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Design and Implementation of Z-Source Based Multilevel Inverter

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***Abstract*-Thispaper presents a novel Z-source based seven level multilevel inverter. It can be used to boost the output voltage of the inverter using shoot through state control techniques. A new technique has been produced by using three signals and a triangular carrier signal which are used to generate the PWM signals for switches of the inverter. The shoot through state for Z-source network has been achieved by inserting DC signal. The benefit of this Z-source network is to boost the output voltage and reduce the number of switching components, and this topology is suitable for applications working at lower and medium power levels. The performance of this Z-source based multilevel inverterisvalidated using MATLAB/SIMULINK software and the prototype of the same has been developed.**

***Keywords*-Multilevel inverter, Z-source network, Shoot through state, Non shoot through state, SPWM.**

I. INTRODUCTION

Multilevel inverter is a power electronic circuit which provides desired AC voltage level at the output using multiple lower level DC voltages as an input [11]. Generally a two-level inverter is used to generate the AC voltage from DC voltage [11]. A two-level inverter produces two different voltages for the given load i.e. suppose if we provide V_{dc} as an input to a two level inverter then it will provide + $V_{dc}/2$ and $-V_{dc}/2$ on output [11]. In order to produce an AC voltage, these two newly generated voltages are usually switched. For switching mostly PWM is used [11]. Although this method of producing AC voltage is effective but it has few drawbacks as it creates harmonic distortions in the output voltage and also has a high dv/dt as compared to that of a multilevel inverter [11]. Generally this method is commonly used but in few applications it creates problems particularly those where less distortion in the output voltage is required [11]. Hence, the concept of multilevel inverter is used where modification of two-level inverter is done. In multilevel invertersmore than two voltage levels are combined together and the output waveform thus obtained in this case has lower dv/dt and also has lower harmonic distortions. Smoothness of the output waveform depends upon the voltage levels, as the voltage level is increased, the output waveform becomes smoother but the complexity of controller circuit and components also increases along with the increased levels [11].

There are several topologies of multilevel inverters available. But there is difference in the method of switching and the source of input voltage to the multilevel inverters. Common ones are diode clamped, cascaded H - bridge, and modified H - bridge multilevel inverters[11].

In this paper, a Z-Source based seven level H-bridge multilevel inverter is proposed for PV systems. It employs Z-source network between the DC source and inverter circuit to achieve boost operation. The output voltage of proposed Z-source multilevel inverter can be controlled by using modulation index and shoot through duty cycle.Simulation of the circuit configurations have been performed in MATLAB/SIMULINK.

II. Z-SOURCE BASED MULTILEVEL INVERTER

The circuit diagram of Z-source based seven level multilevel inverter is shown in Fig.1.It has single-phase H-bridge inverter, Z-source impedances and DC voltage sources.DC sources can be obtained from batteries, fuel cells, solarcells. H-bridge Z-Source inverter can generate three different output voltages $+V_{in}$, 0, $-V_{in}$[2]. Output voltage can be higher than the input DC voltage when boost factor, B>1[2]. This topology has an additional switching state: shoot through zero state as compared to cascaded H-bridge inverters. During the shoot through zero state, the voltage across Z-source network becomes zero[2].

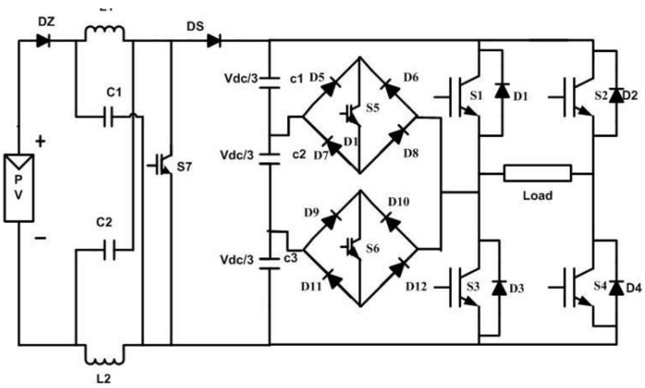

Fig.1:Circuit Diagram of Seven Level Z-Source MLI

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This paper presents the development of a novel modified H-bridge single-phase multilevel inverter that has two diode embedded bidirectional switches and a novel pulse width modulated (PWM) technique.

III. PRINCIPLE OF OPERATION

A. *Z-Source Network*

Fig. 2(a) shows the suggested basic unit of a proposed Z-source topology. This consists of a DCvoltage source, Z-source network with one switch S7 and Diode DS [1]-[2]. It can operate in two modes:non shoot through zero state and shoot-through zero state [12]. In the shoot-through zero state, switch S7 is on, diode DS is off and output voltage ofz-source network is zero. The shoot-through pulse is generatedby comparing a DC reference signal with the triangular carrier signal.

*1) Shoot-through zero state:*The equivalent circuit of shoot-trough state is shown in Fig. 2(b). With the analysis of circuit2(b), it can be expressed as:

$V_L = V_C$ (1)

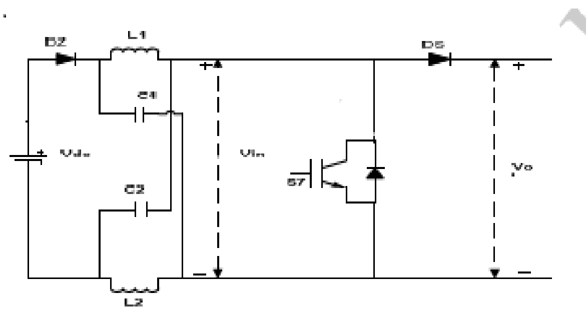
$V_{in} = 0$ (2)

*2) Non Shoot-through zero state:*The equivalent circuit in non-shoot through zero state is shown in Fig.2(c). Inductor voltage and output of Z-source LC network can be calculated as:

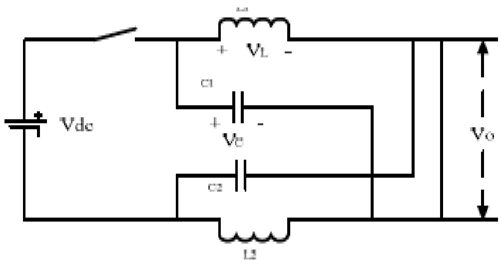
$V_L = V_{dc} - V_c$ (3)

$V_{in} = V_c - V_L$ (4)

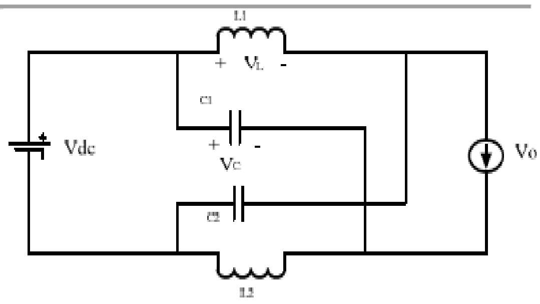
$V_{in} = 2V_c - V_{dc}$ (5)



(a)



(b)



(c)

Fig.2 Circuit diagram of (a) single phase proposed basic circuit, (b) basic circuit in shoot through state, (c) basic circuit in non-shoot through state.

Let's assume that average voltage of inductor is zero.Hence, relation between capacitor and output voltage is found as:

$$\frac{V_c}{V_{in}} = \frac{T_{ns}}{T_{ns}-T_{sh}} \quad (6)$$

Where T_{sh} is the total shoot-through state period and T_{ns} is the total non-shoot through state period during the period of switching. Substituting (7) in to (6) during non-shoot through state,V_{in} is obtained.

$$V_{in} = \frac{V_{dc}}{1-2\frac{T_{sh}}{T}} \quad (7)$$

$$B = \frac{1}{1-2\frac{T_{sh}}{T}} \quad (8)$$

Where T is period of switching and B is boost factor and it is clear that B > 1

TABLE I
Switches State and V_0 Value

State	Output Voltage(V_0)	Switches
1	Vin(Non Shoot-through)	S7 OFF, DS ON
2	0(Shoot-through)	S7 ON, DS OFF

B. *Multilevel Inverter Topology*

The proposed single-phase seven-level inverter is developed from the lower-level inverter [13]-[14]. It consists of a single-phase conventional H-bridge inverter, two bidirectional switches and a capacitor voltage divider formed by C1, C2, and C3 as shown in Fig.1. This modified H-bridge multilevel inverter topology is significantly advantageous over other topologies, i.e., less number of power switches, power diodes, and less capacitors for inverters of the same number of levels. Photovoltaic (PV) arrays are connected to the inverter via a single Z-source converter. Proper switching of the inverter can produce seven output-voltage levels (Vdc, 2Vdc/3, V dc/3, 0, −Vdc, −2Vdc/3, −Vdc/3) from the DC supply voltage.

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TABLE II
Switching States of ProposedInverter

V_0	S1	S2	S3	S4	S5	S6
V_{dc}	On	Off	Off	On	Off	Off
$2V_{dc}/3$	Off	Off	Off	On	On	Off
$V_{dc}/3$	Off	Off	Off	On	Off	On
0	Off	Off	On	On	Off	Off
0*	On	On	Off	Off	Off	Off
$-V_{dc}/3$	Off	On	Off	Off	On	Off
$-2V_{dc}/3$	Off	On	Off	Off	Off	On
$-V_{dc}$	Off	On	On	Off	Off	Off

IV. CONTROL TECHNIQUES

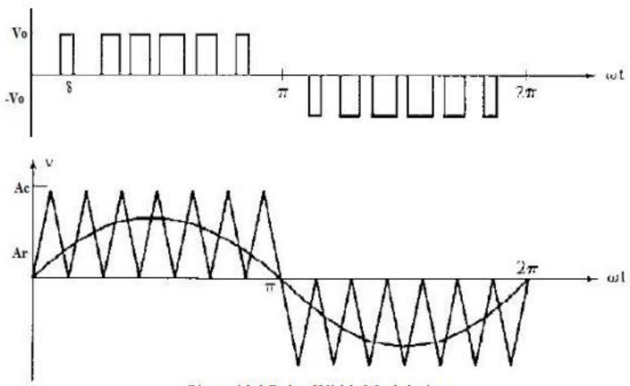
The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration which can be done by modulating the duty cycle [4]. Analog PWM control requires the generation of both reference and carrier signals that are feed to the comparator and based on some logical output, the final output is generated. The reference signal maybe sinusoidal or square wave, while the carrier signal is either a saw tooth or triangular wave at a frequency significantly greater than the reference. There are various types of PWM techniques. Among these, sinusoidal PWM is used for the proposed circuit topology [4].

A. Sinusoidal Pulse Width Modulation

In this modulation technique, there are multiple number of output pulses per half cycle and pulses are of different width. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the center of the same pulse. The gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal.
The RMSAC output voltage,

$$V_0 = V_g\sqrt{\frac{p\delta}{\pi}}$$

Where, p is the number of pulses and δ is the pulse width.



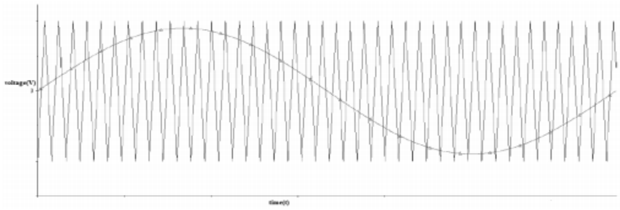
Sinusoidal Pulse Width Modulation

Fig.3 Circuit Diagram of SPWM

Features for comparing various PWM techniques are:

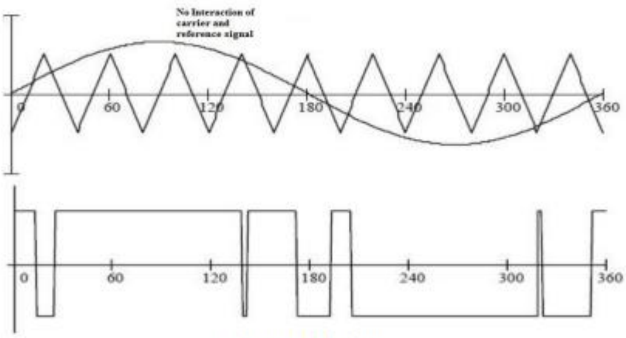
- Switching losses
- Linearity in voltage and current control
- Sine Wave Generation
- Harmonics contents in the voltage and current.

The most common and popular method of generating sinewave is by Pulse Width Modulation (PWM) method. Sinusoidal Pulse Width Modulation is the best technique for generating pure sine wave. This PWM technique generates a digital waveform, for which the duty cycle can be changed in such a way so that the average voltage waveform corresponds to a pure sine wave. The simplest and common method of producing the SPWM signal is through comparing a low power sine wave reference with a high frequency triangular wave. This generated sinusoidal PWM signal can be used to control switches. With an LC filter, the output of Full Wave Bridge Inverter with SPWM signal will generate a wave which is approximately equal to a sine wave. This method produces a more similar AC waveform than that of others. The primary harmonic is still present and there is relatively high amount of higher level harmonics in the signal.



SPWM comparison Signals
Fig.4 Circuit Diagram of SPWM Comparison Signals

Let the modulating signal is a sinusoidal of amplitude $A_m$and the amplitude of the triangular carrier is A_c, the ratio $M=A_m/A_c$ is known as Modulation Index (MI). Note that controlling the MI, controls the amplitude of the output voltage with a sufficiently high carrier frequency. A higher carrier frequency increases the number of switching per cycle and hence increased power loss.



Overmodulation
Fig.5 Circuit Diagram of SPWM with Over Modulation

There are periods of the triangle wave in which there is no intersection of carrier and the signal as shown in the fig.5. However, a certain amount of this “over modulation” is often allowed in the interest of obtaining a large AC voltage magnitude even though the spectral content of the voltage is poor.

B. SPWM Harmonic Elimination

The sinusoidal PWM waveform has harmonics of several orders in the phase voltage waveform. The dominant ones are the fundamental and other of the order of n and n±2 where n=fc/fm. With the method of Selective Harmonic Elimination, only selected harmonics are eliminated with the smallest number of switching [4].

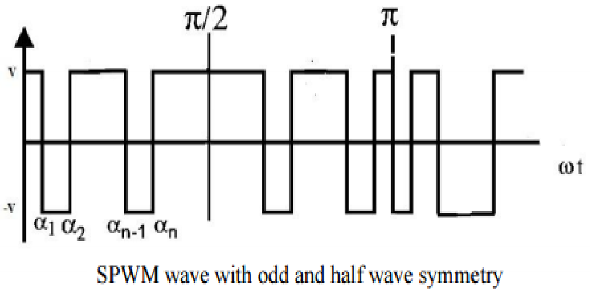


Fig.6 Circuit Diagram of SPWM with Selective Harmonic Elimination

V. RESULTS AND ANALYSIS

A. Simulation Results and Analysis

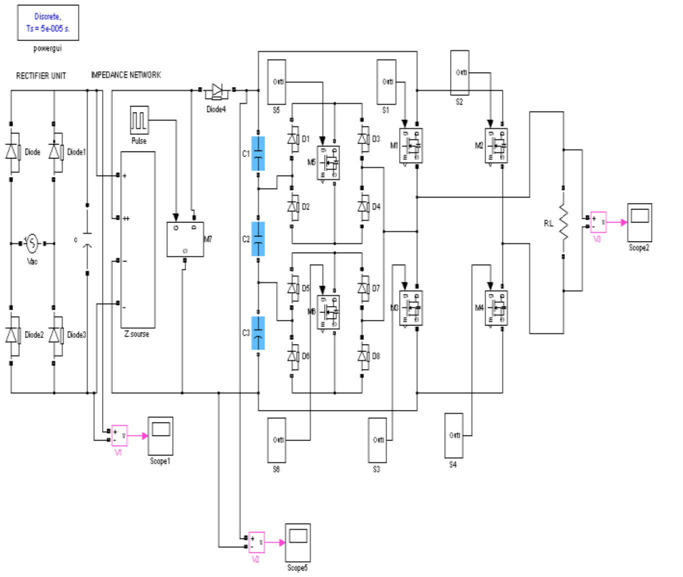


Fig.7 MATLAB Simulink Modelof Proposed ZSMLI

Fig.7 Shows matlab/simulink model of Z-Source based seven level MLI using PWM signal with boost factor 1.25. An AC voltage is given to the rectifier circuit which rectifies applied AC voltage into DC voltage. This rectified voltage is connected to the Z-source network. Z-source network boosts the DC voltage to higher level. Another advantage of this Z-source network is it reduces the number of switches and this configuration is suitable for applications working at lower and medium power levels. The boosted DC voltage is then given to the multi level inverter which produces AC voltage greater than input DC volatage to the Z-source network.

Case 1) Simulated waveforms for input DC volatage of 206V:

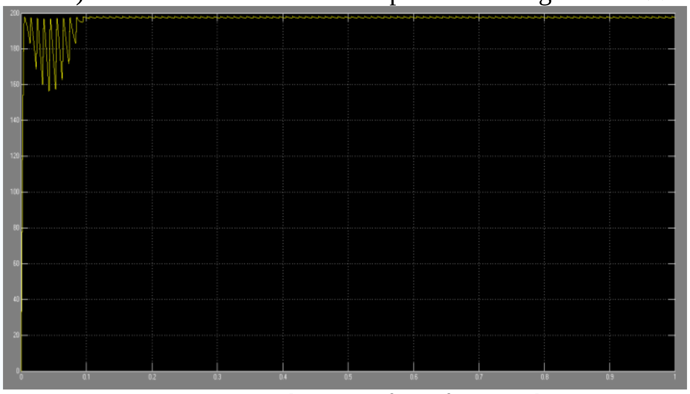


Fig.8 Input DC Voltage Waveform of Z-network

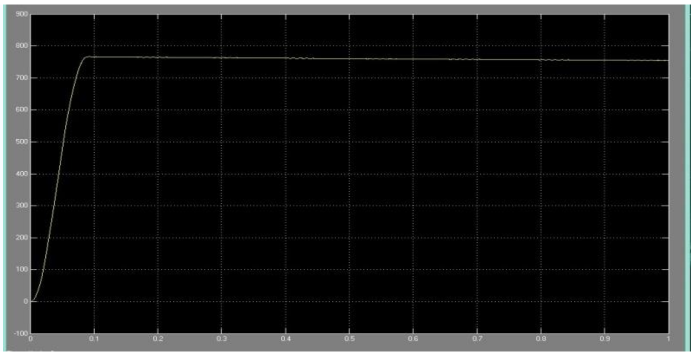


Fig.9 Output DC Voltage Waveform of Z-network

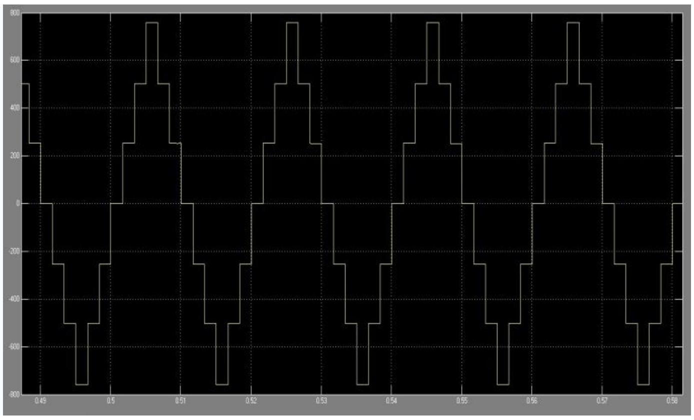


Fig.10 Output AC Voltage Waveform of ZSMLI

An input DC voltage of 206V shown in fig.8 is applied to Z-source network. Z-source network boosts the input DC voltage to 780V as shown in fig.9. DC boosted voltage of 780V from Z-Source network is applied to seven level multilevel inverter which converts 780V DC to 780V AC as shown in fig.10.

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Case 2) Simulated waveforms for input DC volatage of 236V:

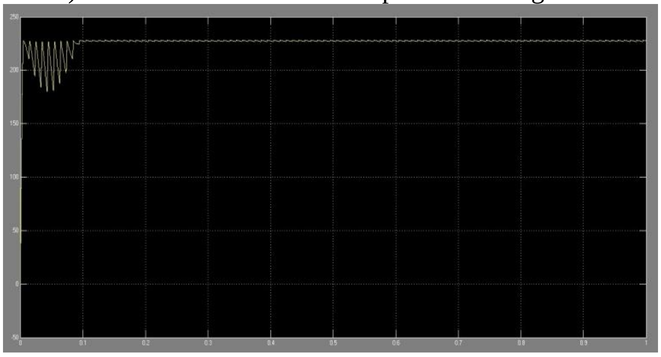

Fig.11 Input DC Voltage Waveform of Z-network

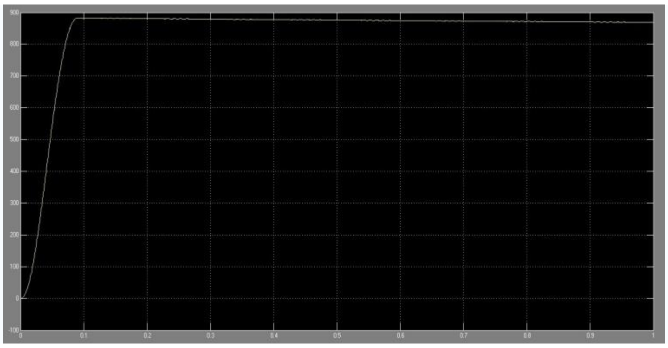

Fig.12 Output DC Voltage Waveform of Z-network

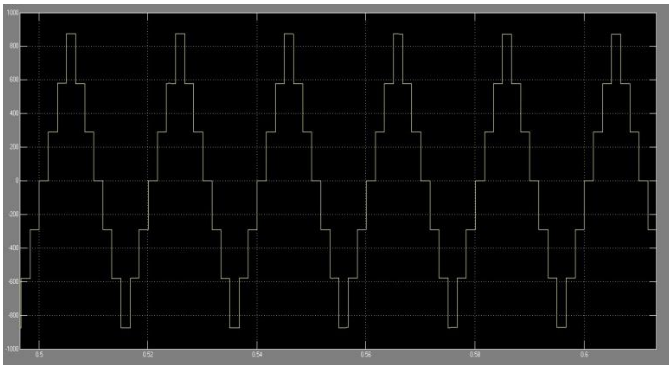

Fig.13 Output AC Voltage Waveform of ZSMLI

An input DC voltage of 236V shown in fig.11 is applied to Z-source network. Z-source network boosts the input DC voltage to 880V as shown in fig.12. DC boosted voltage of 880V from Z-Source network is applied to seven level multilevel inverter which converts 880V DC to 880V AC as shown in fig.13.

Case 3) Simulated waveforms for input DC volatage of 256V:

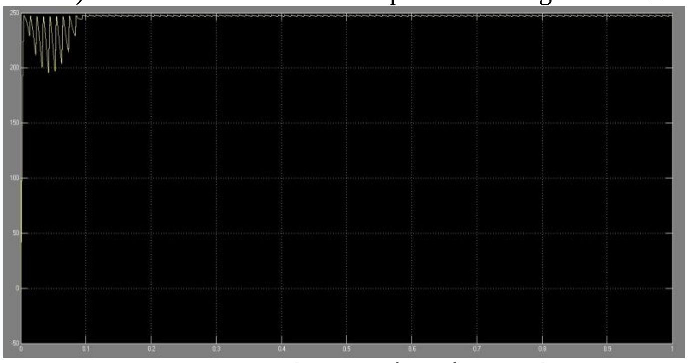

Fig.14 Input DC Voltage Waveform of Z-network

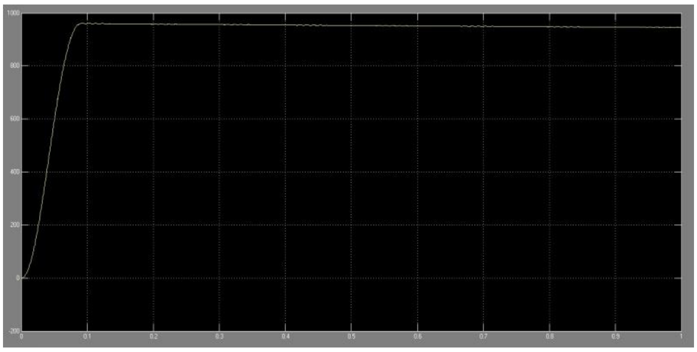

Fig.15 Output DC Voltage Waveform of Z-network

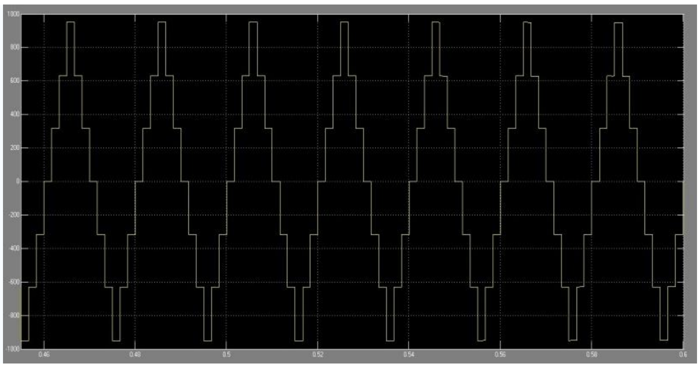

Fig.16 Output AC Voltage Waveform of ZSMLI

An input DC voltage of 256V shown in fig.14 is applied to Z-source network. Z-source network boosts the input DC voltage to 980V as shown in fig.15. DC boosted voltage of 980V from Z-Source network is applied to seven level multilevel inverter which converts 980V DC to 980V AC as shown in fig.16.

Hence, from the above results it can be observed that output AC voltage of a multilevel inverter can be more than input DC voltage by using a Z-source network at the input to the multilevel inverter. This Z-source network boosts the input

DC voltage to higher value. The table III gives the comparison of all the three cases mentioned above.

TABLE III
Comparison of All the Three Cases

Case	Rectifier input in V	Rectifier output in V	Z-source output in V	Multilevel inverter output in V
1	200 AC	206 DC	780 DC	780 AC
2	230 AC	236 DC	880 DC	880 AC
3	250 AC	256 DC	980 DC	980 AC

B. Experimental Results and Analysis

Fig.17Prototype of Z-Source Based Multi-Level Inverter.

The proposed prototype for Z-Source based seven level multilevel inverter is shown in above fig.14. In this prototype, a 230/12V step down transformer is used and the transformer secondary 12V AC supply is given to the input of the bridge rectifier. This rectifier converts 12V AC to 14.4V DC. This DC supply is given to the input of the Z-source network which then boosts the voltage. This boosted DC Voltage is given to the input of the multilevel inverter. Multilevel inverter converts boosted DC voltage to AC voltage. The output voltage of the multilevel inverter is 28.8VAC at required 50Hz frequency. Thus the output AC voltage of the multilevel inverter is more than the input DC voltage which can be achieved by boosting the input DC voltage through Z-source network.

In the above circuit, PIC microcontroller is used to generate pulses to the MOSFET switches. These pulses are given to the MOSFET switches through driver circuit. The experimental output waveform of the prototype is shown in fig. 18.

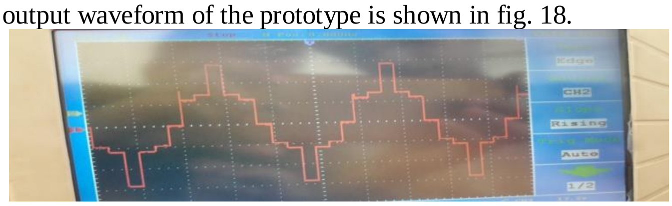

Fig.18 Experimental Output Waveform.

VI. CONCLUSION

In this paper the modeling and simulation of novel single phase Z-source based multilevel inverter is presented. The PWM switching signals are generated by comparing reference signals against a triangular carrier signal. The voltage level of input DC source is improved by using Z-source network & multilevel inverter. The proposed topology has minimum number of switches as compared to other configurations. In this paper the input DC voltage to the multilevel inverter is boosted by using Z-source network and hence, the output AC voltage of the multilevel inverter is more than input DC voltage. The proposed topology is proved through MATLAB simulation and hardware prototype.

REFERENCES

[1]J.Kohila, R.Munia Raj and Dr.S.Kannan*"Z-SOURCE MULTILEVEL INVERTER FOR PHOTOVOLTAIC APPLICATION"*, International Journal of Innovative Research in Science, Engineering and Technology Volume 3, Special Issue 3, March 2014.
[2]Anandkumar T, Kannan.C and Ponmanikandan P *"Z-Source Based Multi Level Inverter"*, International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 5, May - 2013 ISSN: 2278-0181.
[3] B. K. Bose, *"Energy, environment, and advances in power electronics,"IEEE Trans. Power Electron.*, vol. 15, no. 4, pp.688–701, Jul. 2000.
[4]Miaosen Shen, Stefan Hodek, Fang Z.Peng, *"Control of the Z-Source Inverter for FCHEV with the battery Connected to the Motor Neutral Point"*, Power Electronics Specialists Conference, pp. 1485-1490,2007 .
[5] Amitava Das, DebasishLahiri, A.K.Dhakar ,*"Residential Solar Power Systems Using Z-Source Inverter"*, TENCON, IEEE Regional 10 Conference, 2008.
[6] Jin Wang, Fang Z. Peng, Leon M. Tolbert, Donald J. Adams, *"Maximum Constant Boost Control of the Z- Source Inverter "* , Industry Application Conference, 39 th Annual meeting Conference Record, Vol.1,2004.
[7] J. Rodríguez, J. S. Lai, and F. Z. Peng, *"Multilevel inverters:A survey of topologies, controls, and applications,"IEEETrans. Ind. Electron.*, vol. 49, no. 4, pp. 724–738, Aug. 2002.
[8] J. Rodriguez, S. Bernet, B. Wu, J. O. Pontt, and S. Kouro, *"Multilevel voltage-source-converter topologies for industrial medium-voltage drives,"IEEE Trans. Ind. Electron.*, vol. 54, no. 6, pp. 2930–2945,Dec. 2007.
[9] M. M. Renge and H. M. Suryawanshi, *"Five-level diode clamped inverter to eliminate common mode voltage and reduce dv/dt in medium voltage rating induction motor drives,"IEEE Trans. Power Electron.*, vol. 23, no. 4, pp. 1598–1160, Jul. 2008.
[10] E. Ozdemir, S. Ozdemir, and L. M. Tolbert, *"Fundamenta frequency modulated six-level diode clamped multilevel inverter for three-phase stand-alone photovoltaic system,"IEEETrans. Ind. Electron.*, vol. 56, no. 11, pp. 4407–4415, Nov. 2009.
[11] www.theengineeringprojects.com Internet Source.
[12] P.C.Loh, F.Blaabjerg, and C.P. Wong, *"Comparative evaluation of pulse width modulation strategies for Z source neutral point clamped inverter,"* in proc. IEEEPESC'06, 2006, pp.1316-1322.
[13] G. Ceglia, V. Guzman, C. Sanchez, F. Ibanez, J. Walter, and M. I. Gimanez, *"A new simplified multilevel inverter topology for DC–AC conversion,"* IEEE Trans. Power Electron., vol. 21, no. 5, pp. 1311–1319, Sep. 2006.
[14] V. G. Agelidis, D. M. Baker, W. B. Lawrance, and C. V. Nayar , *"A multilevel PWMinverter topology for photovoltaic applications,"* in Proc. IEEE ISIE, Guimäes, Portugal, 1997, pp. 589–594.