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Analysis and Simulation of Three Phase Impedance Source Inverter with Maximum Boost Control PWM Using PSIM

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Abstract- *This paper present new z-source inverter topology which eliminates barriers and limitations of traditional two voltage-source inverter (VSI) and current-source inverter (CSI) limitations for inverter topology. Here discuss for different load and implemented in PSIM. Different PWM control methods for Z-source inverter topology like maximum boost control method implemented for generation of gating signals. In this paper Simulation results and THD analysis of Z- source three phase Inverter with maximum boost control PWM.*

Keywords- *Voltage source inverter, Current source inverter, Impedance source Inverter, Simple boost control, maximum boost control.*

I. INTRODUCTION

The main objective of inverter is to produce an ac output waveform from a dc power supply. There are two traditional converters: - (1) voltage-source (or voltage-fed) and (2) current-source (or current-fed) converters. Fig.1shows the traditional three-phase voltage-source converter structure. Fig. 2 shows the three phase current source converter.

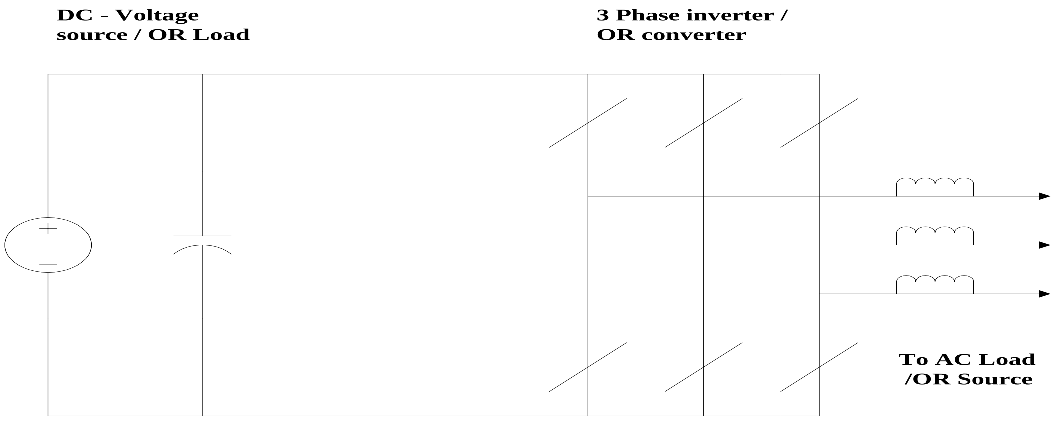

Fig.1.1 Voltage source inverter [1]

Fig. 1 shows the traditional voltage source converter structure. There are six switches are used in the main circuit. Each switch composed of a power transistor and an antiparallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability. A relatively large capacitor supported to dc voltage source to the main converter circuit, a three-phase bridge. The dc voltage source can be a battery, fuel-cell stack, diode rectifier. Usually voltage source inverter is used for DC to AC Conversion. There are some conceptual and theoretical barriers and limitations of converter have the follows.

1. Main limitation is that, the upper and lower devices of each phase leg cannot be gated on simultaneously either by purpose or by EMI noise. Otherwise, a shoot-through would occur and destroy the devices. The shoot-through problem by electromagnetic interference (EMI) noise's misgating-on is a major killer to the converter's reliability. Dead time to block both upper and lower devices has to be provided in the V-source converter, which causes waveform distortion, etc

2. The ac output voltage is limited below and cannot exceed the dc-rail voltage or the dc-rail voltage has to be greater than the ac input voltage. Therefore, the V-source inverter is a buck (step-down) inverter for **dc-to-ac** power conversion and the V-source converter is a boost (step-up) rectifier (or boost converter) for **ac-to-dc** power conversion.

3. There is always required an additional dc-dc boost converter to obtain a desired ac output. Where a wide voltage range is desirable, the additional power converter stage increases system cost, lowers efficiency and increase switching losses.

4. An output *LC* filter is needed for providing a sinusoidal voltage compared with the current-source inverter, which causes additional power loss and control complexity.

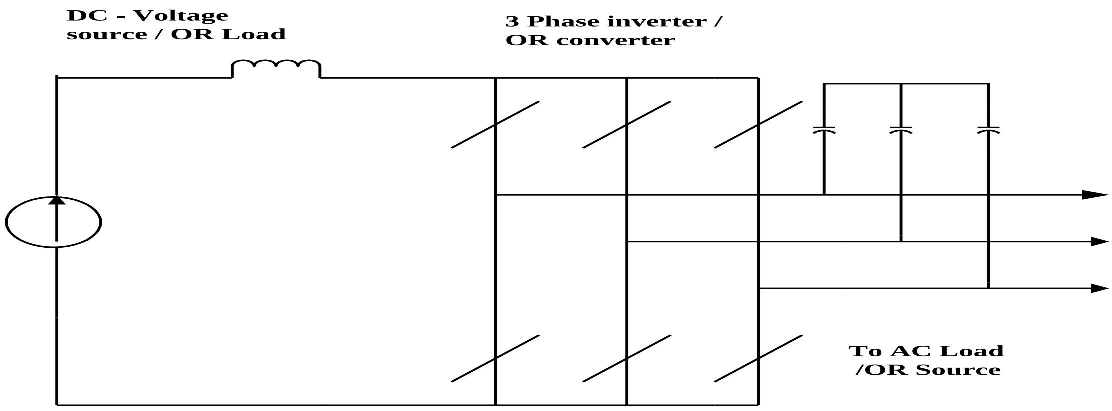

Fig.1.2 current source inverter [1]

Fig. 2 shows the traditional three-phase current-source converter structure. A dc current source feeds the main converter circuit, a three-phase bridge. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuel-cell stack, diode rectifier, or thyristor converter Six switches are used in the main circuit, each is traditionally composed of a semiconductor switching device with reverse block capability such as a gate-turn-off thyristor (GTO) and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking. There are some conceptual and theoretical barriers and limitations of converter have the follows.
1. At least one of the upper devices and one of the lower devices have to be gated on and maintained on at any time. Otherwise, an open circuit of the dc inductor would occur and destroy the devices. The open-circuit problem by EMI noise's misgating-off is a major concern of the converter's reliability. Overlap time for safe current commutation is needed in the I-source converter, which also causes waveform distortion, etc.
2. The ac output voltage has to be greater than the original dc voltage that feeds the dc inductor or the dc voltage produced is always smaller than the ac input voltage. Therefore, the current source converter is a boost inverter for **dc-to-ac** power conversion and the current source converter is a buck rectifier (or buck converter) for **ac-to-dc** power conversion.
3. There is always required an additional dc-dc boost converter is needed to obtain a desired ac output. Where a wide voltage range is desirable, the additional power converter stage increases system cost and lowers efficiency.
4. The main switches of the current-source converter have to block reverse voltage that requires a series diode to be used in combination with high-speed and high-performance transistors such as insulated gate bipolar transistors (IGBTs). This prevents the direct use of low-cost and high-performance IGBT modules and intelligent power modules (IPMs).

In addition, both the V-source converter and the I-source converter have the following common problems.

- They are either a boost or a buck converter and cannot be a buck–boost converter. That is, their obtainable output voltage range is limited to either greater or smaller than the input voltage.
- Their main circuits cannot be interchangeable. In other words, neither the V-source converter main circuit can be used for the I-source converter, nor vice versa.
- They are vulnerable to EMI noise in terms of reliability.

I. WHAT IS Z-SOURCE?

The configuration of 3-phase Z-source inverter is shown in fig. 3. It consists of 2 identical inductors and 2 identical capacitors 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.

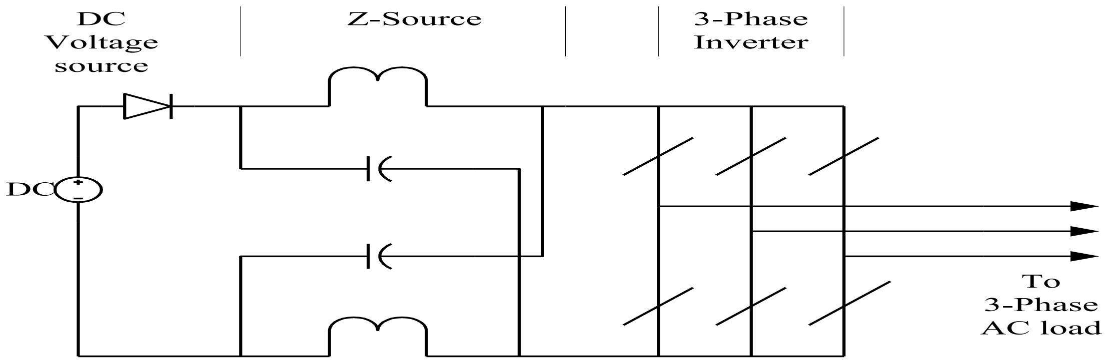

Fig.2.1. Structure of the Z-source converter. [1]

To overcome the problems of traditional VSI and CSI, an Z-source power converter topology is used. The dc source or load can be either a voltage or a current source or load. Therefore, the dc source can be a battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the antiparallel combination as shown in Fig. It employs a unique impedance network 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 where a capacitor and inductor are used, respectively. Z-source inverter can boost dc input voltage with no requirement of dc-dc boost converter or step up transformer, hence overcoming output voltage limitation of traditional voltage source inverter as well as lower its cost. A comparison among conventional PWM inverter, dc-dc boosted PWM inverter, and Z-source inverter shows that Z-source inverter needs lowest semiconductors and control circuit cost, which are the main costs of a power electronics system. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

- **Equivalent Circuit, Operating Principle, and Control.**

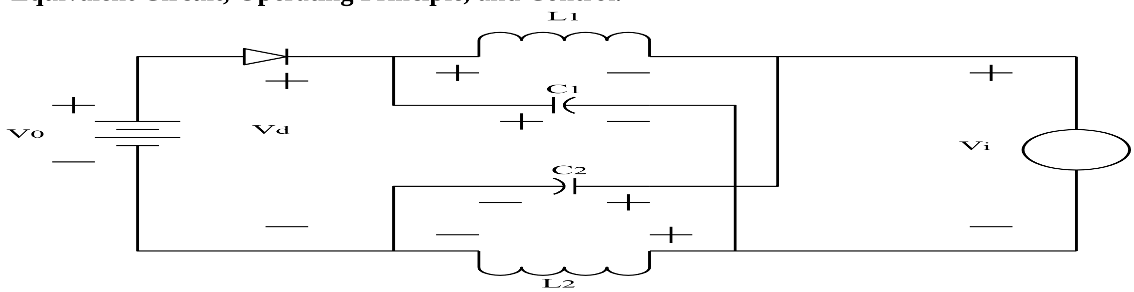

Fig. 2.2 Equivalent circuit of the Z-source inverter viewed from the dc link. [1]

Shown in fig. Equivalent circuit of z- source inverter. A diode to block reverse current, To describe the operating principle and control of the Z-source inverter Z-source inverter bridge has nine permissible switching states unlike the traditional three-phase V-source inverter that has eight. The traditional three-phase V-source inverter 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, the 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 (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state is forbidden in the traditional V-source inverter, because it would cause a shoot-through. We call this third zero state the shoot-through zero state, which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter.

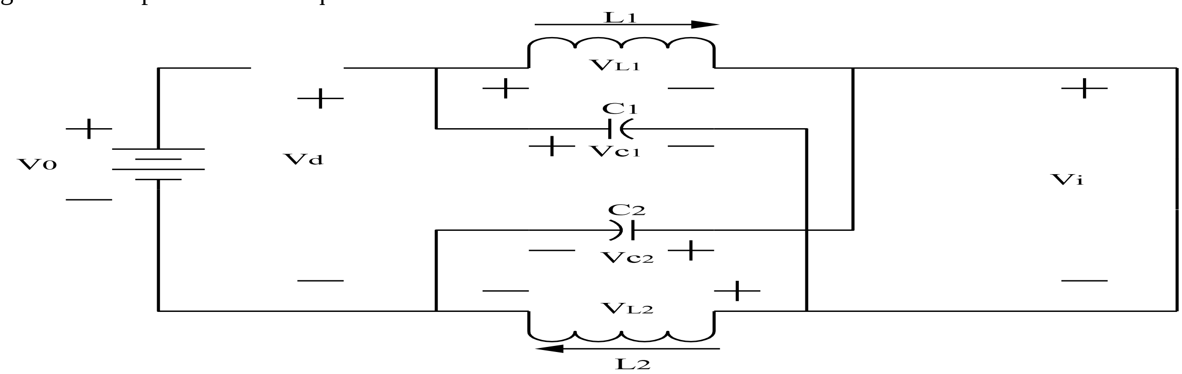

Fig.2.3 Equivalent circuit of the ZSI when the bridge is in the shoot-through zero state.

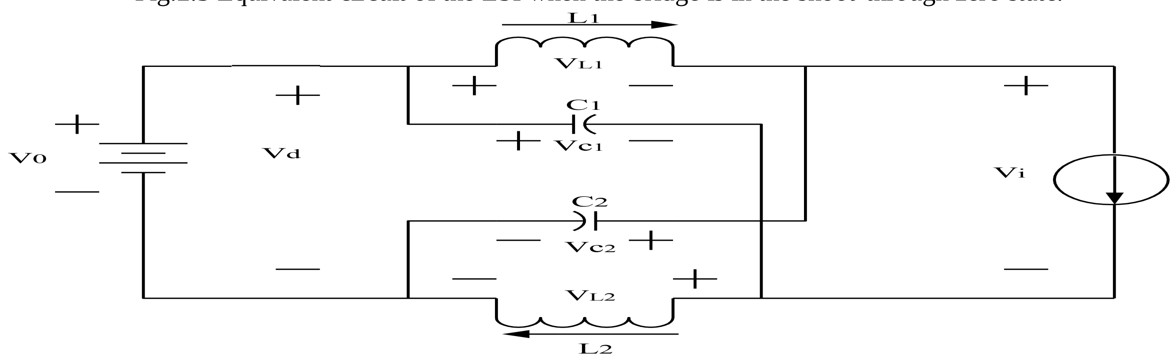

Fig.2.4 Equivalent circuit of the ZSI when the inverter bridge is in one of the eight non shoot-through switching states.

- **Operating Principle and Obtainable Output Voltage**.

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

$$V_{C1} = V_{C2} = V_C \qquad V_{L1} = V_{L2} = V_L \quad \text{.....(1)}$$

Given that the inverter bridge is in the shoot-through zero state for an interval of T_0, during a switching cycle, T and from the equivalent circuit, fig. 5

$$V_L = V_C \qquad V_d = 2V_C \quad \text{.....(2)}$$

Now consider that the inverter bridge is in one of the eight non shoot- through states for an interval of T_1 , during the switching cycle, T. From the equivalent circuit. Fig. 6

$$V_L = V_0 - V_C, \qquad V_d = V_0, \qquad V_i = V_C - V_L = 2V_C - V_0 \quad \text{.....(3)}$$

where V_0 is the dc source voltage and

$$T = T_0 + T_1$$

The average voltage of the inductors over one switching period (T) should be zero in steady state, from (2) and (3), thus, we have

$$V_L = \overline{V}_L = \frac{T_0 \cdot V_C + T_1(V_0 - V_C)}{T} = 0 \quad \text{.....(4)}$$

OR

$$\frac{V_C}{V_0} = \frac{T1}{(T_1 - T_0)} \quad \text{.....(5)}$$

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

$$V_i = \overline{V}_i = \frac{T_0 \cdot 0 + T_1 \cdot (2V_C - V_0)}{T} = \frac{T1}{(T_1 - T_0)} = V_C \quad \text{.....(6)}$$

The peak dc-link voltage across the inverter bridge is expressed in (3) and can be rewritten as,

$$\hat{V}_i = V_C - V_L = 2V_{C} - V_0 = \frac{T1}{(T_1 - T_0)} V_0 = B \cdot V_0 \quad \text{.....(7)}$$

Where

$$B = \frac{T1}{(T_1 - T_0)} = \frac{1}{(1 - 2T_0/T_1)} \geq 1, \quad \text{.....(8)}$$

is the boost factor resulting from the shoot-through zero state. The peak dc-link voltage 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,

$$V_{ac} = M \cdot \frac{V_i}{2} \quad \text{.....(9)}$$

Where M is the modulation index. Using (7), (9) can be further expressed as,

$$V_{ac} = M \cdot B \frac{V_0}{2} \quad \text{.....(10)}$$

For the traditional V-source PWM inverter, we have the well known relationship:

$$V_{ac} = M \cdot \frac{V_0}{2}$$

Equation (10) shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor BB,

$$B_B = M \cdot B \quad \text{.....(11)}$$

From (1), (5) and (8), the capacitor voltage can expressed as,

$$V_{C1} = V_{C2} = V_C = \frac{1 - (T_0/T)}{(1 - 2(T_0/T)} V_0 \quad \text{.....(12)}$$

The buck–boost factor is determined by the modulation index and boost factor. The boost factor as expressed in (8) 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.

Advantages of Z-source Inverter [8]

- When compared to the two traditional inverters topology voltage source inverter and current source inverter.

- Secures the function of increasing and decreasing of the voltage in the one step energy processing. (lower costs and decreasing losses)
- Resistant to short circuits on branches and to opening of the circuits.
- Improve resistant to failure switching and EMI distortions.
- Relatively simple start-up (lowered current and voltage surges).
- Provide ride-through during voltage sags without any additional circuits.
- Improve power factor reduce harmonic current and common-mode voltage.
- Provides a low-cost, reliable and highly efficient single stage for buck and boost conversions.
- Has low or no in-rush current compared to VSI.

II. PWM TECHNIQUES FOR Z SOURCE INVERTER

There are a different control methods which have been presented so far to control Z-source inverter, Mainly there are three control method for Z-source inverter.[5]

1) Simple boost control method
2) Maximum boost control method
3) Maximum constant boost control method

Now, new mordant control method also used [9]

1) Space vector pulse with modulation
2) Modified space vector pulse with modulation

Here in this paper maximum boost control method for the Z course inverters.

1. Maximum boost control method

It is similar to the traditional carrier-based PWM control method. The point is this control method maintains the six active states unchanged and turns all zero states into shoot-through states. Thus maximum *To* and *B* are obtained for any given modulation index *M* without distorting the output waveforms. As can be seen from Fig, the circuit is in shoot-through state when the triangular carrier wave is either greater than the maximum curve of the references (*V*a, *V*b, *V*c) or smaller than the minimum of the references. The shoot-through duty cycle varies each cycle. To calculate the voltage gain, what we are interested in is the average shoot-through duty cycle. The shoot-through state repeats periodically every (π /3).

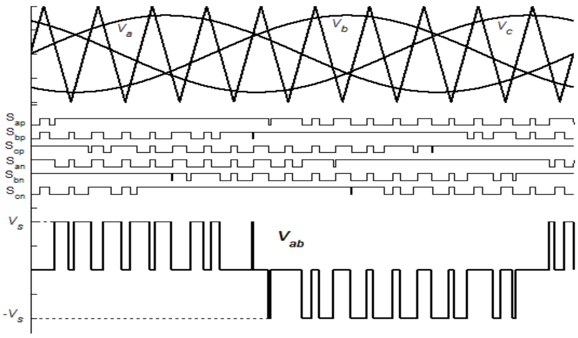

Fig.3.1Maximum boost control method [5]

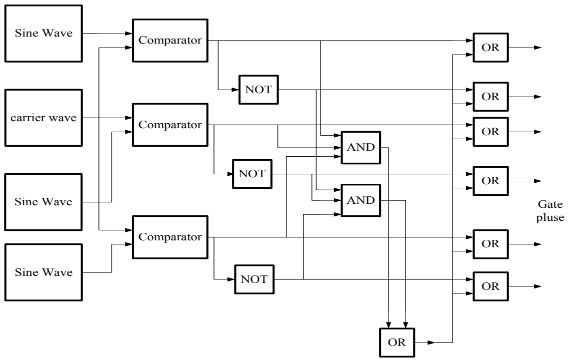

Fig 3.2. Block Diagram of SBC method

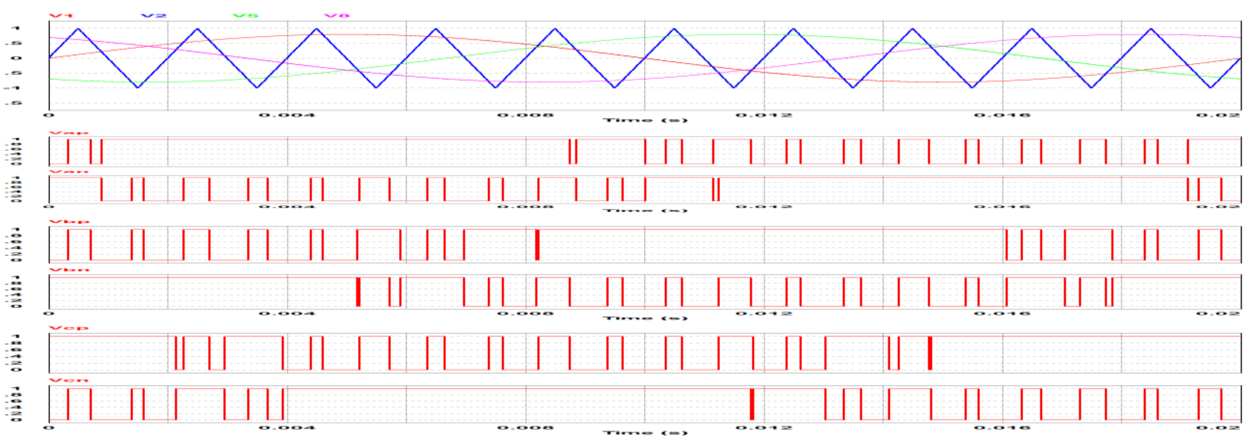

Fig3.3 Implementation of MBC in PSIM

III. POWER CIRCUIT

The Power circuit for the three phase impedance source three phase inverter implemented in PSIM, the gating pulse to the switches given by the simple boost control method. Various subsystems created viz: Inverter, Z source and load circuit.

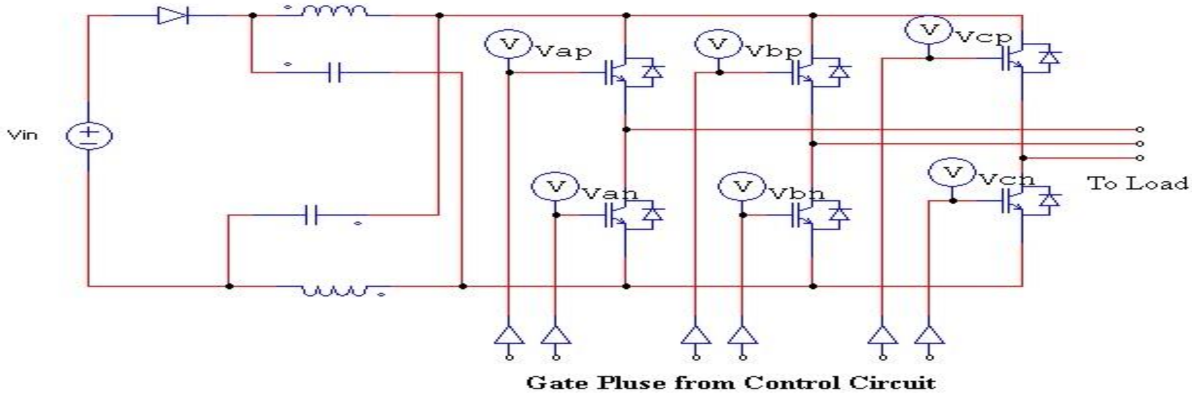

Fig 4.1 Power Circuuit

❖ **Different Load Circuit**

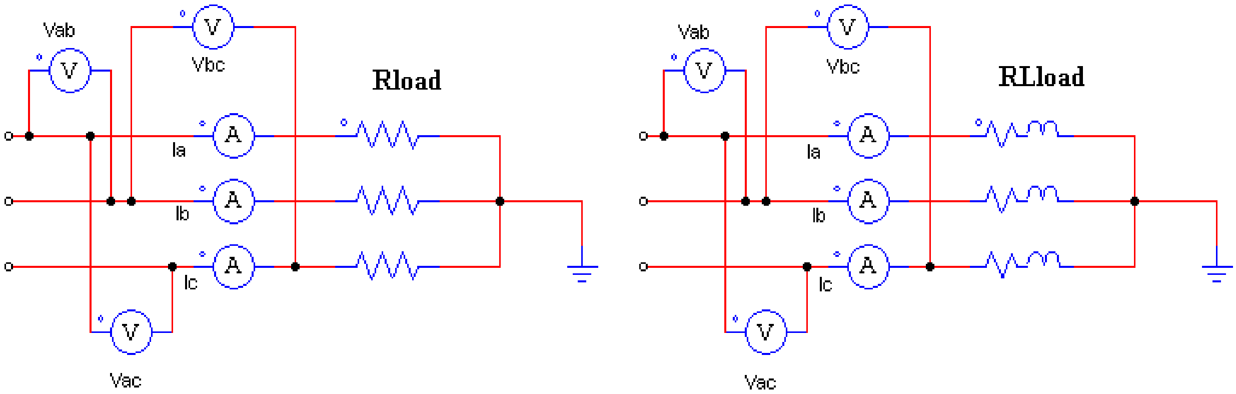

Fig 4.2 Load Circuit

IV.SIMULATION RESULTS

For Z-Circuit
Input DC Voltage =150
Inductor L1 & L2 = 20mH
Capacitor C1 & C2 = 100µF
Switching Frequency = 5K Hz

❖ Analysis For R-load R= 50Ω

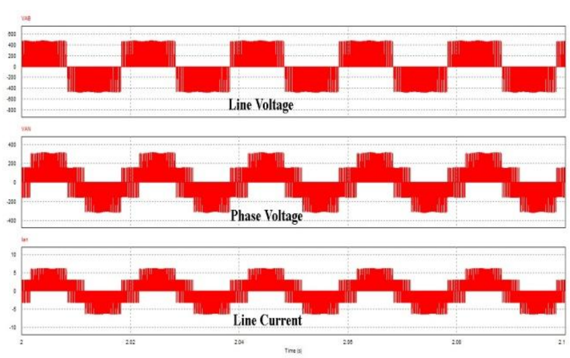

Fig4.3Line Voltage, Phase Voltage, Line Current

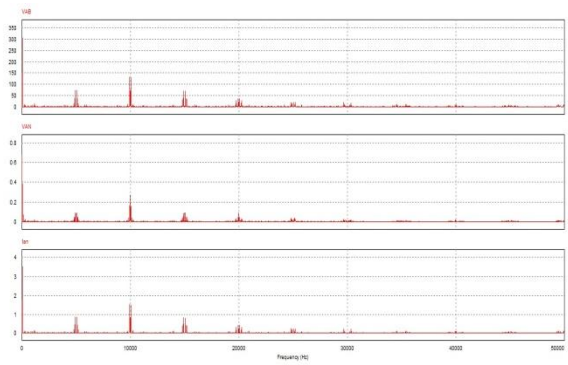

Fig4.4FFT Analysis

RMS Value

Time From	2.0000000e+000
Time To	2.1000000e+000
VAB	3.0204533e+002
VAN	1.7432506e+002
Ian	3.4865011e+000

THD

Fundamental Frequency	5.0000000e+001 HZ
VAB	9.7516117e-001
VAN	9.7583879e-001
Ian	9.7583879e-001

Fig4.5THD Analysis

Fig 4.6 RMS Value

❖ For RL- Load R= 50Ω & L=10 mH

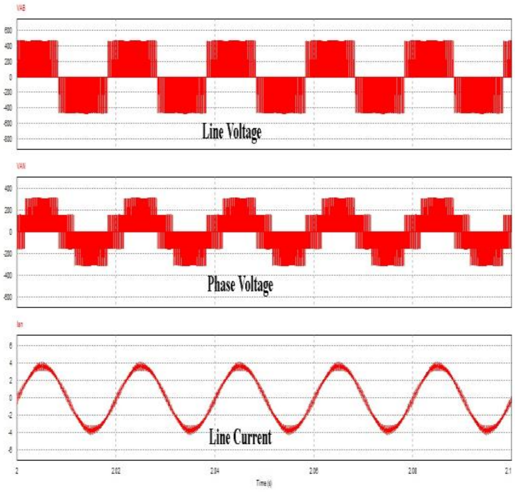

Fig 4.7Line Voltage, Phase Voltage, Line Current

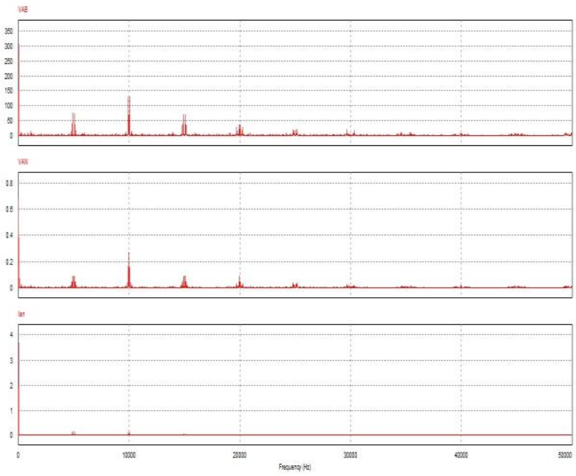

Fig 4.8 FFT Analysis

RMS Value

Time From	2.0000000e+000
Time To	2.1000000e+000
VAB	3.0169289e+002
VAN	1.7418391e+002
Ian	2.6204460e+000

THD

Fundamental Frequency	5.0000000e+001 HZ
VAB	9.7070966e-001
VAN	9.7177065e-001
Ian	7.9719745e-002

Fig 4.9 THD Analysis

Fig 4.10 RMS Value

❖ Result Analysis

Input DC voltage = 150 volt

For R-Load
Out pout AC voltage RMS value = 302 volt
Out pout AC current RMS value = 3.48 Amp

For RL-Load
Out pout AC voltage RMS value = 301 volt
Out pout AC current RMS value = 2.62 Amp

V.CONCLUSION

With the above simulation results the impedance source based inverter can overcome the limitation of the traditional Voltage and current source inverter. The Z source has extra zero state vector.when the load terminals are shorted through both the upper and lower devices of any one phase leg.(i.e., both devices are gated on).This type of inverter can be used for the fuel cell applications & wind generation system.

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