Indonesian Journal of Electrical Engineering and Computer Science
Vol. 6, No. 1, April 2017, pp. 1 ~ 8
DOI: 10.11591/ijeecs.v6.i1.pp1-8

Z–Source Multilevel Inverter Based On Embedded Controller

K. Vijayalakshmi*, C. R. Balamurugan
Arunai Engineering College, Thiruvannamalai, Tamil Nadu, India
*Corresponding author, e-mail: drcrb2015@gmail.com

Abstract

In this paper Embedded based Z-source multilevel inverter (ZSMLI) is proposed. This work implements a five level cascaded H-bridge Z-source inverter by using embedded control. Switching devices are triggered using embedded controller. In this controller coding is described by using switching table. The presence of Z-source network couples inverter main circuit to the power source that providing special features that can overcome the limitations of VSI (voltage source inverter) and CSI (current source inverter). The Z-source concept can applicable in all dc-ac, dc-dc, ac-dc and ac-ac power conversions. Simulation model of Z-source multilevel inverter based on embedded controller has been built in MATLAB/SIMULINK.The Performance parameters of Z-source MLI such as RMS (Root Mean Square) output voltage, THD (Total Harmonic Distortion) and DC component have been analysed for various inductance (L) and capacitance (C) value.

Keywords: *Z-source multilevel inverter, embedded controller, RMS, THD, DC component*

1. Introduction

To overcome the limitations of traditional multilevel inverter, in this paper Z-source multilevel inverter is proposed. It comprised by Z-source network and multilevel inverter topology. Multilevel inverter has a unique structure they are specially suited for applications which need low THD. Multilevel inverter is a power electronic device built to synthesize a desired AC output voltage from several DC voltage sources. Multilevel inverter not only can generate the output voltage with very low distortion, but also can reduces the the Electromagnetic Compatibility Problems (EMC). Proper selection of pulses in the Z-source MLI can limit the THD in the output voltage.

Cascaded multilevel inverters have been developed for electric utility applications. This paper provides features and control schems of the cascaded multilevel inverter for utility applications including renewable energy, VAR compensation, voltage regulation and harmonic filtering in power systems [1]. The Z source inverter can overcome the limitations of both VSI and CSI. It reduces line harmonics, improves power factor and high reliability [2]. The method of triangular carrier switching control of two level inverters is extended for the cascaded multilevel inverter controlled systems [3]. This paper presents a survey of different topologies, control strategies and modulation techniques of cascaded multilevel inverter [4]. The performance of Z-source multilevel inverter have been analysed and simulation results are presented using MATLAB/SIMULINK. The output voltage can be boosted with Z-network shoot through state control [5].

Z-source seven level diode clamped inverter for photovoltaic applications have been presented. Higher output voltage is obtained through its Z-source network [6]. The system configuration and operating principle of voltage source inverter fed STATCOM system have been presented [7]. The performance of the multilevel inverter controlled by using the embedded controller.These proposed topologies producing the high quality output which is nearer to the sinusoidal waves [8].The proposed cascaded multilevel inverter is controlled by using digital and embedded controller. It used to reduce the total harmonic distortion (THD) in the output voltage [9]. To boost the voltage there are many maximum power points tracking (MPPT) methods are introduced [10]. To overcome the limitations of conventional Z-source inverter, the performance analysis of Z-source multilevel inverter have been presented using three level NPC inverter [11]. Isolated and non-isolated dc-power supply based three phase

Received December 1, 2016; Revised February 5, 2017; Accepted March 5, 2017

half-bridge MLI are investigated [12]. It presents the design and implementation of z-source inverter which demonstrates the boosting capability [13]. Z-source inverters are a new breed of inverters. This paper discusses the latest development in the field of Z-source inverters [14]. A new topology for switched Z-source inverter is proposed. The performance of the proposed inverter in different operating modes is investigated and also compared with conventional Z-source inverter [15]. Design and implementation of a DSP based induction motor drive using hybrid multilevel inverter is discussed in this paper.It focusing mainly on THD [16]. Z-source based balanced capacitor multilevel inverter is proposed with a single source and single impedance network. Balancing capacitor is used to balance the voltage across all capacitors [17]. This work implements a different topologies and control strategies employed for the operation of multilevel inverter. Advantages and disadvantages of the topologies in relation to one another are equally reviewed [18]. Presence of LC impedeance in network embedded Z-source inverter overcomes all theoretical and practical barriers of conventional VSI and CSI. It provides desired AC output voltage, reduces the harmonics and improves the power factor [19].
A FPGA Based Design and Validation of Asymmetrical Reduced Switch Multilevel Inverter are proposed [20]. Developed a Genetic Algorithm Application in Asymmetrical 9-Level Inverter [21].

2. Proposed Topology

Z-source multilevel inverter based on embedded controller is modeled in simulink model. The proposed topologies are simulated using MATLAB/SIMULINK.

2.1. Multilevel Inverter based on Embedded Controller

The main feature of a multilevel inverter is its ability to reduce the voltage stress across on each power device due to the utilization of multiple DC sources. The multilevel inverter can create an output near sinusoidal waveform and reduces the switching losses. The cascaded multilevel inverter is to use capacitors and switches and requires less number of components in each level.Cascaded multilevel inverters are formed by the series connection of two or more H-bridge inverters. Each module is connected to its own DC source to produce an AC voltage.

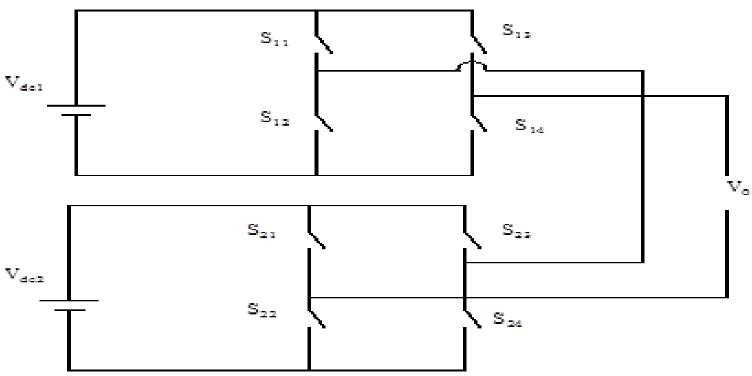

Figure 1. Cascaded multilevel inverter

To achieve a five level output two distinct DC sources are considered. Each module can generate three different output voltage $+V_{dc}$, 0,$-V_{dc}$.This topology does not require any transformer or clamping dioides or flying capacitors. Power circuit of cascaded multilevel inverter is shown in figure 1. It comprising eight switches in order to produce five level output.

Embedded controllers are the heart of an industrial control system or a process control application. To trigger the pulses the embedded controller codings are used. Coding is made by using switching table. The coding is developed with the help of MATLAB software.

```
function y = fcn (u)
a = mod (u*1000, 10);
b= mod (u*1000, 20);
if a<1.2 %0
```

```
 p5=1;
 p6=0;
 p7=1;
 p8=0;
 p9=0;
 p10=1;
 p11=0;
 p12=1;
elseif a<3.1 %3
 p5=1;
 p6=1;
 p7=0;
 p8=0;
 p9=0;
 p10=1;
 p11=0;
 p12=1;
elseif a<7.2 %4
 p5=1;
 p6=1;
 p7=0;
 p8=0;
 p9=1;
 p10=1;
 p11=0;
 p12=0;
elseif a<9.1 %5
 p1=1;
 p2=1;
 p3=0;
 p4=0;
 p5=0;
 p6=1;
 p7=0;
 p8=1;
else %0
 p5=1;
 p6=0;
 p7=1;
 p8=0;
 p9=0;
 p10=1;
 p11=0;
 p12=1;
end
if b<10
y=[p5,p6,p7,p8,p9,p10,p11,p12];
else
0y=[p7,p8,p5,p6,p11,p12,p9,p10];
end
```

The performance of embedded based multilevel inverter is analysed by simuation using MATLAB/Simulink. The input voltages of this system V_{dc1} and V_{dc2} are 100V.The value of R load assumed to be 10 ohms. Figure 2 represents the output voltage of five level inverter using embedded controller without filter. The synthesized output waveform has more steps. Figure 3 shows the THD plot for five level inverter based on embedded controller without filter. The Total Harmonic Distortion, which is a measure of closeness in shape between a waveform and its funadamental component. Figure 4 displays the output voltage of five level inverter with filter arrangement. Figure 5 shows the THD plot of five level inverter based on embedded controller with filter.

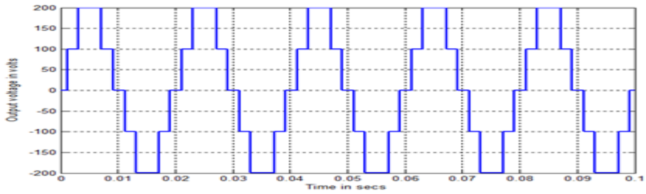

Figure 2. Output voltage of five level inverter using embedded controller without filter

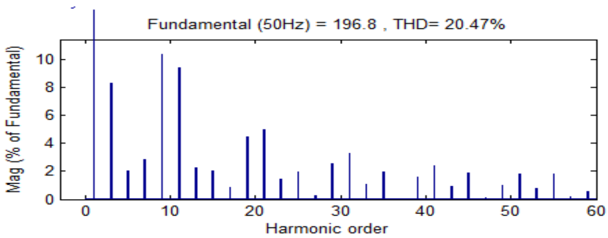

Figure 3. THD plot for five level inverter based on embedded controller without filter

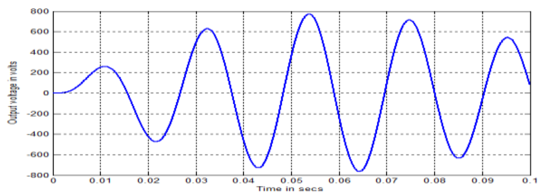

Figure 4. Output voltage of five level inverter based on embedded controller with filter (L=3mH, C=4700µF)

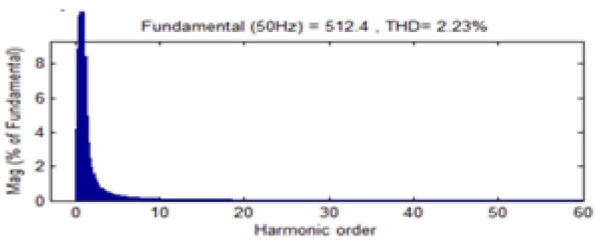

Figure 5. THD plot for five level inverter based on embedded controller with filter (L=3mH, C=4700µF)

2.2. Z-Source Multilevel Inverter based on Embedded Controller

In order to eliminate the limitations of traditional multilevel inverter in this section Z source multilevel inverter is proposed. It consists of impedance network and multilevel inverter. In traditional multilevel inverter output voltage is equal to the input voltage and hence boosting of input voltage is not possible. But in Z-source multilevel inverter proper adjustment of shoot through time period of pulses the voltage can buck or boost the input voltage. Z-source inverter utilize shoot through state when the load terminals are shorted through both the upper and lower devices of same phase leg. In this ZSMLI, switching devices are triggered based on embedded controller. Figure 6 represents the circuit diagram of Z-source multilevel inverter.

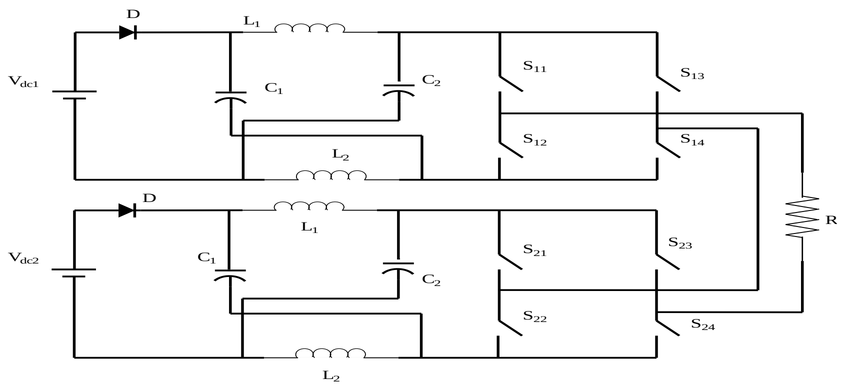

Figure 6. Circuit diagram of Z-source multilevel inverter

Z-source network implemented using a split inductor and two shunt capacitors connected in an X-shape structure. The proposed topology has an extra switching state. This state is also known as shoot through state. During the shoot through state, the diode connented in series with the DC source is reversing biased and output voltage of impedance network is zero. During non-shoot through state the diode is forward biased and the impedance network is connected with the DC source. The capacitors in the impedance network are being charged and the inductor act as an additional current source. Z-source inverters as compared to traditional inverters are less costly, more reliable, less complex and more efficient. In addition to cascaded multilevel inverter advantages proposed configuration employs Z-source inverter advantages. Performance of ZSMLI is analysed for four different inductance (L) and capacitance (C) Values by using MATLAB/Simulink. Table 1 show the chosen L and C values. Figure 7 displays the output voltage of Z-source MLI without filter. Figure 8 represents the THD plot for Z-source MLI without filter. Figure 9 and 11 represents the output voltage and THD plot of Z-source MLI with filter.

Table 1. Chosen L and C Values

Sl.No	Inductance(H)	Capacitance(F)
1	3mH	4700µF
2	3mH	470µF
3	160 µH	1000 µF
4	250 µH	500µF

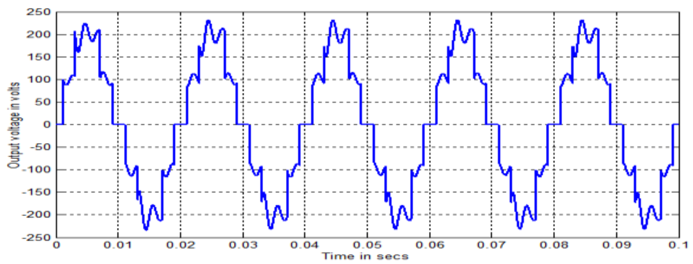

Figure 7. Output voltage across ZSMLI without filter (Impedance network L=250µH, C=500µF)

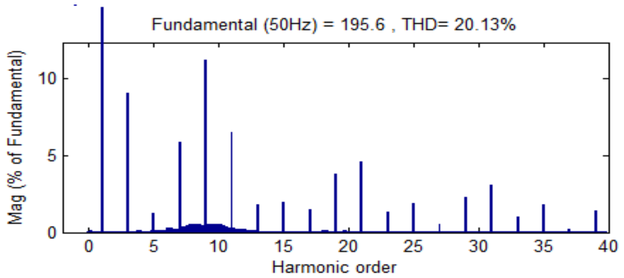

Figure 8. THD plot for ZSMLI without filter (Impedance network L=250µH, C=500µF)

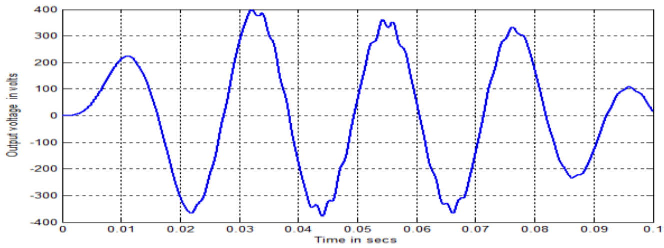

Figure 9. Output voltage across ZSMLI with filter (Impedance network L=250µH and C=500µF)

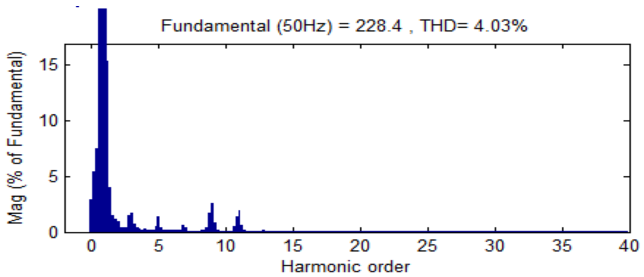

Figure 10. THD plot for ZSMLI with filter (Impedance network L=250µH and C=500µF)

3. Measurement across MLI and ZSMLI

Z-source multilevel inverter based on embedded controller using R load can be modeled in simulink model by using power system block set. Switching signal for MLI developed using embedded controller. The corresponding output voltage and THD is observed by using FFT analysis.

The measured RMS voltage, Total harmonic distortion (THD) and DC component in the output waveform of embedded controlled multilevel inverter and embedded controlled Z-source multilevel inverter is shown in below tables. Table 2 shows the measurement across MLI based on embedded controller. Table 3 represents the measurement across ZSMLI based on embedded controller.

Table 2. Measurement across MLI based on embedded controller

Measured parameters	Without filter	With filter
RMS (V)	139.2 V	362.3 V
THD (%)	20.47 %	2.23 %
DC component	0.01999	21.43

Table 3. Measurement across ZSMLI based on embedded controller

L and C values	Without filter			With filter		
	RMS (V)	THD (%)	DC Component	RMS (V)	THD (%)	DC Component
L=3mH, C=4700μF	137.5	21.11	0.5097	332.6	8.66	27.83
L=3mH,C=470μF	112.9	45.20	0.7418	28.74	28.24	0.5911
L=250μH, C=500μF	138.3	20.13	0.09104	161.4	4.02	6.608
L=160μH,C=1000μF	134.8	23.79	0.2197	125.5	8.42	0.689

Table 4 shows the odd harmonic contents in the proposed MLI and Z-source MLI topology. Table 5 shows the even harmonic contents in the proposed MLI and Z-source MLI topology.

Table 4. Odd harmonic contents in the proposed MLI and Z-source MLI topology

Harmonic order	MLI without filter based on embedded controller	MLI with Filter based on embedded controller	Z-source MLI without filter based on embedded controller	Z-source MLI with filter based on embedded controller
1	100%	100%	100%	100%
3	8.33%	0.77%	9.05%	1.67%
5	2.05%	0.32%	1.25%	1.37%
7	2.82%	0.21%	5.90%	0.40%
9	10.43%	0.12%	11.27%	2.61%
11	9.42%	0.10%	6.52%	1.89%
13	2.28%	0.09%	1.76%	0.07%
15	2.03%	0.08%	1.99%	0.07%
17	0.83%	0.07%	1.45%	0.03%
19	4.50%	0.06%	3.82%	0.08%
21	4.98%	0.05%	4.57%	0.05%
23	1.46%	0.05%	1.29%	0.02%
35	2.00%	0.04%	1.87%	0.02%
27	0.29%	0.04%	0.52%	0.02%
29	2.58%	0.04%	2.26%	0.02%
31	3.32%	0.03%	3.38%	0.02%
33	1.11%	0.03%	1.01%	0.01%
35	1.95%	0.03%	1.81%	0.02%
37	0.04%	0.03%	0.19%	0.01%
39	1.60%	0.03%	1.41%	0.02%

Table 5. Even harmonic contents in the proposed MLI and Z-source MLI topology

Harmonic order	MLI without filter based on embedded controller	MLI with filter based on embedded controller	Z-source MLI without filter based on embedded controller	Z-source MLI with filter based on embedded controller
2	0.01%	1.94%	0.05%	0.96%
4	0.02%	0.48%	0.11%	0.23%
6	0.02%	0.25%	0.30%	0.12%
8	0.01%	0.16%	0.56%	0.09%
10	0.02%	0.12%	0.54%	0.06%
12	0.01%	0.10%	0.20%	0.07%
14	0.02%	0.08%	0.05%	0.04%
16	0.02%	0.07%	0.06%	0.03%
18	0.01%	0.06%	0.09%	0.03%
20	0.02%	0.06%	0.07%	0.02%
22	0.01%	0.05%	0.08%	0.02%
24	0.02%	0.05%	0.04%	0.02%
26	0.02%	0.04%	0.02%	0.02%
28	0.01%	0.04%	0.04%	0.02%
30	0.02%	0.04%	0.03%	0.02%
32	0.01%	0.03%	0.05%	0.02%
34	0.02%	0.03%	0.03%	0.01%
36	0.02%	0.03%	0.02%	0.01%
38	0.01%	0.03%	0.03%	0.01%
40	0.02%	0.03%	0.02%	0.01%

4. Conclusion

In these paper embedded controller based cascaded multilevel inverter and Z-source multilevel inverter are proposed. The important advantage of multilevel inverter is the number of output voltage levels will be increased. The total harmonic distortion value of proposed embedded controlled multilevel inverter is 20.49%. It can be reduced to 2.23% by using LC filter (L=3mH, C=4700µF) in the load side. Performance of Z-source based multilevel inverter topology is analysed for various L and C values. In ZSMLI total harmonic distortion is reduced up to 4.02% by using 250µH and 500µF values in impedance network. The order of harmonics 3^{rd}, 9^{th}, 11^{th}, 19^{th} and 21^{st} are dominant in multilevel inverter based on embedded controller without filter. In Z-source based multilevel inverter based on embedded controller the order of harmonics 3^{rd}, 7^{th}, 9^{th}, 11^{th},19^{th} and 21^{st} are dominant.

References

[1] Peng Fang–Zen, Qian Zhao-ming. Applications of Cascaded Multilevel Inverters. *Journal of Zhejiang University Science*. 2003; 4(6): 658-665.

[2] B Justus Rabi, R Arumugam. Harmonic Study and Comparision of Z-Source Inverter with Traditional Inverter. *American Journal of Applied sciences*. 2005; 2(10): 1418-1426.

[3] Rajesh Gupta, Arindam Ghosh, Avinash Joshi. Switching Characterization of Cascaded Multilevel-Inverter-Controlled Systems. *IEEE Transactions on Industrial Electronics*. 2008; 55(3): 1047-1058.

[4] Mariusz Malinowski, K Gopakumar, Jose Rodriguez, Marcelo A Perez. A Survey on Cascaded Multilevel Inverters. *IEEE Transactions on Industrial Electronics.* 2010; 57(7): 2197-2206.

[5] Surya Suresh Kota, Vishnu Prasad Muddineni, Adithya Kumar Dadibonia, Gopilatha Venna. Simulation and Analysis of Novel Cascaded Z Source Inverter. *International Journal of Advances in Engineering and Technology*. 2013; 5(2): 207-215.

[6] J Kohila, R Munia Raj, S Kannan. Z Source Multilevel Inverter for Photovoltaic Applications. *International Conference on Innovations in Engineering amnd Technology*. 2014; 3(3): 492-497.

[7] Venkata Kishore P, S Rama Reddy. Embedded Controlled Multi Level Voltage Source Inverter Based Distribution Statics Synchronous Compensator. *American Journal of Applied Sciences*. 2014; 11(8): 1201-1211.

[8] S Sivasankari, CR Balamurugan. Embedded Controlled Based Multilevel Inverter Topologies. *Electrical and Electronics Engineering: An International Journal*. 2014; 3(2): 81-89.

[9] CR Balamurugan, SP Natarajan, S Shama, R Bensraj. Embedded and Digital Controller Based Multi Level Inverter. *International Journal of Hybrid Information Technology.* 2015; 8(3): 367-374.

[10] Navdeep Singh. Z Source Inverter: Comparative Analysis. *International Journal of Advanced Reasearch in Electrical, Electronics and Instrumentation Engineering.* 2016; 5(1): 401-408.

[11] Deepshikha, Rahul Kumar. Performance Analysis of Multilevel Z-Source Inverter using Three Level NPC Inverter. *International Journal of Current Engineering and Technology.* 2016; 6(3): 891-896.

[12] Md Mubashwar Hasan, A Abu-Siada, Md Rabiul Islam. Design and Implementation of a Novel Three Phase Cascaded Half-Bridge Inverter. *IET Power Electronics*. 2016; 9(8): 1741-1752.

[13] Mahmooda Mubeen. Design of Z-Source Inverter for Voltage Boost Application. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering.* 2016; 4(2): 136-140.

[14] Himanshu, Rintu Khanna, Neelu Jain. A Survey on Various Topologies of Z-Source Inverters. *SSRG International Journal of Electrical and Electronics Engineering*. 2016; 3 (7): 5-9.

[15] Ebrahim Babei, Elias Shokati Asl, Mohsen Hasan Babayi and Sara Laali. Developed Embedded Switched-Z-Source Inverter. *IET Power Electronics*. 2016; 9 (9): 1-29.

[16] DP Mageshwari, AS Pandya. Development and Implementation of Emedded DSP Controllers for Cascaded H-Bridge Multilevel Inverter based Drive*. International Journal of Current Engineering and Technology.* 2016; 6(5): 1805-1810.

[17] BM Manjunatha, K Shaguftha Zabeen, A Suresh kumar. Z-Source Multilevel Inverter with Enchanced Performance. *IJCTA*. 2016; 9 (29): 197-212.

[18] [18] Gaddafi Sani Shehu, Abdullahi Bala Kunya, Ibrahim Haruna Shanono and Tankut yalcinoz. A Review of Multilevel Inverter Topology and Control Techinques. *Journal of Automation and Control Engineering.* 2016; 4(3): 233-241.

[19] Chakor Atmaram Munjaji, Tamhane. *An Embedded Z-Source Inverter Feed based Industrial Adjustable Speed Drives.* International Conference on Electrical, Electronics and Optimization Techniques. 2016; 966-971.

[20] C Bharatiraja, Harshavardhan Reddy, Sunkavalli Satya Sai Suma, N SriRamsai. FPGA Based Design and Validation of Asymmetrical Reduced Switch Multilevel Inverter. *IJPEDS.* 2016; 7(2): 340–348.

[21] Rachid Taleb, M'hamed Helaimi, Djilali Benyoucef, Zinelaabidine Boudjema. Genetic Algorithm Application in Asymmetrical 9-Level Inverter. *International Journal of Power Electronics and Drive System.* 2016; 7 (2): 521–530.