Simulation of Transformer Based Z-Source Inverter to Obtain High Voltage Boost Ability

A.Shanmugapriya[1], M.Ishwarya Niranjana[2], G.Jagadeeswaran[3]

[1] *Assistant Professor (ECE), Pollachi Institute of Engineering and Technology, Pollachi*

[2] *Assistant Professor(ECE),. Pollachi Institute of Engineering and Technology, Pollachi*

[3] *PG Scholar, Sri Eshwar College of Engineering,Coimbatore.*

***Abstract*:** **The Transformer based Z-Source inverter is an enhanced series inductance Z-Source impedance network. This proposed inverter is used to combine the main circuit and the power source. This configuration delivers a strong boost capacity to overcome the barriers of the series inductance Z-source inverter. Further, with the usage of low voltage capacitors and the transformer, the capacitor voltage strain gets reduced. The advantage of projected topology over series inductance Z-source inverter is that two built-in capacitors block DC currents in transformer windings and prevents core saturation, which results in easy construction with effective cost and the efficiency is also improved. The stray inductance effects are reduced by transformer. The main point of the proposed technique is that, a very short shoot through zero state is essential to obtain high voltage conversion which improves the output power quality. This circuit can be applied to several power conversion applications which use impedance-type power inverters. The output results of the Transformer based Z-source inverters are simulated in MATLAB/Simulink using a 120 degree mode pulse circuit. The simulated output results of the conventional and proposed inverters are compared and verified**.

Keywords: **Improved voltage ability, switched inductor network, transformer based Z-Source, 120 degree mode pulse operation.**

I. INTRODUCTION

In the power electronics applications, the dc-dc buck/Boost converter acts as major part. Using this converter circuit, the input voltage is increased or decreased corresponding to their applications. It is used in lite and heavy load conditions. For a heavy load conditions, such as drive applications needed a high output voltage in the range of 415V. The input voltage is boosted in order to achieve the high range of output voltage. The Z-source inverter services a unique impedance network, which is connected between the power source and inverter circuit, thus providing unique features that cannot be obtained in the traditional voltage-source and current-source inverters [4]. It allows the turning ON of both switches in the same inverter phase leg (shoot-through state) without damaging the inverter switches [8]. The problem in the traditional source inverters are solved by impedance source inverter [2]. The inverter switches are designed with low voltage ability. The increased input voltage does not affect the inverter switches. In the traditional inverter circuits single stage of power conversion circuit is not available. The voltage source inverter acts as a buck converter, which step down the input voltage or limit the input voltage and transfer the voltage to the inverter circuit.

The current source inverter acts as a boost converter which steps up the input voltage or increases the output voltage and transfer the voltage to the inverter circuit. Either buck or boost operation is possible in the above mentioned traditional inverters. An extra circuit is added to get high or low output voltage. This causes lower efficiency, high cost and the circuit becomes complex. It is seriously restricted due to their narrow obtainable output voltage range; shoot through problems caused by misfiring and other difficulties due to their bridge type structures.

II. Z-SOURCE INVERTER

The two capacitors and two inductors are connected by means of cross or X-Shape and form the Z-Source network is shown in the Fig.1. This is used to boosting the output voltage by increasing the source voltage [1]. The ac output voltage in the Z-Source inverter is mainly depends on following two parameters.

i. Duty cycle
ii. Modulation index

Both are related to each other. In the pulse generation circuit, the high duty cycle of the switching period is used then low modulation index is achieved. The switches in the inverter circuit is turned ON and OFF based on the duty cycle value.

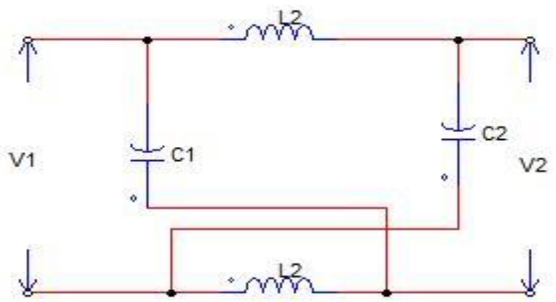

Fig.1 Z-Source network

The main drawback is that, alternate switching creates oscillations at the output when the large duty ratio is used. It degrades the performance of the inverter by reducing the amplitude of the ac output voltage [2]. Further a high voltage stress is imposed on Z-Source capacitor and Inverter Bridge.

III. SERIES INDUCTANCE Z-SOURCE INVERTER

In order to avoid the disadvantages of Z-Source inverter, the series inductance Z-Source inverter is developed. An extra amount of one inductor and three diodes are added into the topmost and bottommost arms of the Z-Source network to obtain high boost ratio and it is shown in the Fig.2. The boost factor has been increased from 1/(−2D) to (1+D)/(1−3D). In this inverter, a large value of modulation index is used to reduce the oscillations at the ac output voltages [5]. The duty cycle of the switching period is very short. The pulses for the inverter circuit are generated by using 120 degree mode method.

The two operating modes are performed and their detailed operation is explained below.

*A. **Non-shoot through state:***

In this mode, there are six active states and two zero states of the main circuit. During this sub-state, the switch S is in OFF condition, whereas both diodes D_{in} and D_o are ON. For the SL cell in the upper arm, the diodes D_1 and D_2 are OFF and D_3 is ON. The magnetic energy stored in the series connected inductors L_1 and L_3 are transferred to the main circuit. For the SL cell in the lower arm, the diodes D_4 and D_5 are OFF and D_6 is ON, the inductors L_2 and L_4 are connected in series and the stored magnetic energy is transferred to the main circuit.

At the same time, to supplement the consumed energy of C_1 and C_2 during the shoot through state, C_1 is charged by V_{in} via the bottom SL cell and C_2 is charged by V_{in} via the top SL cell.

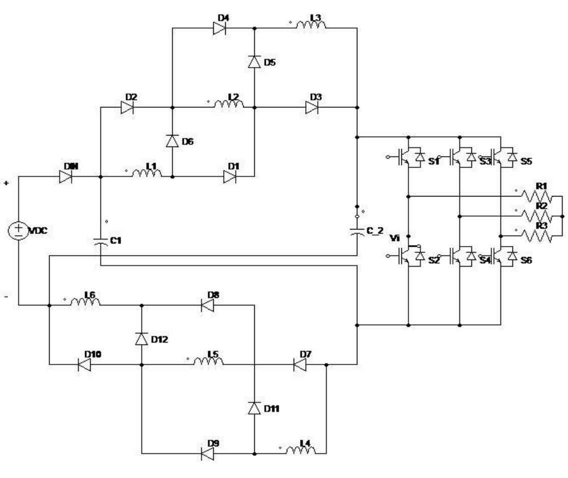

Fig.2 Series Inductance Z-Source inverter

IV.120 DEGREE MODE PULSE CONTROL

In this type of control each switch conducts for 120 degree. Only two switches remain ON at any instant of time. The gating signals are shown in Fig.3, the conduction series of switches is 61, 12, 23, 34, 45, 56, 61 and shoot through state is represented as following sequence 14, 25, 14, 52, 14. There are three modes of operation in one half cycles. 120 degree mode was adopted to control all the topologies discussed in the paper [3], [7]. The waveforms for the switching pulses are shown in the Fig.3.

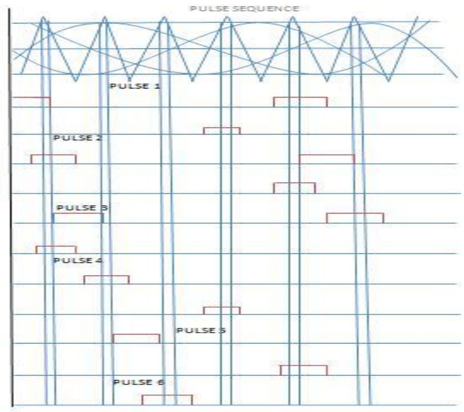

Fig.3 Switching Pulse Generation

The developed impedance source inverter intentionally utilizes the shoot-through zero states to boost dc voltage and produces an output voltage greater than the original dc voltage [6]. But 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. The voltage gain of the Z-source inverter can be expressed as

During mode 1 for 0≤wt≤π/3, transistor 1and 6 conduct.

$$V_{an} = \frac{V_S}{2}, V_{bn} = \frac{V_S}{2}, V_{cn} = 0 \tag{1}$$

During mode 2 for π/3≤wt≤2π/3, switch 1and 2 conduct

$$V_{an} = \frac{V_S}{2}, V_{bn} = 0, V_{cn} = \frac{V_S}{2} \tag{2}$$

During mode 3 for 2π/3≤wt≤π, switch 2and 3 conduct

$$V_{an} = 0, V_{bn} = \frac{V_S}{2}, V_{cn} = \frac{V_S}{2} \tag{3}$$

Line to neutral voltage can be expressed as,

$$V_{an} = \sum_{n=1,3,5}^{\infty} \frac{2V_S}{n\pi} \frac{\sin n\pi}{3\sin n(\omega t + \frac{\pi}{6})} \tag{4}$$

$$V_{bn} = \sum_{n=1,3,5}^{\infty} \frac{2V_S}{n\pi} \frac{\sin n\pi}{3\sin n(\omega t - \frac{\pi}{2})} \tag{5}$$

$$V_{an} = \sum_{n=1,3,5}^{\infty} \frac{2V_S}{n\pi} \frac{\sin n\pi}{3\sin n(\omega t - \frac{7\pi}{6})} \quad (6)$$

Line to Line voltage can be expressed as

$$V_{ab} = \sqrt{3}V_{an} \quad (7)$$

$$V_{ab} = \sum_{n=1,3,5}^{\infty} \frac{2\sqrt{3}V_S}{n\pi} \frac{\sin n\pi}{3\sin n(\omega t + \frac{\pi}{3})} \quad (8)$$

$$V_{bc} = \sum_{n=1,3,5}^{\infty} \frac{2\sqrt{3}V_S}{n\pi} \frac{\sin n\pi}{3\sin n(\omega t - \frac{\pi}{3})} \quad (9)$$

$$V_{ac} = \sum_{n=1,3,5}^{\infty} \frac{2\sqrt{3}V_S}{n\pi} \frac{\sin n\pi}{3\sin n(\omega t - \pi)} \quad (10)$$

$$\frac{V_0}{\frac{V_{dc}}{2}} = M_0 B \quad (11)$$

where,

V_o is the output peak phase voltage,
V_{dc} -input dc voltage, M_a - Modulation index, B- Boost factor.
B is determined by

$$B = \frac{1}{1 - 2D_0} \quad (12)$$

where,
D_o is the shoot through duty ratio.
The control scheme uses a high frequency sine carrier that helps to maximize the output voltage for a given modulation index.

A. Shoot Through

For the proposed PWM, the shoot through duty ratio is determined by

$$D_0 = \left(\frac{\pi - 2\sin^{-1} M_a}{2\pi} \right) \quad (13)$$

The boost factor B and the voltage gain can be calculated:

$$B = \frac{\pi}{\sin^{-1} M_a} \quad (14)$$

$$\frac{V_0}{\frac{V_{dc}}{2}} = M_0 B = \frac{\pi M_a}{\sin^{-1} M_a} \quad (15)$$

In the conventional 120 degree mode control method, a triangular carrier is used to control the shoot-through duty ratio [2]. In this case, the shoot-through time per switching cycle is constant, which means the boost factor is constant. In this conventional triangular carrier PWM the shoot through duty ratio is given expressed as

$$D_0 = 1 - M_a \quad (16)$$

In this conventional 120 degree mode control method, to achieve the high output voltage, it is required to increase the shoot through duty ratio which can only be achieved with the reduction of modulation index. But small modulation index results in greater voltage stress on the device, hence it restricts the obtainable gain because of the limitation of device voltage rating

The proposed control strategy uses the conventional sinusoidal reference, whereas the carrier wave is modified for the same modulation index.

For the proposed PWM, the shoot through duty ratio is determined by

$$D_0 = \left(\frac{\pi - 2\sin^{-1} M_a}{2\pi} \right) \quad (17)$$

The boost factor B and the voltage gain can be calculated:

$$B = \frac{\pi}{\sin^{-1} M_a} \quad (18)$$

$$\frac{V_0}{\frac{V_{dc}}{2}} = M_0 B = \frac{\pi M_a}{\sin^{-1} M_a} \quad (19)$$

V. TRANSFORMER BASED Z-SOURCE INVERTER

In the Series Inductance Z-Source inverter, the output voltage (AC Voltage) is increased corresponding to DC input voltage, when increasing the number of inductor stages.

The stray inductance effects are induced, which affects the performance of the system. More number of stages makes the system complexity and increases the system cost. To remove the above disadvantage, the transformer based Z-Source Inverter is proposed [9].

Transformer based Z-Source Network is the arrangement of the two capacitors and one transformer that can be connected between the dc source and the inverter bridge while maintaining the main features of the SL Z-source network shown in Fig.4.

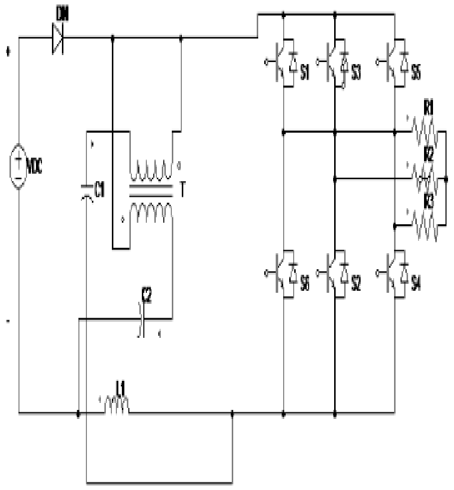

Fig.4 Transformer based Z-Source inverter circuit

In order to accomplish single-stage power conversion with buck-boost abilities the proposed inverter is used. This inverter turns on both power switches in a leg to boost the dc bus voltage.

The current drawn from the dc source is continuous. Both shoot-through states and the transformer turn ratio can be regulated to control the boost voltage gain.

The output voltage can be adjusted over a wide range, and can be boosted to a higher value .Both of the power switches in a leg can be turned on at the same time, which eliminates dead time and significantly improves the reliability while reducing the output waveform distortion[10].

The exclusive property of this inverter is that, no energy is stored in the transformer windings. The two DC-current blocking capacitors connected in series with the transformer also prevent the transformer core from saturation during the following three operating modes.

- Shoot through mode
- Non shoot through mode with ID>0
- Non shoot through mode with ID=0

Only one inductive element is used to store the energy during the boost operation. The average currents of two transformer windings over the period of the output voltage are equal zero.

VI. SIMULATION RESULTS

To verify the mentioned theoretical results, a simulation example for the voltage inversion from DC 24 V to AC 185V (rms) is given in MATLAB which will be difficult to achieve with the Series Inductance Z-source inverter. Without using any boost converter circuit high AC voltage was obtained. The main circuit parameters are chosen as follows:

- Transformer based Z-source impedance network
- L_1 = 0.05 mH and C_1 = C_2 = 800 μF;
- 3 phase output filter: L_f = 100 μH, C_f = 1000 μF;
- The switching frequency f_s = 1/T = 50 Hz;
- All components are assumed ideal.

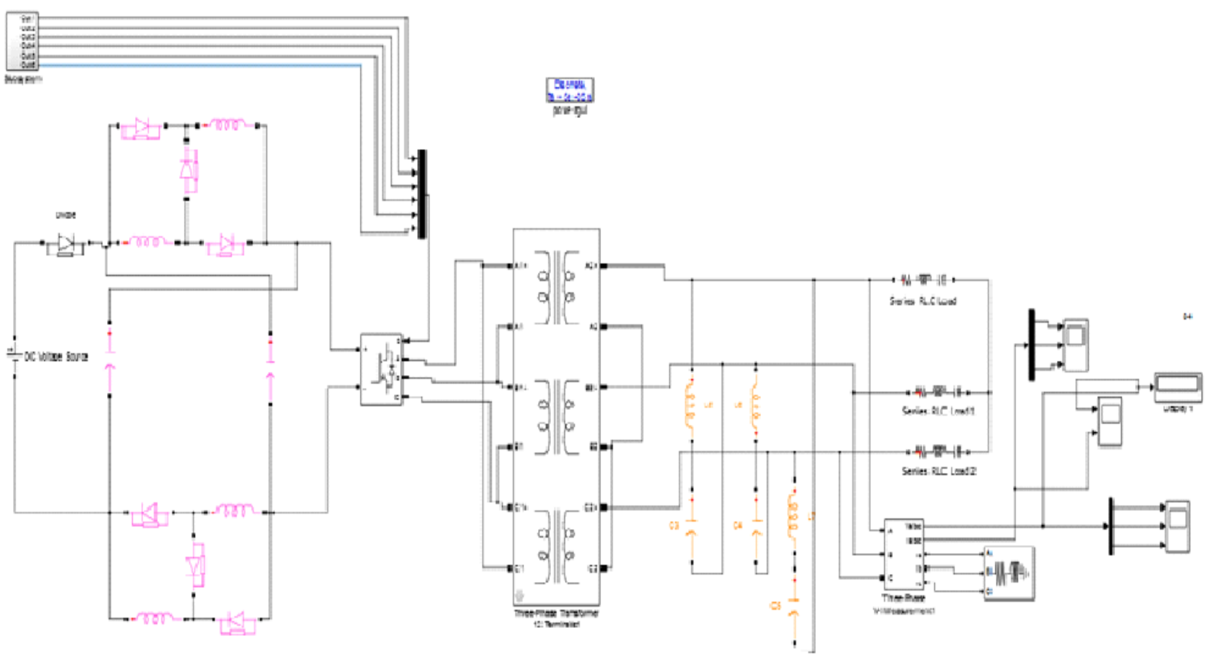
Fig.5 Simulation diagram for Series inductance Z-Source inverter

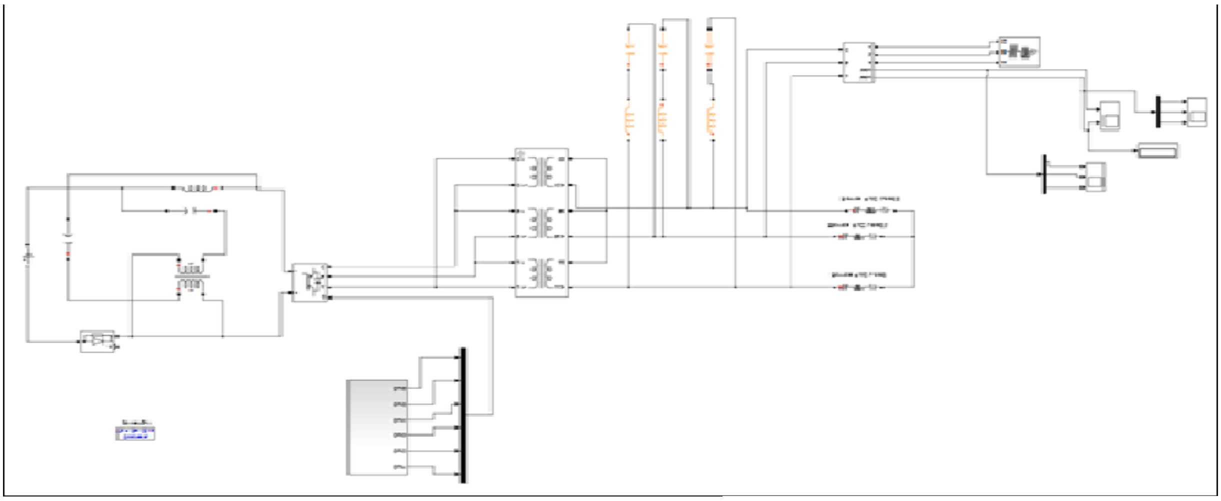

Fig.8 Simulation diagram for series inductance Z-Source inverter

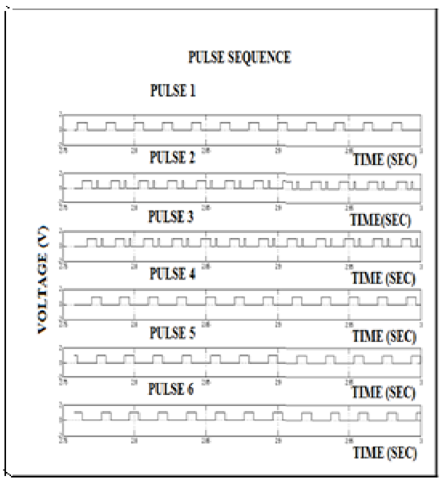

Fig .6 Pulses for the circuit

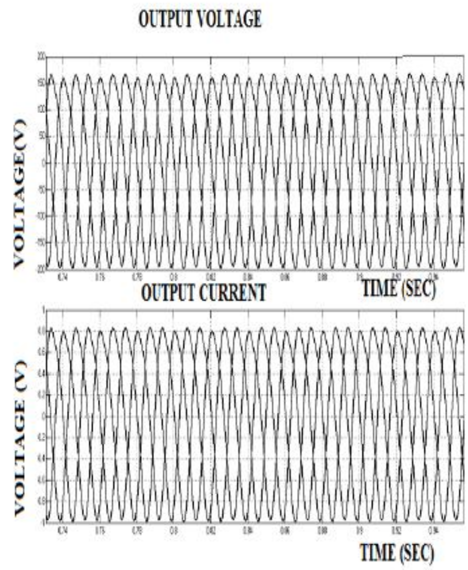

Fig.7 Output Voltage and Current waveform for Series inductance Z-Source inverter (V_o =155V)

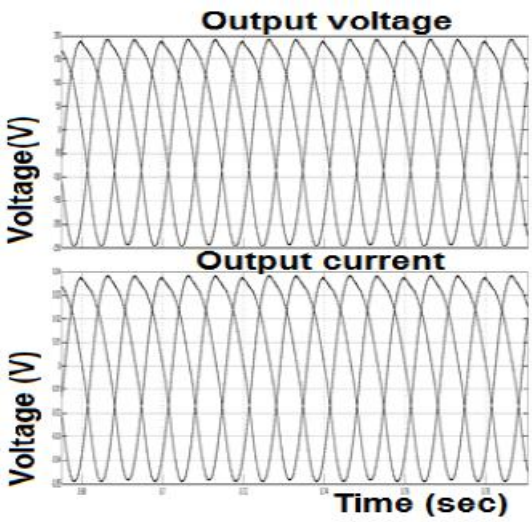

Fig.9 Output Voltage and Current waveform for Transformer base Z-Source inverter (V_o =185V)

VII.CONCLUSION

In this work, the 120 degree pulse generation circuit is developed and the gate pulses are generated for the inverter circuit. The Series Inductance Z-Source inverter is designed in MATLAB environment and the output voltage is measured to be 155V for an input of 24V. Then the Transformer-based Z-Source inverter is designed. The generated output voltage of 185V for the same input voltage of 24V as fed in the previous conditions. The operating modes of the proposed inverter and its realization are discussed. The voltage transfer ratios of these inverter circuits have been observed and tabulated. Both the inverter outputs are obtained by MATLAB/SIMULINK. Among these two inverters, the transformer based Z-Source inverter provides good performance in terms of maximum boost output voltage. The major advantages of this proposed inverter are low cost, reduced number of passive components, high efficiency, reduced stray inductance losses and no additional circuits needed to boost the output voltage, which is impossible in the traditional inverters.

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