink Data**

Input voltage = 150 V

Output voltage = 180 V

Switching frequency = 10 KHz

Fundamental frequency = 60 Hz

Modulation index (m) = 0.632

Load Resistance(R) = 1Ω

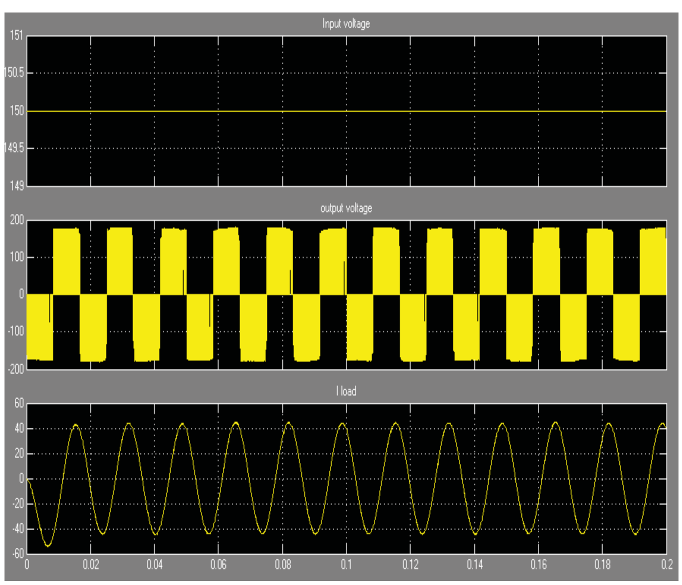
Load Inductor (L)= 5mH

L1 = L2 = 1e-6 H

C1 = C2 = 1e-3 F

5.2 Results

- Waveform of Input voltage, Output voltage and Output current



CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

- ✓ The proposed topology has improved significantly in performance of single phase matrix converter
- ✓ The main characteristics of generalized single phase Z-source matrix converter are as follow:
- ➢ Providing wide range frequency in output
- ➢ Good harmonic spectrum
- ➢ working both in buck and boost mode

6.2 FUTURE SCOPE

- ➢ Assembling both Simulink model
- ➢ To create closed loop simulink model of single-phase z source buck boost matrix converter
- ➢ Analysis result of that model
- ➢ Give conclusion from the results

Bibliography / References

[1] Minh-Khai Nguyen, Young-Gook Jung, Young-Cheol Lim, "A single- phase Z-source buck–boost matrix converter," IEEE Trans. Power Electronics., vol. 25, no. 2, pp. 453–462, Feb. 2010

[2] P. Deivasundari, V. Jamuna," A Z-source single phase matrix converter with safe commutation strategy", Volume 2, Issue 3, 2011 pp.579-588

[3] Yeyuan Xie', Zhaoming Qian', Xinping Ding', Fangzheng Peng1"2" A Novel Buck-Boost Z-Source Rectifier" 'Zhejiang University, Hangzhou, China, 310027

[4] P.H. Zope and Ajay Somkuwar," Design and simulation of single-phase Z-source inverter for utility interface" ISSN 0976-6553(online), volume 1 number1, may – june (2010), pp.127-143

[5] Budi Yanto Husodo*1, Shahrin Md. Ayob2, Makbul Anwari3, Taufik4," Simulation of Modified Simple Boost Control for Z-Source Inverter" San Luis Obispo, CA 93407, USA

[6] DURGA BABU KOKKERAGADDA and AMAR KIRAN," Simulation Model of a new Single-phase toSingle-phase Cycloconverter based on Single-phaseMatnx Converter Topology with Sinusoidal PulseWidth Modulation" IJERA ISSN: 2248-9622, Vol. 3, Issue 1, January -February 2013, pp.1041-1050

[7] Thomas A. Lipo, D. Grahame Holmes, "Pulse width modulation for power converters", IEEE Press on power engineering, 2003