Design and Development of Z-Source Multi-Level Inverter for Solar energy

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***Abstract*— Global warming and the shortage of fossil fuels have led to the development of renewable energy resources in order to satisfy the feature energy demand of depleting plant. Multilevel inverters compared to single level inverters have advantages like minimum harmonic distortion, reduced EMI generation. Multi-level inverter is energy conversion device that is generally used to in medium voltage and high power application. This paper proposed a new solar power generation system, which is composed of a Z-source network and a new seven level inverter. In this new seven level inverter topology with the decreased number of power switches and its modulation technique is introduced. In this way, the proposed solar system generates a sinusoidal output voltage. The salient features of the proposed seven level inverter are that only six power switches and this structure allows a reduction of the system cost and size. Effectiveness of proposed topology has been illustrated by analysis and simulation.**

***Index Terms*— Multi-level inverter, Power converter, Pulse width modulation, single-phase, Harmonics, H-bridge.**

I. INTRODUCTION

Global warming and the shortage of fossil fuels have led to the development of renewable energy resources in order to satisfy the feature energy demand of our depleting plant. Power electronics converters, especially pulse width modulation inverters have been expanding their range of use in industry because they provide abbreviate energy consumption and better system efficiency [1].

An abstract idea of multi-level converter has been proposed since 1975. The cascaded multi-level inverter was first introduced in 1975 [2]. The word multi-level is derived from the three-level converter [3]. Consequently, different multi-level inverter topology have been developed [4].

Diode-clamped multi-level inverter plans were proposed in 1981 [5]. Capacitor-clamped multilevel inverter were developed in 1992 [6] and during the year 1996 cascaded multi-level inverter were introduced [1], [7]. Recently, some new advanced topologies of multilevel inverters have emanated. These multilevel inverter can increase the inverters output voltage and power by increasing the number of voltage levels.

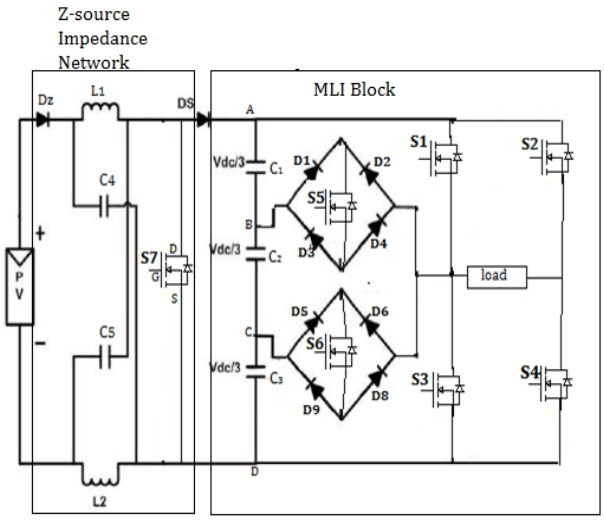

Fig .1. Proposed single-phase Z-source multi-level inverter.

A seven level multilevel inverter was originated with nine switches from the main traditional multilevel inverter [8]. It proposals seven level output with lower total harmonic distraction. A seven level multilevel inverter with seven switches with again reducing two more switches from the previous topology [9]. This paper describes the design and development of Z-source single phase multilevel inverter that consisting of Z-source impedance network, two bi-directional switches and a pulse width modulated technique.

This paper is divided as follows: section II describes the proposed topology with Z-source network and multilevel inverter topology. Section III shows the pulse width modulation technique. Section IV presents the MATLAB simulation results and in section V presents the conclusions of proposed multilevel inverter.

II. PROPOSED TOPOLOGY.

The proposed seven level multi-level inverter was derived from the 5-level inverter in [10]-[11]. The proposed multilevel inverter topology embraces a single-phase H-bridge inverter and bi-directional switches as shown in Fig.1.

A. Z-source network

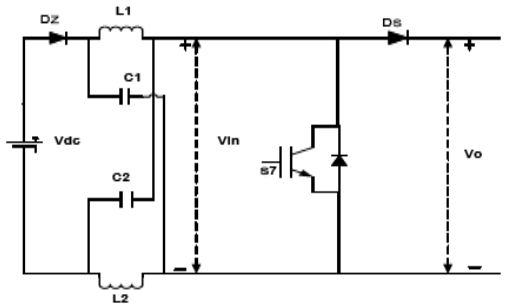

Fig. 2. Electrical Equivalent circuit model of Z-source module.

By using a unique LC network shown in fig (2). This Z-source module consisting of a DC source, Z-source impedance having two inductor and two capacitor, MOSFET and a unidirectional diode. Z-source impedance network can operate in two modes: one is Shoot through mode and another one is Non-shoot through stage.

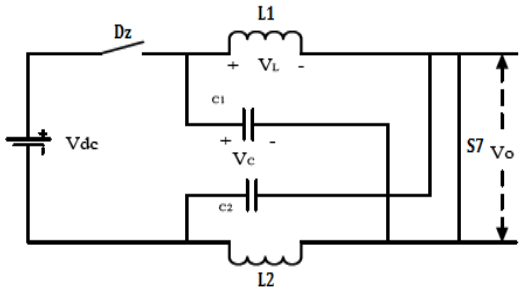

Fig.3. circuit diagram of shoot through mode.

In shoot through mode, unidirectional diode is in off state and switch is turn-on, the output voltage across the Z-source is zero is shown in Fig.3.

In this model

$$V_L = V_C \tag{1}$$

$$V_L / V_{in} = T_{ns} / (T_{ns} - T_{sh}) \tag{2}$$

Where

T_{sh} = Total Shoot Trough State Period

T_{ns} = Total Non-Shoot through State period

In non-shoot through mode, unidirectional diode is in on-state and switch is turn-off, the output voltage across the Z-source is boosted and circuit diagram is shown in Fig. 4.

In this mode of operation

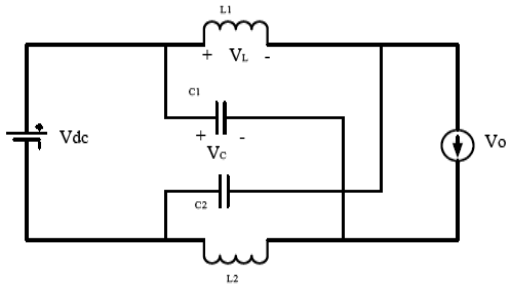

Fig. 4.Circuit diagram of Non-shoot through mode.

$$V_L = V_{dc} - V_C \tag{3}$$

Inductor voltage is

$$V_L = (1+B/2)V_{max} \tag{4}$$

Inductor value is

$$L = (V_L * T_o)/\Delta I \tag{5}$$

Capacitor value is presented by the equation (6)

$$C = (V_L * T_o)/\Delta V_C \tag{6}$$

Where V_L is the voltage across the inductor. B is the Modulation index. T_O is the shoot through period per switching cycle. Gating signal to the switch is generated by comparing a reference signal with the carrier signal. The complete circuit analysis and characteristic are present in [1].

B. Multi-level inverter topology.

The proposed single-phase seven level multilevel inverter was derived from the 5-level inverter. It comprises of a capacitor C_1, C_2, C_3 and H-bridge inverter can be used as voltage divider as shown in Fig.1.

The traditional H-bridge topology is representatively beneficial over other topology i.e. switch reduction in the topology and reduced number of diodes for an inverter of same level. Photo voltaic system was connected to the multi-level inverter through Z-source network and output of the Z-source network is connected to load. Power switching states of proposed inverter can obtained from seven different voltage levels

Table I. Switching states of proposed inverter

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

III. NOVEL PWM TECHNIQUE.

The gating signals were propagated by a pulse width modulation technique. The three reference waves (V_{ref1}, V_{ref2}, V_{ref3}) were correlated with a carrier wave is as shown in Fig.5. An each reference signal were checked with the carrier signal. If the signal V_{ref1} has exceed the maximum voltage of carrier signal, after V_{ref1} compared with carrier signal, reference signal (V_{ref2}) was correlated with the carrier signal until it had exceeded the peak voltage of carrier signal. Then, onwards reference signal (V_{ref3}) was correlated with the signal of the carrier wave until it reached null value. Once reference signal V_{ref3} signal has reached zero value, reference signal V_{ref2} signal would be correlated till it reached zero. Then, onward reference signal Vref1 were checked with carrier signal.

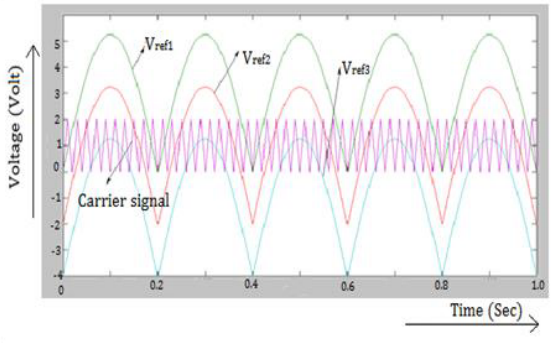

Fig. 5. Pulse Width Modulation signals.

IV. MATLAB SIMULATION RESULTS

The complete circuit diagram of Z-source single-phase multilevel inverter is shown in Fig.6. Z-source multilevel inverter consisting of photo voltaic array, Z-source impedance network, multi-level inverter and a load.

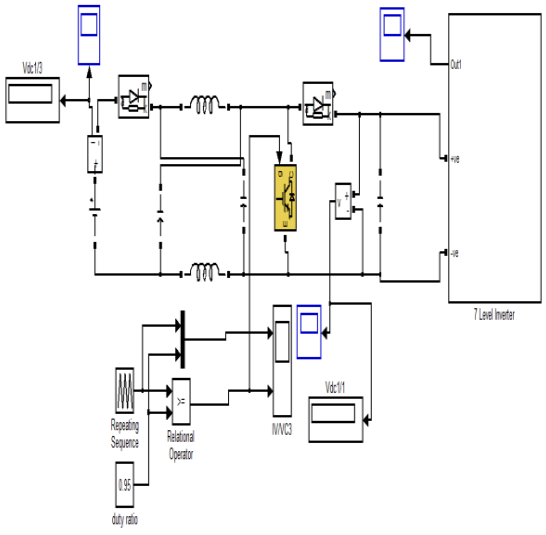

Fig .6. Complete circuit diagram of seven level inverter

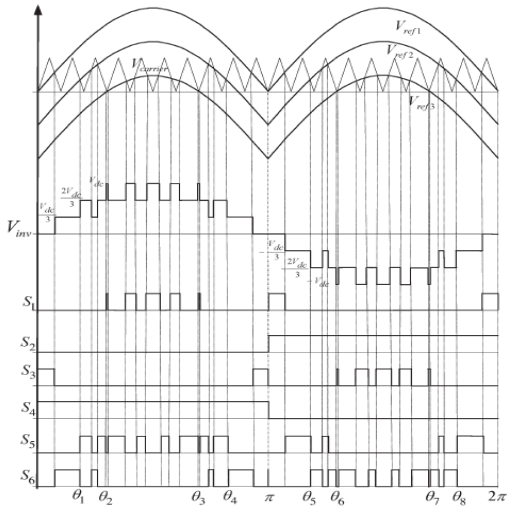

Fig.7. switching patterns of individual switches.

The switching patterns of individual switches are shown in Fig.7. The switch S_1 and S_3 are conducting for 180 degree. Switch S_1 is conducting for positive half cycle and Switch S_3 is conducting for negative half cycle.

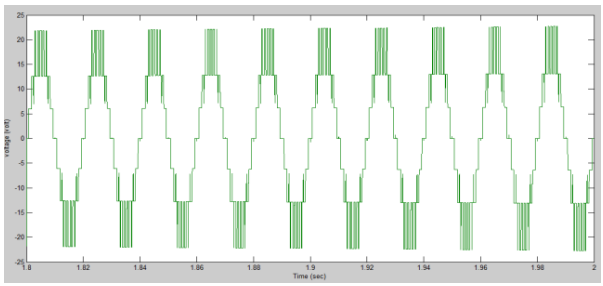

Fig.8. output voltage of single-phase Z-source inverter.

Output voltage of Z-source multi-level inverter is shown in fig.8. The rating of the proposed multilevel inverter is 40W, 23V, 8A, and 10 KHz. The multi-level inverter having a less total harmonic distortion [THD]. This result provides that, as the level of inverter goes on increases, the total harmonic distortion reduces, which is an important parameter for load connected to PV system.

V. HARDWARE RESULTS.

The experimental setup of the Z-source multi-level inverter is shown in Fig.9. It consists of multiple output power supply stage, converter stage, controller stage as shown in the experimental setup.

The result of the hardware model of the Z-source multilevel inverter is shown in Fig.10. The 5V DC voltage from solar energy is supplied to the input of Z-source impedance network. The Z-source impedance network is used to boost the input voltage from 5V DC to 24V DC. The output voltage of Z-source impedance network is connected to the input of multi-level inverter. The multilevel inverter converter 24V DC into 24VAC voltage.

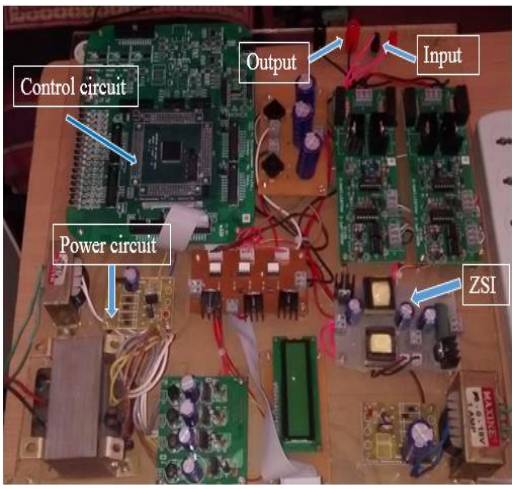

Fig.9.Experimental setup of Z-source multilevel inverter.

Fig 10. Hardware output result of Z-source multilevel inverter.

Table 2: Conduction of switches and output voltage for different levels

No of levels	Voltage Level	Switches are **ON**	Output Voltage
1	Zero	S_3 and S_4	0 V
2	$\frac{V_{dc}}{3}$	S_6 and S_4	6 V
3	$\frac{2V_{dc}}{3}$	S_5 and S_4	12.5 V
4	V_{dc}	S_1 and S_4	24 V
5	$\frac{-V_{dc}}{3}$	S_5 and S_2	-6 V
6	$\frac{-2V_{dc}}{3}$	S_6 and S_2	-12.5 V

VI. CONCLUSION

In this paper, the Z-source multi-level inverter was designed and implemented. The Z-source impedance network was used to boost the input voltage to the required output voltage level. An FPGA controller was used in the control circuit, to generate PWM gating signals for the switches in the inverter. This MLI employed only six switches and eliminating the use of clamping diode and capacitor. The design of proposed converter is successfully implemented and the experimental results observed closely match with the simulation values.

Photo voltaic system is connected to the Z-source impedance network. The Z-source impedance network boost the voltage from 5V DC to 24V DC. The multilevel inverter converts 24V DC to 24V AC. This MLI is operated in the voltage range of 24V-25V with full load current rating of 2A. A high quality output voltage with a THD of 2.74% was obtained.

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