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# Comparative Analysis of Modified Z-Source Inverter With Conventional Z-Source Inverter

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***Abstract :*** This paper investigates the performance analysis of Modified-Z-source inverter with simple boost control technique for boosting the voltage. Z- Source network provides an efficient means of power conversion in grid connected photovoltaic applications meeting the requirements in single stage only. But the Z-source inverter suffers from drawbacks of high voltage stress, capacitors of high voltage rating. To overcome the drawbacks Z-network is modified for achieving high boosted voltage, while using a same shoot-through duty ratio as of Z-source inverter. In this paper the performance of Z-source inverter is compared with Modified Z-source inverter using the MATLAB.

***Keywords :*** Z-source inverter, Modified-Z-source inverter, Voltage gain.

## 1. INTRODUCTION

Now-a-days most of the power electronic applications frequently require voltage boosting, particularly for photovoltaic applications when directly connected to grid. Fig.1 shows the electric power conversion between source and load in a wide range of electric power conversion applications.

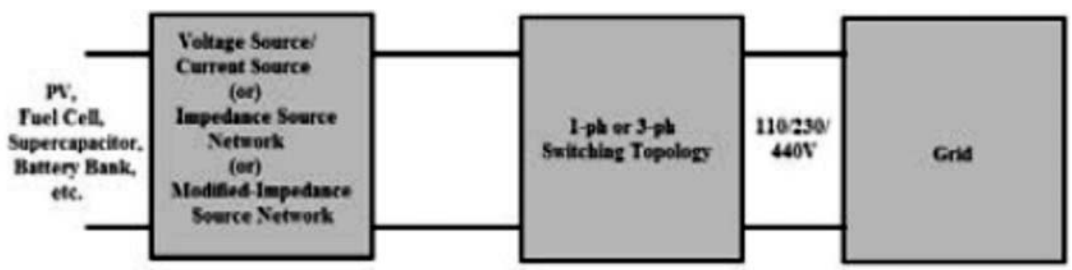


**Fig. 1. Block diagram of electric power conversion between source and load.**

Fig. 2 shows the conventional three-phase voltage source inverter (VSI) structure. The DC voltage source supported by a relatively large capacitor feeds the main converter circuit, a three phase bridge. The DC voltage source can be a battery, fuel-stack cell, diode rectifier and capacitor. Six switches are used in main circuit each is conventionally composed of power transistor and anti parallel (or freewheeling) diode (D) to provide bidirectional flow and to prevent unidirectional voltage blocking capacity.[1]

The output AC voltage is less than input DC voltage (buck inverter). The VSI has following limitations:[1]-[2]

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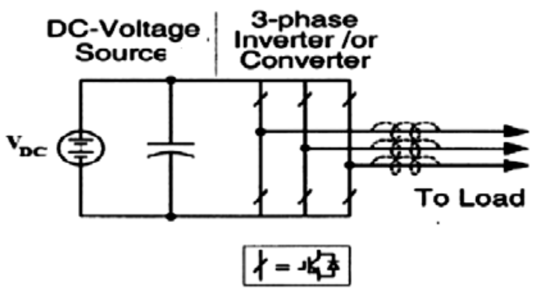


**Fig. 2. Circuit diagram of Voltage Source Inverter.**

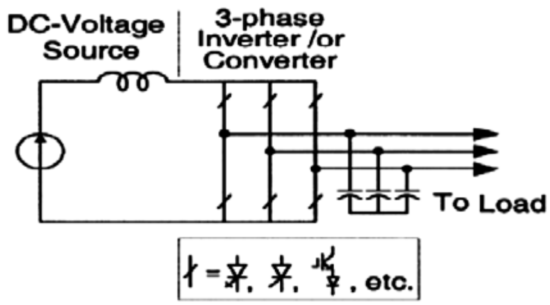


**Fig. 3. Circuit diagram of Current Source Inverter.**

- From the applications point of view, where wide range voltage is desirable, an additional DC-DC boost (or buck) converter is needed.
- The Upper and lower devices of each phase leg cannot be switched on simultaneously.

Fig. 3 shows the conventional three-phase current source inverter (CSI) structure. Unlike VSI, CSI has nine switching modes in those six are active modes and three are zero modes. The output AC voltage is greater than DC input voltage (boost inverter).However, CSI has the following limitations:

For the applications point of view, where over drive is desirable, an additional DC-DC boost converter is needed to obtain a desired AC output voltage.

The one of the upper and lower devices have to be switched on simultaneously and should be maintained on at any instant.

In current source converter needed in the overlap time for safe current commutation and which is also a cause of waveform distortion, etc.

## 2. Z-SOURCE INVERTER

Z-source inverter is a advanced topology when compared with VSI and CSI as it eliminates the requirement of DC-DC boost converter. The ZSI involves combination of VSI and CSI to from a X-shape coupled network of two inductors and two capacitors, known as Z-source network. It has the advantages of *buck and boost operation, single stage conversion*.[1]-[4]

Fig.4 shows the conventional three-phase Impedance source inverter (ZSI) structure. Z-source network consists of two same inductors and capacitors are connected in series legs and capacitors are connected in diagonal. Two switches in any of same leg are switched on simultaneously, known as shoot through state gives boosting capability to the inverter without any damage to the circuit. Fig.5 shows the conventional three-phase Impedance source inverter (ZSI) equivalent circuit. ZSI operates in three different modes:

- Zero Mode
- Active Mode
- Shoot through Mode

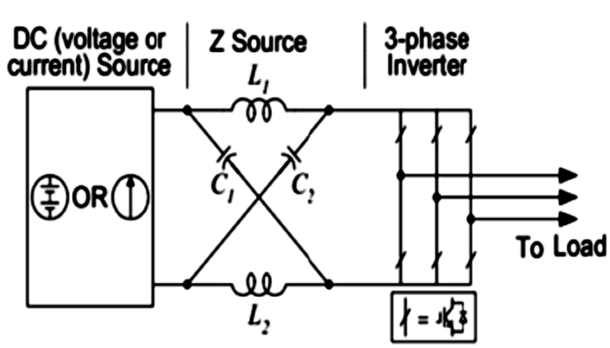


**Fig. 4. Circuit diagram of Z-Source inverter**

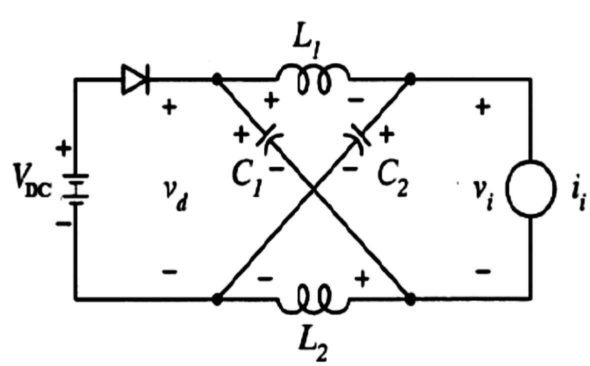


**Fig. 5. Equivalent circuit diagram of the Z-Source inverter from the dc-link**

## 3. ZSI EQUIVALENT CIRCUIT AND OPERATING MODES

### ZERO MODE

ZSI has two zero modes in which the output voltage is zero. In this mode, upper (or) lower three switches are turned on simultaneously, thus acting as an open circuit and diode (D) is forward biased shown from Fig. 6. The capacitors ($C_1$ & $C_2$) and inductors ($L_1$ & $L_2$) are charged from the $V_{DC}$. In this mode the output AC voltage ($V_{AC}$) is zero.

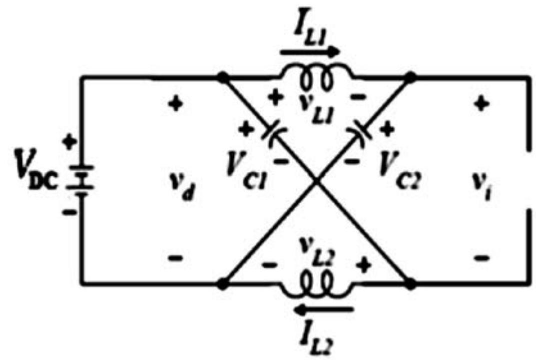


**Fig. 6. Equivalent circuit diagram of ZSI in Zero Mode.**

### SHOOT THROUGH MODE

Shoot Through Mode arises when *Two switches in same leg (or) Two switches each from any two phases (or) All the six switches of three phases* conducts. Fig.7 shows the equivalent circuit of ZSI in shoot through mode. During shoot through mode energy is transformed from capacitor to inductor and hence ZSI gains the voltage boosting capability. In this mode, the diode (D) at input side is reverse biased.

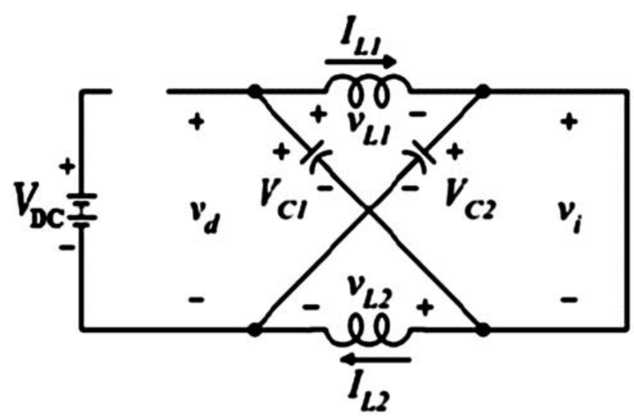


**Fig. 7. Equivalent circuit diagram of ZSI in Shoot through Mode.**

Assuming a similar impedance network ($C_1 = C_2 = C$ and $L_1 = L_2 = L$), it can be observed that :

$$V_{L1} = V_{L2} = V_L \quad (1)$$

$$V_{C1} = V_{C2} = V_C \quad (2)$$

$$V_C = V_L \quad (3)$$

$$V_d = 2 * V_C \quad (4)$$

The dc-link voltage across inverter during shoot through time period ($T_0$) is

### NON-SHOOT THROUGH MODE

It has six non shoot through states. As shown in fig.8 when the three phase inverter ($V_i$) switches are one leg positive switch and other leg negative switches are shorted. It this mode, the diode (D) at input side forward biased and capacitors are charge (or no action) and inductors are discharge.

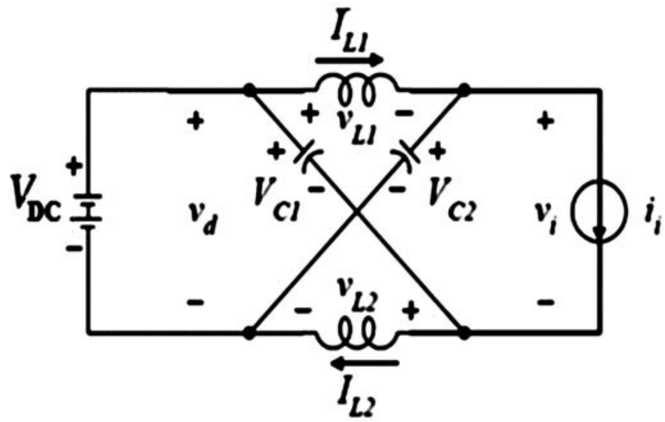


**Fig. 8. Equivalent circuit diagram of ZSI in non-Shoot through Mode.**

The dc-link voltage across the inverter during non-shoot through interval ($T_1$) is,

$$V_d = V_{DC} \tag{5}$$

$$V_i = 2 * V_C - V_{DC} \tag{6}$$

$$V_i = B_f * V_{DC} \tag{7}$$

**Voltage across the capacitor:**

$$V_C = \left(\frac{1 - D_{st}}{1 - 2 * D_{st}}\right) * V_{DC} \tag{8}$$

Boost factor $(B_f) = \dfrac{1}{1 - 2 * D_{st}}$

**The ZSI suffers from the following drawbacks:**

- Not flexible to provide continuity of inductor current.
- Voltage across the capacitor is more than the input voltage.
- Higher the voltage boost gain, the smaller the modulation index is used.
- High voltage stress is presented.

To conclude, although the traditional three-phase inverters (VSI & CSI) and impedance-source inverter (ZSI) has been widely used, it has some limitations and barriers that would finally limit the overall performance of the circuit and increases the system costs.

## 4. TRANS-Z-SOURCE INVERTER

The Trans-Z-Source Inverter is a new topology in power conversion. Trans-z-source inverter extends the Z-Source inverter concept to Transformer-based Z-Source inverter. These inverters have two inductors which can be replaced by a magnetic coupled inductor. By doing so, the two inductors are coupled through magnetic field and one capacitor can be removed thus reducing the capacitor count.[5]-[9]

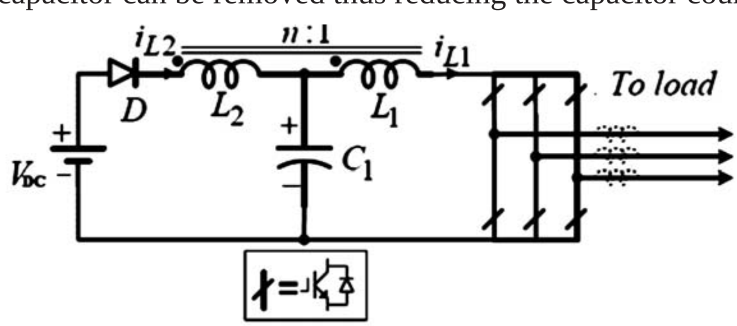


**Fig. 9. Circuit diagram of Trans-Z-Source Inverter (Trans-ZSI).**

As shown in fig.9 when the Trans-ZSI has the turn ratio one the inverter dc-link voltage boost gains same with the ZSI. The turn ratio is over one($n$ > 1). The inverter voltage boost gains high in the same modulation index. The transformer should be designed with low leakage inductance & very high transformer is difficult to implement. The DC-AC voltage gain cannot exceed two in the boost operation. The Trans-ZSI suitable for low to medium power applications.

## VOLTAGE-FED-TRANS-Z-SOURCE INVERTER

The Main & equivalent circuit of Voltage-Fed-Trans-ZSI are shown in Fig.10& Fig.11. In the voltage fed tans-ZSI with continuous input current two inductors can be coupled. Coupled inductor has the property of reflecting the voltage across the inductor $L_1$ to inductor $L_2$ through magnetic coupled. Here the coupled inductor turns ratio should be chosen as 2:1. These kinds of trans-ZSI has properties of buck-boost operation, single stage conversion and low dc voltage of capacitor ($C_1$), increases the voltage gain and decreases the voltage stress.[6]-[8]

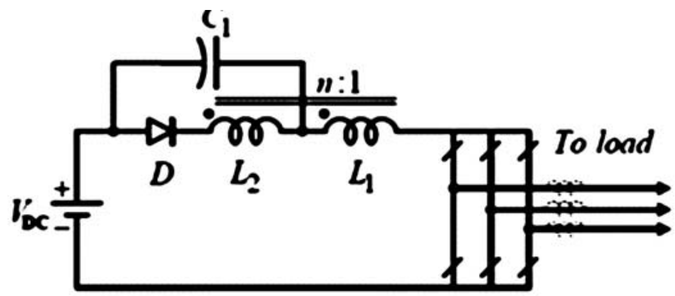


**Fig. 10. Circuit diagram of Voltage-Fed-Trans-Z-Source Inverter.**

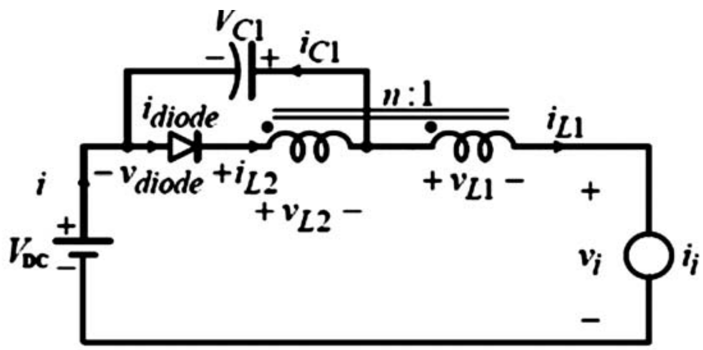


**Fig. 11. Equivalent circuit diagram of Voltage-fed-Trans-ZSI.**

## SHOOT THROUGH MODE

It is same as same traditional ZSI operation. It is also one shoot trough state (The three phase inverter switches are shorted through (turn on simultaneously) both upper and lower of any one leg and two legs or three legs). The diode (D) is reverse biased (because the cathode voltage is greater than the anode voltage). The capacitor $C_1$ is discharge. The equivalent circuit diagram in the shoot through mode is shown in Fig.12.

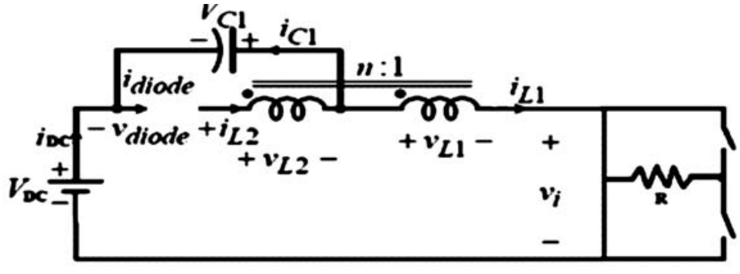


**Fig. 12. Equivalent Circuit diagram of Voltage-fed-Trans-ZSI in Shoot though Mode.**

**By applying KVL :**

$$V_{L1} = V_{C1} + V_{DC} \quad (10)$$

$$V_{L1} = n^* \ V_{L1} \quad (11)$$

$$V_{L2} = \left(\frac{n_2}{n_1}\right) * V_{L1} \quad (12)$$

Where $n$ = Turns Ratio

## NON-SHOOT THROUGH MODE

Its have six non shoot through modes. When the three-phase inverter ($V_i$) switches are one leg positive switches and other leg negative switches are shorted. In this state the diode (D) at input side forward biased and capacitor ($C_1$) is charged. The equivalent circuit diagram in the non shoot through mode is shown in fig.13.

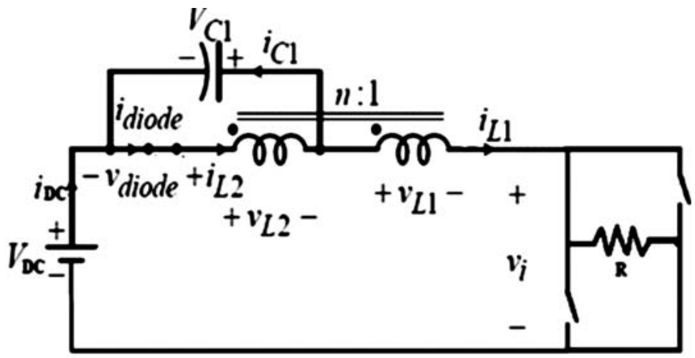


**Fig. 13. Equivalent circuit of Voltage-fed Trans-ZSI in Non-Shoot through Mode.**

**By applying KVL :**

$$V_{C1} + V_{L2} = 0 \quad (13)$$

$$V_{DC} = V_{L1} + V_{L2} \quad (14)$$

$$V_{L2} = -V_{C1} \quad (15)$$

$$V_{L1} = \left(\frac{n_1}{n_2}\right) V_{L2} \quad (16)$$

$$V_{L1} = -\frac{n_2}{n_1} * V_C \text{ (or) } -\frac{V_C}{n} \quad (17)$$

From the above equation, the capacitor voltage can be computed as,

$$V_{C1} = \left(\frac{n * D_{st}}{1-(1+n)* D_{st}}\right) * V_{DC} \quad (18)$$

From equation (17) &(18), the dc-link voltage across the three phase inverter in the non-shoot through mode can be boosted to

$$V_i = \left(\frac{1}{1-(1+n)* D_{st}}\right) * V_{DC} = B_f * V_{DC} \quad (19)$$

where the boost factor is:

$$B_f = \frac{1}{1-(1+n)* D_{st}} \quad (20)$$

## 5. PWM TECHNQIUES FOR ZSI

### Simple Boost Method

This method uses two straight lines of equal magnitude with opposite polarities are used. To insert shoot through state the magnitude of carrier wave must be greater than the carrier. In this method all carriers are in phase opposition with the neighbor carriers & it is called as Alternate Phase Opposition Disposition (APOD). When the carrier waveform is greater than the upper constant, or lower than the bottom constant line the circuit goes into shoot through state. Otherwise it operates as a conventional carrier based PWM. This method is very simple. However, the resulting voltage stress across the switches is relatively high because some traditional zero states are not utilized. The theoretical values of modulation index, shoot through duty ratio, boost factor, output peak ac voltage & voltage across capacitors is obtained by using below equations[9]-[11].

$$\text{Modulation Index} = m_a = \frac{A_m}{\frac{(m-1)}{2} * A_c} \tag{21}$$

$$\text{Shoot through Duty Ratio} = D_o = (1 - m_a) \tag{22}$$

$$\text{Boost Factor} = B = \frac{1}{1 - D_o} \tag{23}$$

The phase output peak voltage is given by

$$V_{ac} = m_a * B * \frac{V_{dc}}{2} \tag{24}$$

Voltage across capacitor $V_c$ is given by

$$V_c = \frac{1 - D_o}{1 - 2D_o} * V_{dc} \tag{25}$$

## 6. SIMULATION RESULTS

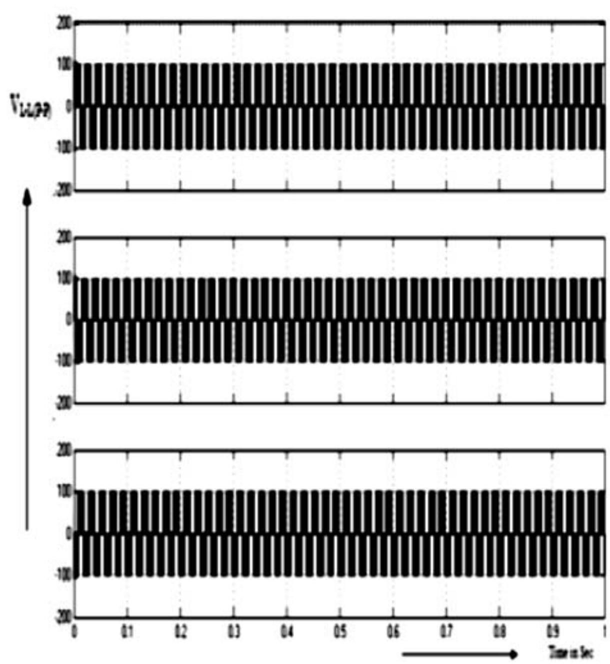

**Fig. 14. (*a*) Output voltages for the traditional Z-source inverters**

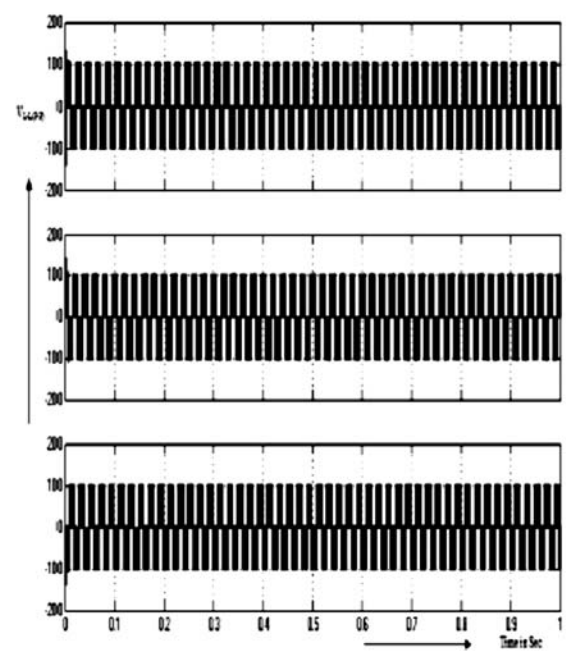

**Fig. 14. (*b*) Output voltages for the Trans Z-source inverter**

To verify the advantages of the proposed Trans-ZSI, MATLAB simulation compares and performance with the traditional ZSI for boost operation. The simulation result of proposed work will validate with MATLAB software. THDs (Total harmonic distortions) analysis are also validate with FFT analysis of MATLAB software for compare to the Trans-ZSI and ZSI.We selected parameters C = 1000F and R = 50ohms/phase. The turns ratio of the transformer is $n = 2$. The magnetic inductance ($L_m$) was set to 0.4145 mH. The magnetization resistance ($R_m$) was set to 0.091 ohms. The switching frequency was 10kHz, the input DC voltage 100($V_{DC}$). Simple boost control was used. To compare the traditional ZSI and Trans-ZSI of simulation results was shown in fig.14,15 & 16.

Fig. 14(*a*) & (*b*) shows output voltages for the traditional Z-source inverter and Trans-z-source inverters when modulation index (M.I) = 1, the shoot through duty ratio is zero ($D_{st\,=}$ 0) ,boost factor is 1 ($B_f$ = 1), the voltage gain also 1 (G = 1). Then the Z-source and Trans-Z-source inverters act as normal inverter in non shoot through mode. Because of the output voltages ($V_{AC}$) are equal to input DC voltage (100 Volts).

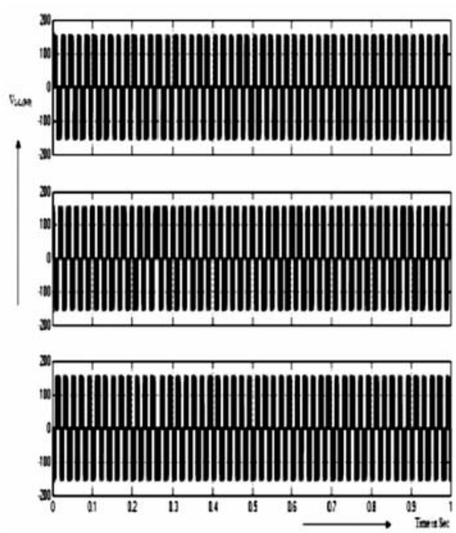

**Fig. 15. (*a*) Output line to line voltages for the traditional Z-source inverter**

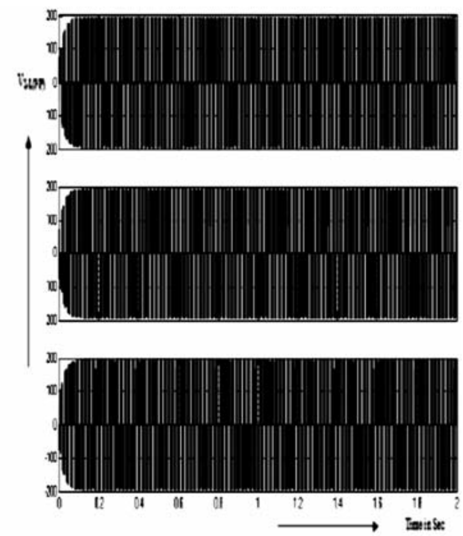

**Fig. 15. (*b*) Output line to line voltages for the Trans Z-source inverters**

From Fig. 15 (*a*) & (*b*) shows compare to the output voltage (line-line) wave forms for traditional Z-source and Trans-Z-source inverters. In traditional Z-source inverter have modulation index is equal to the 0.85(M.I = 0.85), the shoot through duty ratio is 0.15($D_{st}$ = 0.15), the boost factor is equal to 1.428 ($B_f$ = 1.428) and voltage gain is equal to 1.2138 (G=1.2138). In Trans-ZSI also used same modulation index (M.I = 0.85), the shoot through duty ratio is obtained like as traditional ZSI, but to varying the boost factor and voltage gain (*i.e*., $B_f$ = 1.818 and G = 1.5453). The traditional Z-source inverter of the output voltage (peak-peak) is 150Volts ($V_{rms}$ = 113Volts) and proposed Trans-Z-source inverter of the output voltage (peak-peak) is 200Volts ($V_{rms}$ = 143Volts). Then, in this case ZSI and Trans-ZSI act as the shoot through mode operation. The Trans-ZSI obtains a voltage boost with same modulation index and same shoot through duty ratio and input DC voltage ($V_{DC}$ = 100Volts) as compare to the ZSI. When turns ratio is equal to the (n = 1), it is the same output voltage ($V_{AC}$) in traditional ZSI. When $n > 1$, the Trans-Z-source inverter voltage is boosted compare to the ZSI.

Fig. 16.(*a*) and (b) shows compare to the voltage across switch, rms and mean voltages for traditional ZSI and proposed Trans-ZSI. In traditional ZSI have modulation index 0.85(M.I = 0.85), shoot through duty ratio is 0.15; we obtain the voltage across switch 150 Volts, the rms voltage vary 80-100Volts, and mean voltage vary 50-70Volts. In same modulation index and shoot through duty ratio of Trans-ZSI we obtain the voltage across switch 200Volts, the rms voltage vary 100-130Volts, and mean voltage vary 60-90Volts. The voltage stress depends up on the transformer windings (or turns ratio). By increase the turn’s ratio the voltage across switch or voltage stress) is decreases.

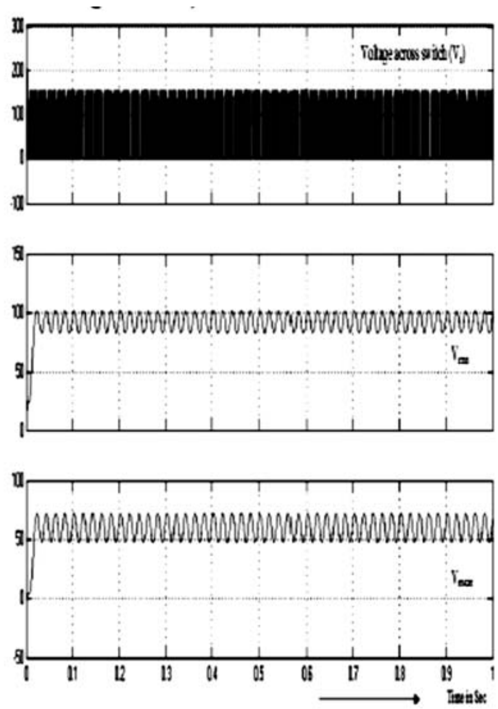


**Fig. 16. (*a*) simulation results of traditional Z-source inverter**

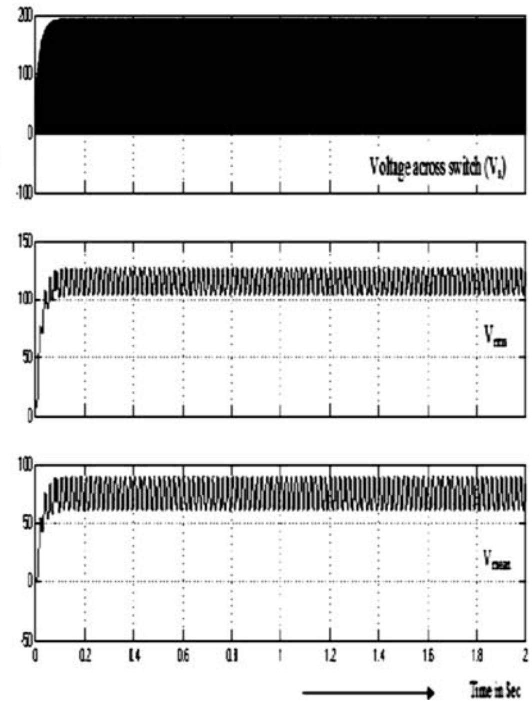


**Fig. 16. (*b*) simulation results of Trans Z-source inverters**

Fig. 17 (*a*) and (*b*) shows simulation results of traditional ZSI and Trans-ZSI. In FFT analysis, fundamental frequency 50Hz and the modulation index 1 and shoot through duty ratio zero. We obtain nearly same FFT analysis of the traditional ZSI and Trans-ZSI.

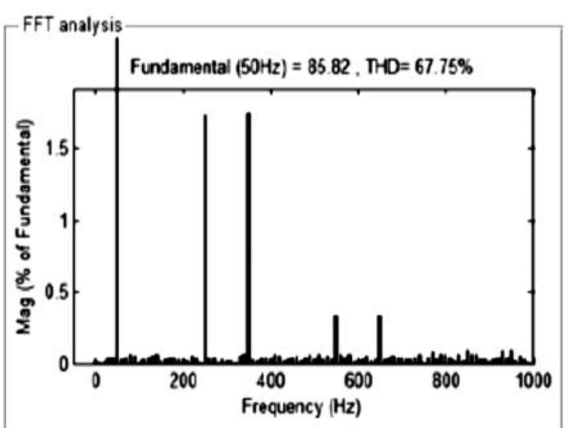


**Fig. 17. (*a*) FFT analysis of traditional Z-source inverter**

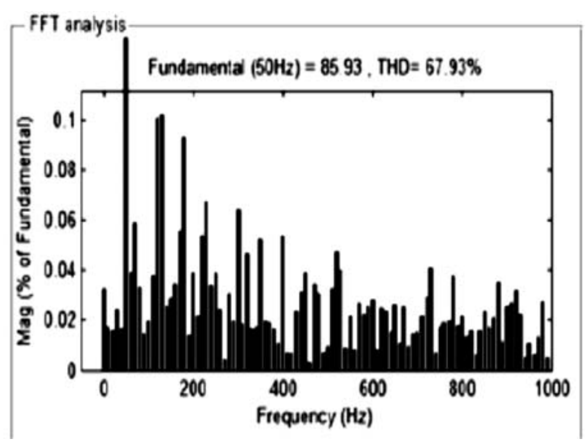


**Fig. 17. (*b*) FFT analysis of Trans Z-source inverters**

## 7. CONCLUSION

A new topology was proposed to Modified-Z-source inverter with the following main characteristics: high boost voltage inversion ability and reduce the voltage stress. Compared with the conventional Z-source inverter and modified-Z-source inverters has a higher modulation index with reduced voltage stress on the dc-link, low current stress flow to the transformer winding and diode, and lower input current ripple. If the modulation index kept fixed, the modified-ZSI uses a lower transformer turns ratio to produce the same input and output voltage compared to the conventional ZSIs. For instance, modified-Z-source inverter provides a promising potential in the applications with very low input voltage, such as the micro inverter for photovoltaic systems. Simulation results of the modified-ZSI and the conventional ZSI have verified the analysis and feature.

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