Modelling and Implementation of Single-Phase Z-Source Inverter using Arduino

Hafsa, B.Venkateswararao, Gummadi Srinivasa Rao, Ch. Ganesh

***Abstract**: This paper presents a single-phase Z-Source Inverter simulation and hardware implementation using Arduino. Z-Source converter uses single stage conversion topology to provide both voltage boost and buck operations. It activates boost property by using shoot-through state that cannot be found in conventional voltage source and current source inverters. The switches of the same phase leg can be switched on using shoot-through state. This improved Z-source technology utilizes less number of switches and increases efficiency of the inverter with less cost. Simulation is done in MATLAB Simulink. Both simulation and hardware results are compared.*

***Index Terms**: Arduino, Current Source Inverter, Voltage Source Inverter and Z-Source Inverter.*

I. INTRODUCTION

Inverter is a power conditioning circuit that converts dc voltage to ac voltage with the help of switching devices. Inverters are used in different applications at homes and also in industries for the efficient usage of electric power. Generally, there are two types of inverters commonly in use: Voltage Source Inverter (VSI) and Current Source Inverter (CSI) [1]. Both inverters can be used as only buck or boost type converters. So, output voltage is limited. For both boost and buck type operations, an additional conversion stage should be utilized for both VSI and CSI. Because of this additional stage, structure becomes complex which further increases cost and reduces efficiency. In voltage source inverter, the two switches of same phase leg cannot be turned on at the same time to avoid short circuit because of which whole inverter may be damaged. So, dead time is included in VSI. This dead time causes output waveform distortion. In Current source inverter one switch in upper part and another switch in lower part of any leg should be turned on to avoid open-circuit problem. So, overlap time is required to eliminate damage of inverter. Here also, the output waveform distortion occurs [2, 3].

Toeliminate the problems in both conventional inverters, a new single-stage power conversion topology, Z-source (Impedance source) inverter was proposed. ZSI can buck or boost the voltage up to required range that cannot be provided by the voltage source and current source inverters. With the presence of Z-source network, the voltage is boosted by using shoot-through state. So, dead time is eliminated and efficiency of the system is improved. Impedance source inverter can be used in all different types of power conversion concepts.

Revised Manuscript Received on December 28, 2018.

Hafsa, UG student, Department of EEE, V R Siddhartha Engineering College (Autonomous), Vijayawada, Andhra Pradesh, INDIA

B.Venkateswara rao, Associate Professor, Department of EEE, V R Siddhartha Engineering College (Autonomous), Vijayawada, Andhra Pradesh, INDIA

Gummadi Srinivasa Rao, Associate Professor, Department of EEE, V R Siddhartha Engineering College (Autonomous), Vijayawada, Andhra Pradesh, INDIA

Ch. Ganesh, UG student, Department of EEE, V R Siddhartha Engineering College (Autonomous), Vijayawada, Andhra Pradesh, INDIA

II. LITERATURE SURVEY

In March 2003 [4], Fang ZhengPeng has proposed a new power conversion concept called Impedance source Inverter. It uses Z-source network consisting of inductors and capacitors to beat the limitations of Voltage source and current source inverters. Three-phase Z-source inverter operation is explained for fuel cell applications with PWM control method. Simulation and experimental results with and without using shoot-through state are also presented in this paper. In 2014 [5], Sattyendrasing A. Seragi presented a single-phase Z-source inverter operating principle with and without shoot-through state. Switching states of single-phase ZSI have been explained. Z-source inverter has been compared with traditional voltage source and current source inverters for different features. In 2016 [6], MeeraMurali et al., have presented single phase Z-source inverter for resistive load. Simulation of Z-source network has been done for different duty ratios. Hardware of Z-source inverter has been made for with and without shoot-through condition. Both simulation and hardware results are compared. In 2017, Mrudul A. Mawlikar and Ms. Sreedevi S. Nair [7] have presented comparative analysis of single-phase Z-Source inverter and DC-DC converter fed Voltage source inverter for RL load. Operating principle of voltage source inverter and Z-source inverter has been explained. Simulation of both voltage source and Z-source inverters is done and results are compared.

In this paper, single-phase Z-source inverter is simulated in MATLAB-Simulink with sinusoidal PWM technique and also with pulse generators. Shoot-through states are included in both SPWM technique and with pulse generators. Hardware circuit is constructed with Microcontroller Arduino to switch on the MOSFETs used in the inverter. Hardware results are made with and without shoot-through state. Both simulation and experimental results are presented.

III. PROPOSEDSYSTEM

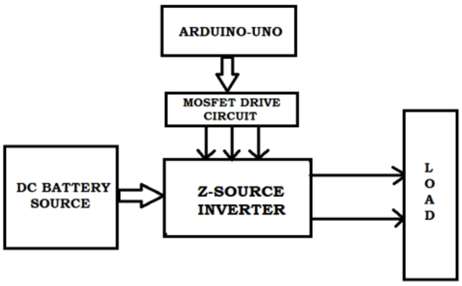

Fig. 1. Block Diagram of proposed system.

Proposed system topology consists of Battery, Z-source inverter, Arduino, MOSFET drive circuit and load.

- Battery: The dc input is supplied from the battery to the Z-source network for boosting the voltage.
- Z-Source Inverter: It is the combination of Z-source network and single phase H-bridge inverter.
- Z-Source Network: It is an X-shaped network of two inductors and two capacitors to provide boosting of input dc voltage to desired level required by the inverter.
- Single-Phase Inverter: It consists of four semiconductor switches in the form of H-bridge. It converts the boosted dc voltage to required ac voltage.
- Arduino: Arduino is an ATMEGA328 Microcontroller board which gives faster response. It is used to generate gate pulses to the inverter switches using PWM pins with the threshold voltage of +5V.
- MOSFET Drive Circuit: By using Arduino, the threshold voltage is in the order of +5Volts, but for faster switching, it should be around +15Volts. So, by using gate drive circuit, turn-on and turn-off times of switches are increased.
- Load: The load can be inductive or capacitive in case of Z-source inverter.

IV. Z-SOURCE INVERTER

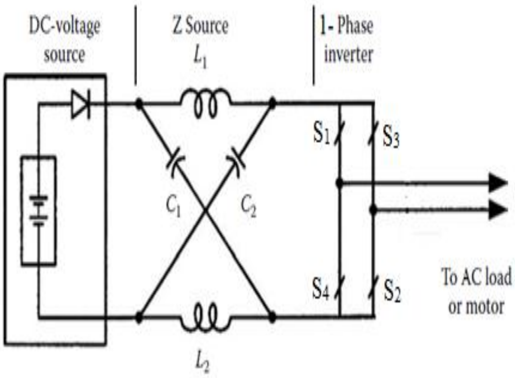

Fig. 2.Single-Phase Z-Source Inverter.

The general structure of single-phase Z-Source inverter is shown in the Fig. 2. Z-source inverter boosts the voltage employing distinctive impedance network which cannot be seen in Voltage source and Current source inverters. Impedance network connects the dc source and the load. Impedance network is a two-port network consisting of inductors, capacitors and a diode in order to boost the dc voltage to required level using shoot-through state. ZSI utilizes single-stage power conversion topology to buck or boost the voltage which is the special feature that overcomes the limitations of two-stage converters. During shoot-through state, the boosting of voltage occurs and appears at next active state.

Shoot through state means both the switches in the same phase leg are switched on or all the switches can be on to form a short path at the same time. For suppose from the below Fig. 3, gate pulses applied to MOSFETs S1 and S2 is shown first and gate pulses applied to S3 and S4 is shown second. Then, finally shoot-through state is shown where all the MOSFETs are switched on at the same time.

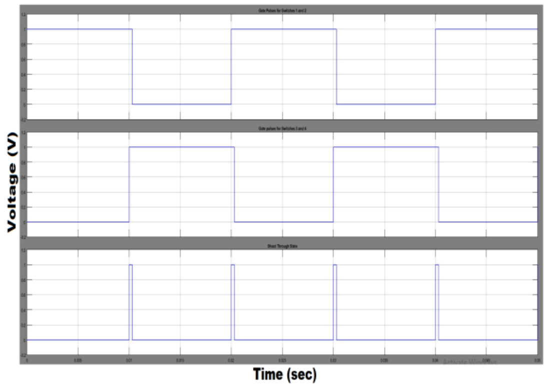

Fig. 3. Shoot-through state employed for single-phase Z-Source Inverter.

So, shoot-through occurs in every-half cycle for some time during which output voltage is zero and the boosted value will appear at next state.

From the below Table I, operating states of single-phase ZSI are explained. Single-phase Z-Source Inverter have two active states during which switches S1 and S2 are turned on at the same time or switches S3 and S4 are turned on at the same time. In this state, the output voltage will be some finite value. ZSI also have zero state, when the switches S1 and S3 are switched on at the same time or S2 and S4 are switched on at the same time. Finally, the shoot-through state, when S1, S4 are on or S2, S3 are on or all the switches are on. This is the most important state in Z-source inverter.

Table I. Switching/operating states of ZSI.

Switching States	S_1	S_2	S_3	S_4
Active States	H	H	L	L
	L	L	H	H
Zero States	H	L	H	L
	L	H	L	H
Shoot-through State	H	S_2	S_3	H
	S_1	H	H	S_4
	H	H	H	H

H- High, L- Low

Published By: Blue Eyes Intelligence Engineering & Sciences Publication

Z-source inverter mainly operates in two modes: Shoot-through mode for boosting and non-shoot through mode.

A.Shoot-through mode

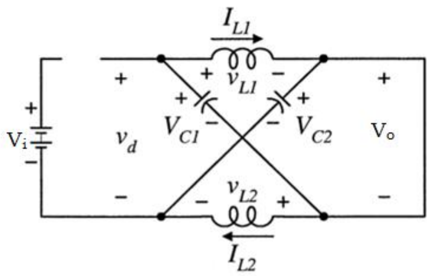

Fig. 4.Equivalent circuit of Z-source inverter in shoot-through state.

ZSI operates in shoot-through mode as shown in the Fig. 4. In this mode, the diode gets reverse biased as the sum of capacitor voltages will be greater than the input dc voltage (Vi). Now, the inductors get charged through capacitors and inductor current increases linearly. Let VC1, VC2 be the voltages across the capacitors C1 and C2. VL1, VL2 be the voltages across inductors L1 and L2.

$$\text{As } V_{C1} + V_{C2} > V_i \quad (1)$$

Voltage across inductors becomes

$$V_{L1} = V_{C1} \text{and} V_{L2} = V_{C2} \quad (2)$$

Then the output voltage (V_0) of inverter becomes Zero.

$$V_0 = 0 \quad (3)$$

Because of this shoot-through state, dead time is avoided in the circuit. Also inductors limit the current ripple.

B. Non-shoot through mode

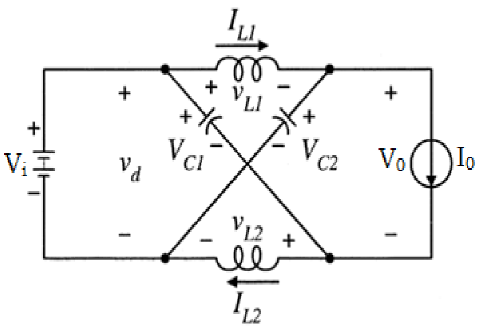

Fig. 5.Equivalent circuit of Z-source inverter in non-shoot through mode.

ZSI operates in non-shoot through mode as shown in the Fig. 5. In this mode, the diode is forward biased and the load is connected across the network. Current through inductor decreases linearly. Finite amount of voltage value will appear as output.

So, the voltage across the inductors will be

$$V_L = V_i - V_C \quad (4)$$

And voltage across the diode is

$$V_d = V_L + V_C \quad (5)$$

The output AC voltage of Z-source inverter is

$$V_{ac} = B \cdot M \cdot \frac{V_i}{2} \quad (6)$$

$$\text{Here } V_0 = B \cdot V_i \quad (7)$$

Where B = Boost Factor

M = Modulation Index

V_0= Output AC Voltage

According to ZSI, the output can be buck or boost up to required level, which can be obtained by changing the modulation index and boost factor. For simulation and hardware, the input voltage is considered to be 12V dc. Reference frequency is 50Hz. Then to boost the voltage to 20V with the load of 15W, the current through inductor will be given by

$$I_L = \frac{P}{V_i} \quad (8)$$

So, the current will be 1.25A. So, to obtain the required boosted voltage, the modulation index will be 0.6. Rating of inductor will be 1mH and the capacitor value will be 1000**µF**.By using the above ratings the circuit is designed to boost the input voltage to required level.

Table II. Design Parameters of single-phase ZSI in simulation and hardware.

S.no	Parameter	Value	
		Simulation	Hardware
1	Input DC Supply	12V	12V
2	Z-Source Inductor	1Mh	1mH
3	Z-Source Capacitor	$1000\mu F$	$1000\mu F$
4	Reference Frequency	50Hz	50Hz
5	Modulation Index	0.6	0.6
6	Resistive Load	15W	15W

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

IV. SIMULATION AND HARDWARE RESULTS

A. Z-source inverter simulation using SPWM technique

The simulation of single-phase Z-source inverter is performed in MATLAB R2015a. The simulation model is shown below in the Fig. 6. Two inductors and two capacitors are placed in the form of X-shape to form a Z-network. The control method used for shoot-through is simple boost control and the gate pulses for the inverter are given through sinusoidal PWM technique. MOSFETs are used as switches. The shoot-through pulses are given to the MOSFET placed before the inverter.

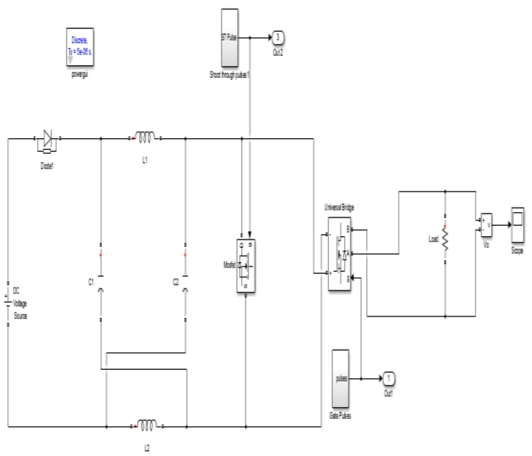

Fig. 6.Simulink Model of Z-source inverter with SPWM technique.

The input dc voltage is 12V. Then the Z-source network boosts the voltage up to 20V. This boosted dc voltage is given as input to inverter and the output of inverter will be nearly equal to 20V.

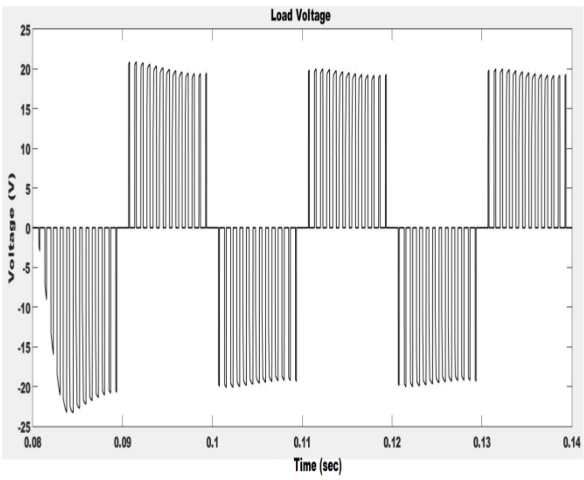

Fig. 7.Output load voltage waveform of ZSI for SPWM technique.

The output voltage across the load using SPWM technique is shown in the Fig. 7. The output is maximum up to 20V. The output will appear in the form of PWM pulses.

B. Zsi simulation using pulse generators

The simulation model of ZSI is shown in the Fig. 8. The gate pulses are given to the MOSFETs using pulse generators. MOSFETs are placed in the form of H-bridge to form a single-phase inverter.

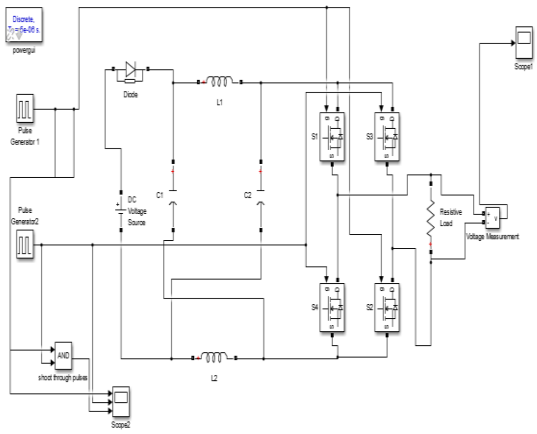

Fig. 8.Simulink Model of ZSI with pulse generators.

Pulse Generator1 supplies pulses to switches S1 and S2. Pulse Generator2 supplies pulses to S3 and S4. Shoot-through pulses are shown using AND gate. By changing the pulse width of pulse generators, shoot-through state is obtained. Then, according to the pulse width the voltage is boosted.

Now the input dc voltage is 12V and no shoot through pulse is given to Inverter Bridge. Pulse width is not changed. So, the inverter operates in buck mode and the output voltage of inverter waveform with zero shoot-through period is shown in the Fig. 9. Here, the output voltage value will be nearly equal to 11V.

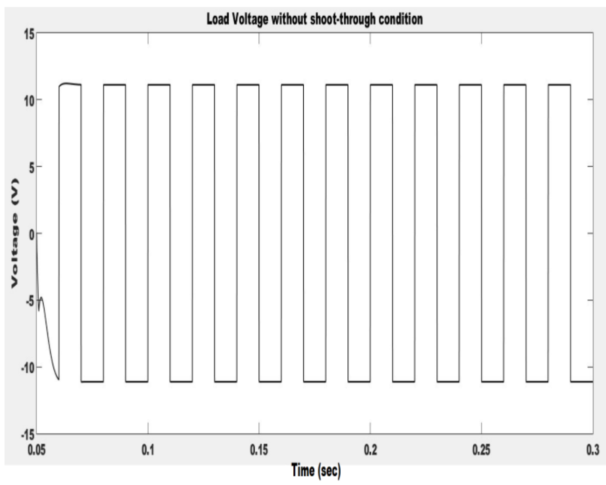

Fig. 9.Output voltage of inverter with zero shoot-through state.

The output voltage obtained in simulation by using pulse generators with shoot-through condition is shown in the Fig. 10 below. With the input of 12V, the output of Z-source network will be boosted upto 20V.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Then, the ac output voltage will be nearly equal to 20V.

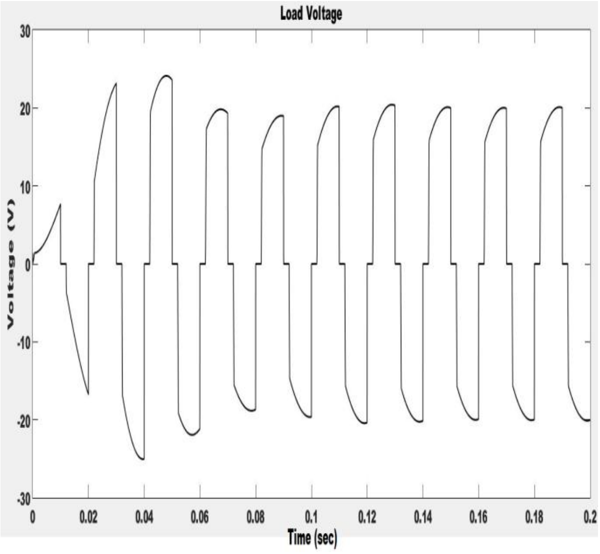

Fig. 10.Output voltage waveform of ZSI with shoot through state.

C.Hardware results

Complete hardware setup of single-phase Z-source inverter is shown in the Fig. 11. MOSFETs-IRF540N are used as switches in the form of H-bride inverter. TLP-250 is used as optocoupler. Gate pulses are given to MOSFETs using Arduino-Atmega328 Microcontroller. Frequency is maintained at 50Hz. First 12V are given as input to the Z-network using battery. Then, by using inductors and capacitors the Z-network boosts the dc voltage up to 15.5V. This boosted dc voltage is given as input to the inverter. So, the output obtained will be 15V AC.

With zero shoot through period, the operation of ZSI observed is buck and the inverter functions as Voltage source inverter. So, with input of 12V the output will be 9.17Vrms and the waveform is in the form of square as shown in the Fig. 12.

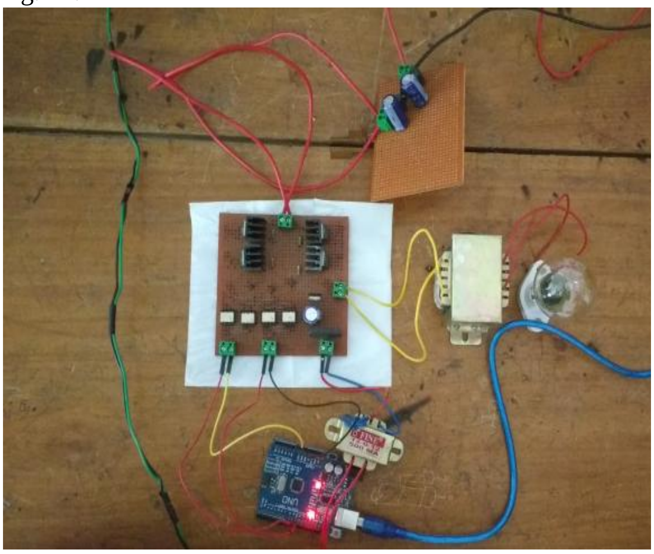

Fig. 11.Experimental setup of single-phase Z-source inverter.

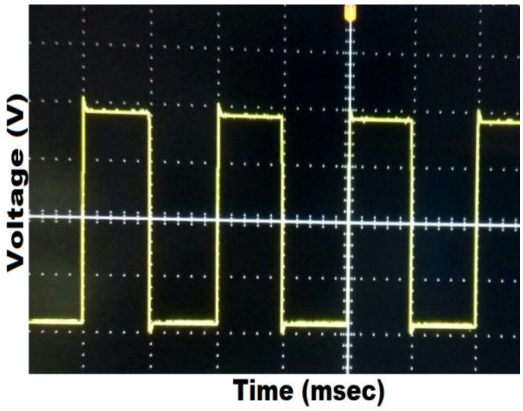

Fig. 12. Load voltage waveform without shoot-through period from hardware.

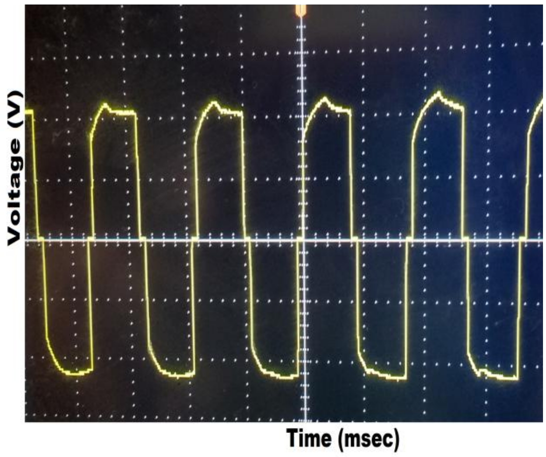

Fig. 13. Output load voltage waveform observed on CRO from hardware circuit with shoot-through period.

Now with the shoot through time as 1.5msec, the output voltage waveform obtained from hardware is shown in the Fig. 13. The output voltage value is nearly equal to 15Vrms.

Table III. Simulation and Hardware results Comparison.

S. no	Parameter	Simulation	Hardware
1	Input DC voltage	12V	12V
2	Load voltage without shoot-through state	11Vrms	9.17Vrms
3	Load voltage with shoot-through state	20Vrms	15Vrms

So, from Table III, it is clear that output voltage is stepped down with zero shoot-through period and the boosted voltage value appears as output with shoot-through period which is the different feature in ZSI that cannot be observed in traditional inverters.

Table IV. Comparison of Z-Source Inverter with Traditional Inverters.

Feature	Traditional Inverters	Z-Source Inverter
No. of stages	2	1
Voltage	Buck or Boost	Both Buck and Boost
Dead Time	Required	Not Required
No. of switches Needed	More	Less
Power Loss	High	Low
Efficiency	Low	High
Reliability	Less	More

V. CONCLUSION

A single phase Z-Source inverter is simulated and implemented for resistive load in this paper. Unique buck-boost operation is observed in Z-Source inverter by using shoot through state which increases output voltage range. Hardware and simulation results are compared. Dead time is not included in this single stage Z-Source inverter which increases efficiency. Cost of the entire system is less with greater reliability. Z-Source inverter can be used universally in different types of power conversions like dc to ac, ac to dc, dc to dc and ac to ac.

REFERENCES

1. PawanKumar J. Aswar and P.H. Zope, “Study and Analysis of Single Phase Z-Source Inverter”, International Journal of Research in Advent Technology, Vol. 1, 2013, pp. 281-289.
2. A. Florescu, O. Stocklosa et al., “The Advantages, Limitations and Disadvantages of Z-Source Inverter”, 2010, pp. 483-486.
3. K.N. Madakwar and Dr. M. R. Ramteke, “Analysis of Single-Phase Z-Source Inverter”, International Journal of Advanced Computing and Electronics Technology (IJACET),Vol. 2, 2015, pp. 54-60.
4. Fang ZhengPeng, “Z-Source Inverter”, IEEE Transactions on Industry Applications, Vol. 39, no.2, March/April 2003, pp. 504-510.
5. Sattyendrasing A. Seragi, “Review on Z-Source Inverter”, National Conference on Advances in Communication and Computing (NCACC),2014, pp. 18-22.
6. MeeraMurali, PiyushaBhavsar et al., “Simulation and Fabrication of Single Phase Z-Source Inverter for Resistive Load”, U.P.B. Sci. Bull., Series C, Vol. 78, 2016, pp. 113-124.
7. Mrudul A. Mawlikar and Ms. Sreedevi S Nair, “A Comparative analysis of Z source inverter and DC-DC converter fed VSI”, International Conference on Nascent Technologies in the Engineering Field (ICNTE), 2017.