

Z-SOURCE MULTILEVEL INVERTER FOR PHOTOVOLTAIC APPLICATION

Ms.J.Kohila^{#1} Mr.R.Munia Raj^{*2} Dr.S.Kannan^{#3}

^{#1} Department Of Electrical and Electronics Engineering, Kalasalingam University, India.

^{*2} Department Of Electrical and Electronics Engineering, Kalasalingam University, India.

^{#3} Department Of Electrical and Electronics Engineering, Kalasalingam University, India.

ABSTRACT - This paper presents Z-source multilevel inverter (ZS-MLI) for photovoltaic (PV) application. MLI possesses the advantage of higher power capability and can operate with higher voltage level. As the number of levels increases, the desired sinusoidal waveform can be obtained for lower total harmonic distortion (THD). MLI has a limitation, that it cannot boost the output ac voltage ($V_{\text{peak-ac}}$) greater than the dc voltage coming from the PV. Z-source network followed by the diode clamped multilevel inverter (DC-MLI) is used to boost up the output voltage to a desired value. Phase disposition pulse width modulation (PD-PWM) technique is used to generate the PWM signals for the inverter switches. The simulation of single phase, seven level Z-source DC-MLI is carried out using MATLAB/SIMULINK.

KEY WORDS— Diode clamped multilevel inverter, Phase disposition pulse width modulation, Photovoltaic, THD, Z-source inverter, Z-source multilevel inverter.

INTRODUCTION

In recent years, due to energy crisis, renewable energy sources, such as wind, photovoltaic (PV) and fuel cell are becoming more popular in industrial and residential applications. Today, PV cells are used in many applications due to the advantages like less maintenance, free from pollution and zero fuel cost. The electric energy generation using PV cell has grown consistently from 20% to 25% per annum over the past 20 years that is mostly because of the falling costs of PV cells [1]. This decline in cost has been driven by the following factors: i) improvement in manufacturing technology and hence an increase in efficiency of PV cells and ii) economy of scale [2].

In the conventional PV cell systems, a dc-dc boost chopper is utilized to increase the PV output dc voltage and an inverter is used to convert it into an ac voltage. In a traditional voltage source inverter (VSI), the two switches

of the same-phase leg should be switched ON at the same time because this cause a short circuit (shoot through of current), which would destroy the switches. In addition, the maximum output inverter voltage (V_{peak}) accessible can never exceed the dc bus voltage. Inverter generates a train of square wave voltage waveforms with different duty ratio.

These limitations can be overcome by the Z-source inverter (ZSI) [3]. In addition, the reliability of the inverter is greatly improved because the shoot through caused by Electro Magnetic Interference (EMI) noise can no longer destroy the circuit. ZSI is cheaper.

Nowadays, there are many applications for MLI, such as Flexible AC Transmission Systems (FACTS), High Voltage Direct Current (HVDC) transmission, Dispersed Generation (DG) systems and electrical drives. In some applications the converter connects one dc source to the network and in some other applications they can connect separate dc sources to the network.

There are different types of MLI, but three of them are important and used in industrial applications: capacitor clamped MLI, diode clamped MLI (DC-MLI) and cascaded MLI with separate dc sources. Each MLI consists of an array of power semiconductors and capacitors to generate an ac voltage. The proper switching permits the addition of capacitor voltages in the output port. This topology results in high voltage generation without stressing the semiconductors. In some cases, it is impossible to have several separate dc buses; or in some industrial applications, due to the economic considerations the power system must be designed just by one dc bus. MLI with large number of levels has the following merits: (i) The approximate sinusoidal output waveform, (ii) a smaller filter size and (iii) a lower EMI. The main advantage of using MLI is the low Total Harmonic Distortion (THD) in the output voltage because of multiple voltage levels and reduced stress on the switching devices [4].

In this paper, ZSI is employed instead of dc-dc boost chopper. The ZSI utilizes the impedance network between the dc source and inverter circuit to achieve the voltage boost operation. This paper is organized as follows: the P-V and I-V characteristics of PV module are provided in section II. Design and switching states of Z-source DC-MLI is presented in section III and its PWM strategy is discussed in section IV. Simulation results are shown in section V. Finally, section VI concludes the comparative study of DC-MLI with and without Z-source network.

II. PHOTOVOLTAIC MODULE

A PV cell is a device that converts light energy into electric energy using the PV effect. It produces dc power which fluctuates with the incident sunlight's intensity. For practical use, this usually requires conversion to desired ac voltages, through the use of inverters. Multiple solar cells are connected inside the module. Modules are wired together to form array, and then connected to an inverter, which produces ac power at the desired voltage, frequency and phase. The use of energy storage is optional in these grid-connected PV systems. In certain applications such as satellites, lighthouses, or in developing countries, batteries or additional power generators are often added as back-ups [5]. Such stand-alone power systems permit operations at night and at other times of limited sunlight. Figure 1 shows the simple design of PV module using Simulink. The subsystem of PV module contains 76 solar cells. One solar cell gives 0.5V. Hence 72 solar cells are connected in series, so that the output voltage is 36V. The P-V and I-V characteristics of PV module are shown in figures 2 and 3.

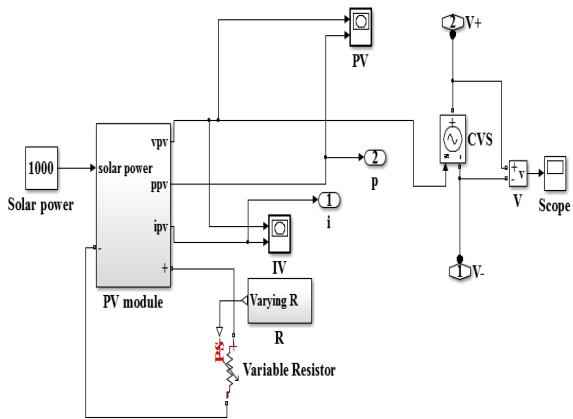


Fig. 1 PV module - Simulink

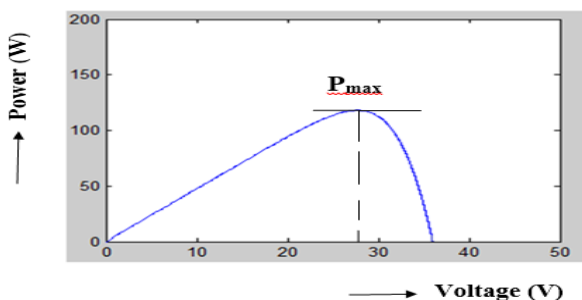


Fig. 2 P-V characteristics

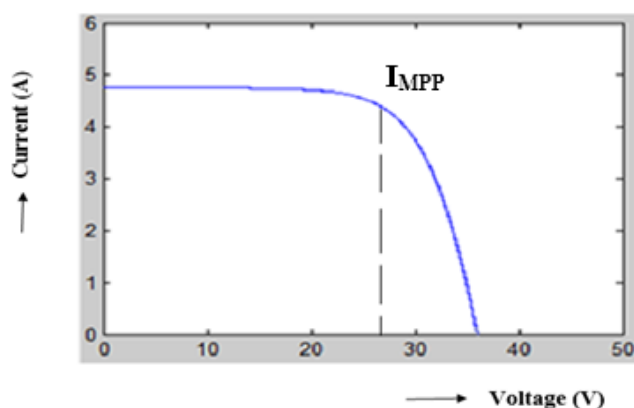


Fig. 3 I-V characteristics

In the P-V characteristics, as the voltage increases, the power increases upto P_{max} . After reaching the maximum power point (MPPT), the voltage increases and the power decreases. In the I-V characteristics, as the voltage increases, the current needs to be maintained at a constant value. After reaching the MPPT, the voltage increases and the current decreases.

III. Z-SOURCE MULTI LEVEL INVERTER

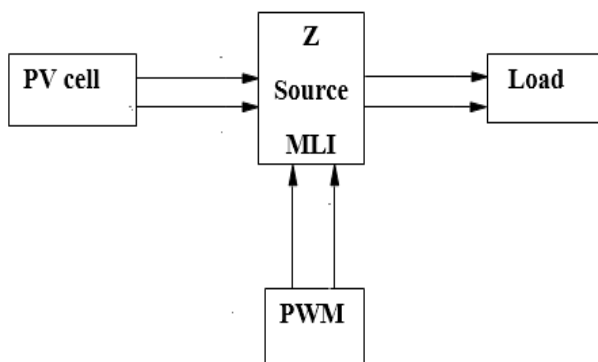


Fig. 4 Block diagram of Z-source MLI

Figure 4 shows the block diagram of ZS-MLI. The PV cell has the low voltage, but the MLI requires higher input voltage. So the Z-source network is used here. Because it boost up the input voltage.

Figure 5 shows the two-port network that consists of inductors (L_1, L_2) and capacitors (C_1, C_2) connected in X shape to provide an impedance source (Z-source) which couples the inverter to the dc source. The ZS-MLI utilizes the shoot through state to boost the input dc voltage of an inverter when both switches in the same phase leg are on. The ZS-MLI is cheaper, reliable, less complex and highly efficient.

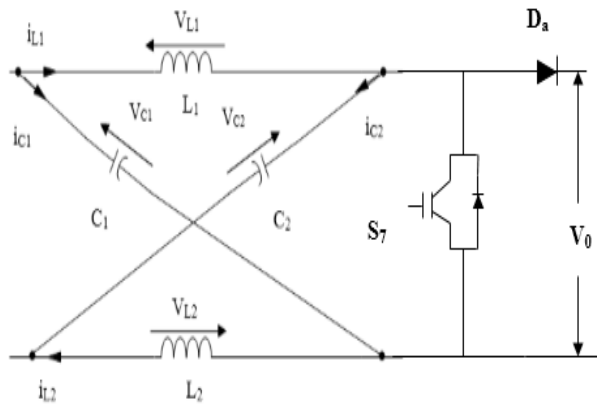


Fig. 5 Z-Source Network

The Z-source network makes the “shoot-through zero state” possible, and it provides the unique buck-boost aspect to the inverter [6]. The Z-source inverter can be operated in two modes which are explained below.

i) Shoot through mode:

In the shoot-through state, switch S_7 is on and diode D_a is off. The equivalent circuit of shoot-through state is shown in Figure 6. The circuit analysis can be expressed as:

$$V_L = V_C \quad (1)$$

$$V_{in} = 0 \quad (2)$$

ii) Non shoot through mode:

The equivalent circuit of non-shoot-through mode is shown in Figure 7. Output of LC network and inductor voltage can be calculated as:

$$V_L = V_{dc} - V_C \quad (3)$$

$$V_{in} = V_C - V_L \quad (4)$$

$$V_{in} = 2V_C - V_{dc} \quad (5)$$

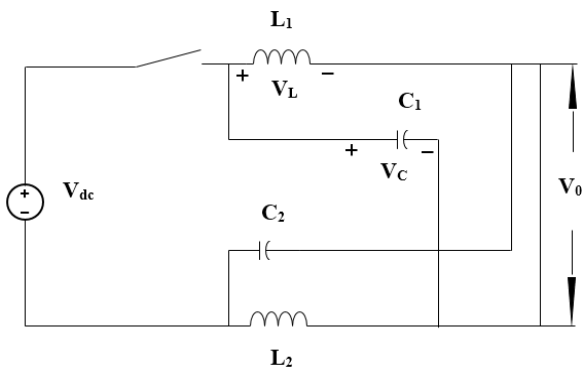


Fig. 6 Equivalent circuit of shoot through mode

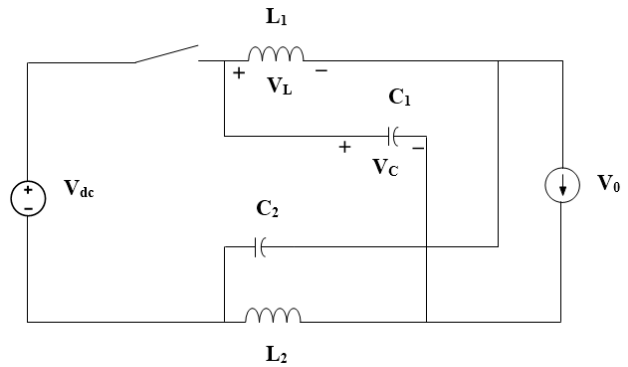


Fig. 7 Equivalent circuit of non shoot through mode.

It is assumed that the average voltage of inductor is zero. So the relationship between capacitor and output voltages is found as:

$$\frac{V_C}{V_{in}} = \frac{T_2}{T_2 - T_1} \quad (6)$$

Where, T_1 is the total shoot through state period and T_2 is the total non shoot through state period during the period of switching.

$$B = \frac{1}{\left(1 - \frac{2T_1}{T}\right)} \quad (7)$$

The boost factor B is determined by the Modulation Index (MI). The shoot-through zero state does not affect PWM control of the inverter. Because, it produces equivalently the same zero voltage to the load terminal, the offered shoot-through period is limited by the MI.

Advantages of ZSI are as follows: (i) increase or decrease of the voltage for energy processing, (ii) reduces the failure switching and EMI distortions, (iii) provides ride-through during voltage sags without any additional circuits, (iv) improved power factor, (v) reduced harmonic current, (vi) reduced common-mode voltage, (vii) cheaper, (viii) reliable and (ix) highly efficient for single stage buck and boost conversions [7].

Figure 8 shows the seven level ZS-MLI, which delivers the staircase output voltage using several levels of dc voltages developed by input dc capacitors. MLI is a switching converter where the appropriate control of an arrangement of switching devices allows combining diverse input voltages to synthesize a sinusoidal output voltage waveform. If m is the number of output voltage level, then the number of capacitors required across the dc bus is $(m-1)$, the number of power electronic switches per phase is $2(m-1)$ and the number of diodes per phase is $2(m-2)$. The dc bus voltage is split into seven levels using six capacitors. The voltage across each capacitor is $V_{dc}/6$ and the voltage stress across each switch is limited to one capacitor voltage through clamping diodes.

IV. PHASE DISPOSITION OF MULTICARRIER PWM STRATEGY

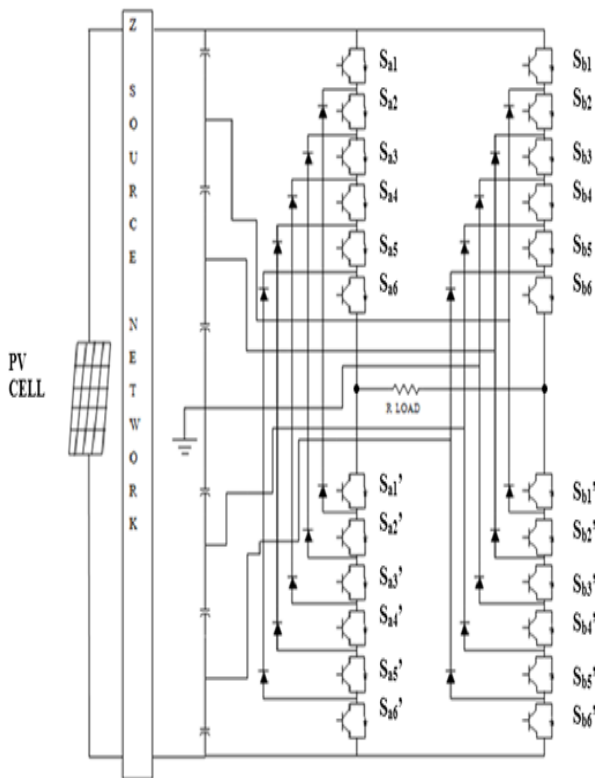


Fig. 8 Seven level Z-source diode clamped multilevel inverter

As the number of levels increases the THD decreases and the efficiency of the inverter increases because of the reduced switching losses. The number of levels in MLI is limited because of the large number of clamping diodes required. It is the drawback of MLI.

TABLE-I SWITCHING STATES FOR PHASE A

V	S _{a1}	S _{a2}	S _{a3}	S _{a4}	S _{a5}	S _{a6}	S _{a1'}	S _{a2'}	S _{a3'}	S _{a4'}	S _{a5'}	S _{a6'}
V ₁	0	0	0	0	0	0	1	1	1	1	1	1
V ₂	0	0	0	0	0	1	1	1	1	1	1	0
V ₃	0	0	0	0	1	1	1	1	1	1	0	0
V ₄	0	0	0	1	1	1	1	1	0	0	0	0
V ₅	0	0	1	1	1	1	1	1	0	0	0	0
V ₆	0	1	1	1	1	1	1	0	0	0	0	0
V ₇	1	1	1	1	1	1	0	0	0	0	0	0

Multicarrier PWM strategy is a widely adopted modulation strategy for MLI. It is like the sinusoidal PWM strategy [8]. Multicarrier PWM is one in which, several cycle of triangular carrier signals are compared with one cycle of sinusoidal modulating signal. The number of carriers are necessary to produce m -level output is $(m-1)$. All carriers have the same peak to peak amplitude A_c and same frequency f_c . The reference waveform has peak to peak amplitude of A_m and a frequency f_m . The reference is always compared with each of the carrier signals and whenever the reference is greater than the carrier signal, a pulse is generated [9]. The formula to find the amplitude of MI is as follows:

$$m_a = \frac{2A_m}{(m-1)A_c}$$

The frequency ratio

$$m_f = \frac{f_c}{f_m}$$

In Phase Disposition PWM (PD-PWM) strategy for m -level inverter, $(m-1)$ carriers with the same amplitude A_c and same frequency f_c are positioned. If the reference wave is more than a carrier signal, then the active devices equivalent to that carrier are switched on; otherwise, the devices are switched off [10]. Figure 9 shows the arrangement of carrier and modulation signals of PDPWM strategy.

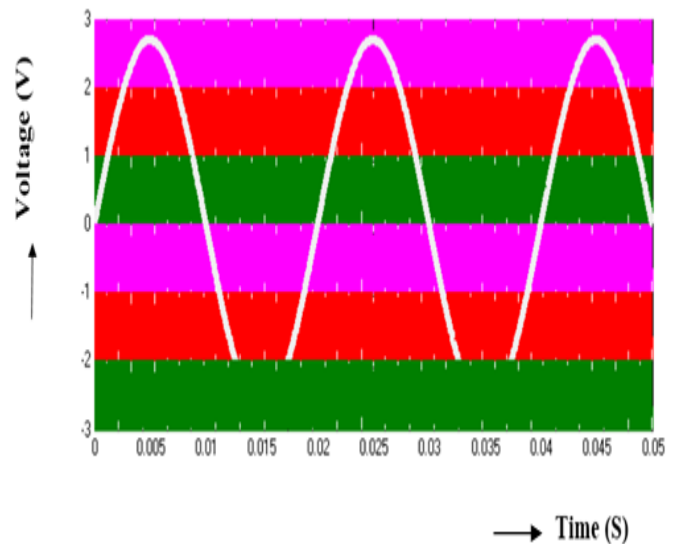


Fig. 9 Phase Disposition PWM Strategy

V. SIMULATION RESULTS

The following parameter values are used for simulation: PV cell voltage = 36 V, $C_1 = C_2 = 2600 \mu F$, $L_1 = L_2 = 10 \text{ mH}$ for Z- source network, $C = 1000 \text{ mF}$, R

(load) = 100Ω, for MLI, $f_c = 10000$ Hz and $f_m = 50$ Hz. The Z-source DC-MLI was modeled in SIMULINK. Switching signals for DC-MLI using PDPWM strategy was carried out. Figure 10 shows the output voltage of MLI. Figure 11 shows the FFT plot for the output voltage of MLI. Figure 12 shows the output voltage of ZS-MLI. Figure 13 shows the FFT plot for the output voltage of ZS-MLI.

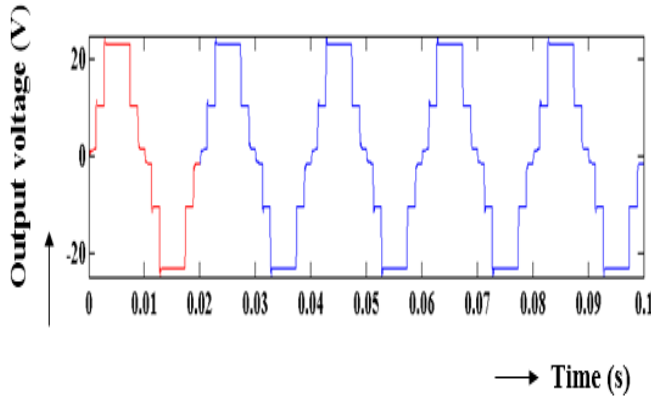


Fig. 10 Output voltage of MLI

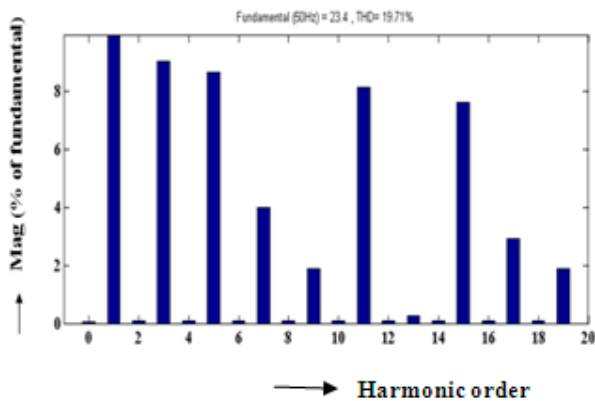


Fig. 11 FFT plot for the output voltage of MLI

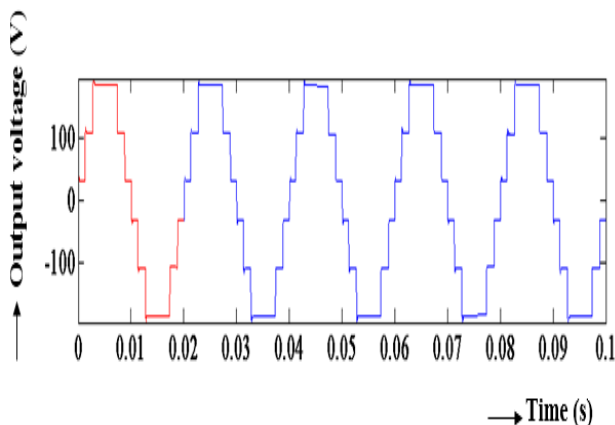


Fig. 12 Output voltage of ZS-MLI

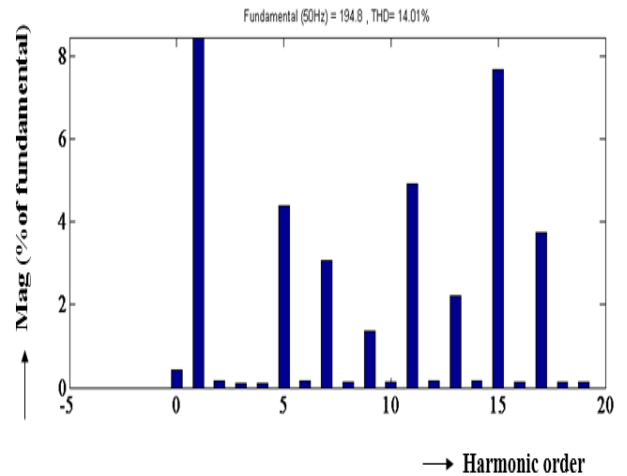


Fig. 13 FFT plot for the output voltage of ZS-MLI

Table II. COMPARISON OF MLI AND Z- SOURCE MLI

Type of Inverter	Input voltage (V)	Output voltage (V)	Total Harmonic Distortion (%)
MLI (seven levels)	35.8	18.46	19.71
ZS-MLI (seven levels)	35.8	142.7	14.01

VII. CONCLUSION

In this paper, Z-source seven level diode clamped inverter for PV application have been presented. ZS-MLI gives higher output voltage through its Z-source network. The PWM signals are made by comparing one reference signal with six carrier signals. By using Z-source network along with MLI, the PV cell voltage is improved. It is found that the ZS-MLI provides higher output voltage and lower %THD than the seven level MLI

REFERENCES

- [1] T.Anand kumar, C.Kannan and P.Ponmanikandan, "Z-Source based multilevel inverter," International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, vol.2, no.5, May 2013.
- [2] S. Rajakaruna and Y.R.L. Jayawickarma, "Designing Impedance Network of Z-Source Inverters," in Proceedings IPEC'05, vol.2, pp. 962-967, 2005.
- [3] F.Z.Peng, "Z-Source Inverter," IEEE Trans. on Industrial Application vol.39, no.2, pp.504-510, Mar./Apr. 2003.
- [4] Sergio Busquets, "Multilevel Diode Clamped Converter for photovoltaic generators with independent voltage control of each solar array," IEEE Trans. on Industrial Electronics, vol.55, no.7, July 2008.
- [5] Trishan Eeram, Patrick L.Chapman, "Comparison of photovoltaic Array Maximum Power Point Tracking Techniques," IEEE Trans. on energy conversion, vol.22, no.2, June 2007.

- [6] 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.
- [7] C.L.Kuppuswamy and T.A. Raghavendiran, "A Novel Z source Neutral Point Clamped Multilevel Inverter for Non Linear Loads," *International conference on Mechanical, Electronics and Mechatronics Engineering (ICMEME'2012) Mar. 17-18, 2012 Bangkok.*
- [8] P.C.Loh, S.Y.Feng, F. Blaabjerg and K.N.Soon, "Pulse width modulated Z source neutral point clamped inverter," IEEE Trans. on Ind. Appl., vol.43, no.5, pp.1054-1061, Sep./Oct. 2007
- [9] Y.Huang, M.Shen and F.Z.Peng, "A Z-source inverter for residential photovoltaic systems," IEEE Trans. Power Electron., vol.21, no.6, pp.1776-1782, Nov. 2006.
- [10] V.Arun and B.Shanthi, "Performance Evaluation of Multicarrier SPWM Strategies for Three Phase Z-Source Seven Level Diode Clamped Inverter," *International Journal of Engineering Trends and Technology (IJETT)*, vol.4, no.6, Jun. 2013.