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HIGH PERFORMANCE PV POWER GENERATION USING Z SOURCE INVERTER

Selva santhose Kumar R[1], Priyaa Dharshini R S [2],
Research Scholar, Anna University, Chennai, India[1]
II Year, M.E (Power Electronics & Drives), M.A.M College of Engineering, Trichy, India[2]
santhosiyal@gmail.com

ABSTRACT**—***Photovoltaic source (PV) has become one of the most promising DC sources of the future. We use inverter to convert the dc output of the PV in order to utilize it for AC appliances. Z-source inverter which is an advancement of traditional converter (VSI & CSI), with a built-in X shaped impedance network. This provides a single stage power conversion concept whereas the traditional inverter requires two stage power conversions for renewable energy applications. With modification to the traditional pulse width modulated (PWM) signal there are three PWM strategies are used for Z-source inverter. In this maximum boost control which helps in high voltage conversion factor with a short shoot through duration and helps in attaining voltage boost gain by converting all traditional zero states into shoot-through state. This prevents the damage of inverter, high voltage stress and reduces dead time delay.*

Key words —current source inverter, pulse width modulation, voltage source inverter, z-source inverter.

1, INTRODUCTION

Renewable energy has been gaining its importance due to their small scale, low maintenance, pollution free and clean source of energy than fossil fuel which cause great impact on environment & becoming extinct too .This made renewable energy to drive its importance in aspect of environmental concern, especially photovoltaic cell. The characteristics of photovoltaic (PV) is expected to play a major role in power generation. In PV power generation, power converter interface is the major part in the overall system .In PV power generation the output voltage varies depending on the temperature and solar irradiation changes. Because of the wide voltage range of variations of PV power generation, the traditional inverters are either oversized to cope with the variations or a DC-DC boost circuit should be used. However, in the ways the cost, reliability and efficiency major constrains of the system. There are a lot of power converter topologies employed in the PV systems, they are characterized by two-stage or single stage conversion, with transformer or transformer less, and with two levels or multilevel inverter. Single stage transformers less power converters are attracting more attention because of higher efficiency, smaller size and less cost. The newly invented Z-source inverter (ZSI) has the unique feature of boosting the voltage and converted to AC in single stage by introducing the shoot-through operation mode which is forbidden in the traditional inverters .Thus it provides single stage structure for both buck and boost conversion. ZSI has proven its efficiency in many PV system applications as shown figure1.

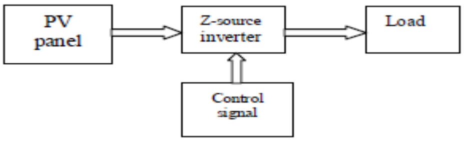

Figure.1 Block Diagram

2, PHOTOVOLTAIC CELL

PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current -that is, electricity. This electricity can then be used to power a load. It can also represented by a diode with its p-n junction exposed to sunlight. When the light photon, strike the PV cell electron in the valence band is ejected to cross the band gap, resulting in production of current in the cell. Generally several PV cells are connected in series and parallel, according to current or voltage requirements. PV cells are connected in parallel to increase the rated current and in series to increase the rated voltage. The, arrangement of PV cells in series or parallel is called a PV array.

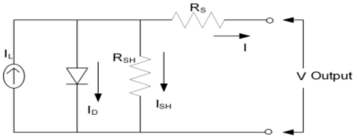

Figure.2 Equivalent circuit of PV

The PV cell output voltage is a function of photocurrent. The photocurrent depends upon the temperature and solar irradiation level as shown in equivalent circuit figure 2. The PV cell output voltage can be expressed as:

$$v = AkT/e \ \ln((Iph + Io - I)/Io) - RsI$$

Where

e = Electronic charge (1.602×10^{-19} C).

k = Boltzmann constant (1.38×10^{-23} J/^{0} K).

I = Cell output current, in A.

I_{Ph} = Photocurrent depends on temperature and solar irradiance (5 A).

I_0 = Reverse Saturation Current of diode

Rs =Series resistance of cell

T = Reference cell operating temperature.

If the temperature and solar irradiation levels change, the output voltage and current of the PV array will follow this change. The variable ambient temperature T_a affects the cell output voltage and cell photocurrent. The output current of the photovoltaic cell is given by,

$$Io=N*Iph-N*Irs*(\exp (q/ (k*T*A)*Vo./Ns)-1)$$

Where,

N - Quality factor of the diode

Iph – Solar induced current

Irs - Reverse saturation current of the photovoltaic cell

q - Electron charge

K - Boltzmann constant

T – Junction temperature

The saturation current of the solar photovoltaic cell can be expressed as Irs,

$$Irs=Irr\ (T/Trefk)\ 3\exp\ (q.E\ (1/Trefk-1/T)/\ (K.A)$$

The Photocurrent is given by,

$$Iph=[(Iscr+ki(T-Trefk))](s/100)$$

Based on the output voltage and current equation of photovoltaic cell PV panel is designed for a particular range of irradiance and temperature. This is the mathematical modeling of the solar panel the output voltage obtained can be able supply a load directly or it can be converted to the required form of ac voltage using inverter.

3, TRADITIONAL INVERTER

Based upon the source of supply to the inverter there exist two traditional converters, voltage source inverter and current source inverter. The major drawbacks of the traditional inverters are, the ac output voltage is limited below and cannot exceed the dc-rail voltage or the dc-rail voltage has to be greater than the ac input voltage. Hence, the V-source inverter is a buck (step-down) inverter for dc-to-ac power conversion and the V-source converter is a boost (step-up) rectifier (or boost converter) for ac-to-dc power conversion. In applications where over drive is desirable and the available dc voltage is limited; an additional dc-dc boost converter is needed to obtain a desired ac output. The additional power converter stage increases system cost and lowers efficiency. The ac output voltage has to be greater than the original dc voltage that feeds the dc inductor or the dc voltage produced is always smaller than the ac input voltage. Therefore, the I-source inverter is a boost inverter for dc-to-ac power conversion and the I-source converter is a buck rectifier (or buck converter) for ac-to-dc power conversion. They are either a boost or a buck converter and cannot be a buck–boost converter that is, their obtainable output voltage range is limited to either greater or smaller than the input voltage. Their main circuits cannot be interchangeable. In other words, neither the V-source converter main circuit can be used for the I-source converter, or vice versa. They are vulnerable to EMI noise in terms of reliability. Thus in order to overcome the above drawbacks and the difficulties that are in traditional inverter are overcome in z-source inverter. The construction and operation of the z-source inverter are analyzed below.

4, Z-SOURCE INVERTER

The above mentioned problems of traditional inverters, increased power capabilities, ease of control and reduced cost of modern power semiconductor devices have made converter affordable in a large number of applications and have opened a host of new conversion topologies for power electronics. The impedance source power converter is a new electronics circuit recognized because of its applications in power conversion. The common problem of voltage source inverter and current source inverter is that they are either a boost or buck converter but not a buck boost converter. To overcome above mentioned problems their main circuit cannot be interchanged. In other words, the voltage source inverter circuit cannot be used for the current source converter and vice versa. In order to overcome the limitations of traditional inverter, a z-source inverter uses a source network to replace the traditional dc-link voltage distortion while operating with either the small source inductor or light load. This decreases the performance of the inverter output voltage.

The basic Z-source converter structure proposed as shown in figure 4 given below. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the above-mentioned conceptual and theoretical barriers and limitations of the traditional V-source converter and I-source converter and provides a novel power conversion concept. It consist of a two-port network that consists of a split-inductor and capacitors and connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter. The dc source/or load can be either a voltage or a current source/or load. Therefore, the dc source can be a battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the anti-parallel combination. The inductance and can be provided through a split inductor or two separate inductors. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The figure 3 shows the traditional two-stage power conversion. The usually produce a voltage that changes widely (2:1 ratio) depending on current drawn from the source. For distributed power generation, a boost dc–dc converter is needed because the V-source inverter cannot produce an ac voltage that is greater than the dc voltage. Z-source inverter for such applications, which can directly produce an ac voltage greater and less than the input voltage. The diode in series is usually needed for preventing reverse current flow.

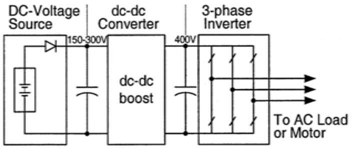

Figure.3 Traditional two-stage power conversions

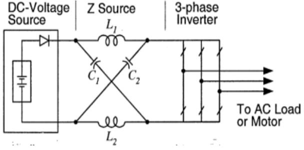

Figure.4 Three Phase Z-source inverter

5, EQUIVALENT CIRCUIT

The below figure 5 shows the equivalent circuit of z-source inverter from the dc link. This consists of unique impedance network with two inductance and capacitance connecter in x shaped. The input is given by dc voltage source with a series diode for bidirectional current flow in the circuit. Note that the inverter bridge can be also represented by a current source.

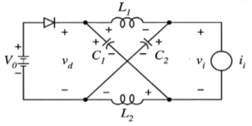

Figure.5 Equivalent circuit of ZSI

The operating principle of z-source inverter can be expalined using the equivalent circuit and considering the basic structure of three phase z-source inverter shwon in figure . The unique feature of the Z-source inverter is that the output ac voltage can be any value between zero and infinity regardless of the input voltage. That is, the Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature. The operation of z-source inverter can be explained in two states. They are Shoot through state and non shoot through state

6, SHOOT THROUGH STATE

In the shoot through state of z-source inverter, two switches from the same leg is turned on, since this type of operation is not allowed in the conventional inverter, therefore switch S is turned on. The three-phase Z-source inverter bridge has nine permissible switching states (vectors) unlike the traditional three-phase V-source inverter that has eight. The traditional three-phase V-source inverter has six active vectors when the dc voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively.

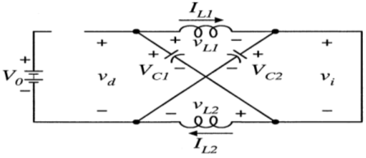

Figure.6 Equivanent circuit of Shoot through state

The three-phase Z-source inverter bridge has one extra zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. We call this third zero state (vector) the shoot-through zero state (or vector), which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter.

7, NON SHOOT THROUGH STATE

In non-shoot through state the switch S is open in this state, and the input diode is forward biased, allowing active or null states of the ZSI. Also, in this state the external power source charges the z-source capacitors, though the inductors. Thus in non-shoot through mode it conducts in any one of the six active states. Note that the inverter bridge can be also represented by a current source with zero value (i.e., an open circuit) when it is in one of the two traditional zero states. The figure 7 shows the equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight non shoot-through switching states.

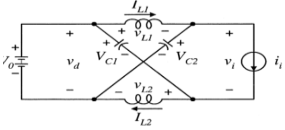

Figure 7. Equivalent circuit of Non shoot through state

Thus in non-shoot-through states it acts ordinary inverter and converters the input dc voltage in to ac voltage. Whereas in shoot-through state the inverter bridge is equivalent to a short circuit by allowing the inverter to conduct two switches on the same leg. Thus z-source inverter utilizes the shoot through state and prevents the damage of the inverter circuit. These are the two states in which z-source inverter operates.

8, MAXIMUM BOOST CONTROL

Pulse width modulation techniques that are used in z-source inverter are different from that of traditional pulse width modulation technique. The distribution of the shoot-through in the switching waveforms of the traditional pulse width modulation concept is the key factor to control the Z-source inverter. The dc-link voltage boost (diagonal capacitor voltage), controllable range of ac output voltage, voltage stress across the switching devices and harmonic profile of the output profile are purely based on the method of control algorithm adapted to insert the shoot-through. These are analyzed and evaluated based on certain parameters like, boost factor (B), gain (G), voltage stress across the switches (*Vs*) with respect to different shoot-through duty ratio (*Do*) and modulation index (*ma*).Maximum boost control turns all traditional zero states into shoot-through state, as shown in figure. The voltage stress across the switching devices is greatly reduced by fully utilizing the zero states. Indeed, turning all zero states into shoot-through state can minimize the voltage stress. Maximum boost control method maintains the six active states unchanged and turns all zero states into shoot-through zero states. Thus maximum T_o and B are obtained for any given modulation index *ma* without distorting the output waveform. Reducing the voltage stress under a desired voltage gain now becomes important to the control of Z-source inverter. To minimize the voltage stress for any given voltage gain, we have to minimize B and maximize *ma*, with the restriction of that their product is the desired value. On the other hand, we should maximize B for any given modulation index to achieve the maximum voltage gain. Consequently, from the above discussion, we have to make the shoot-through duty ratio as large as possible. As can be seen from, the circuit is in shoot through state when the triangular carrier wave is either greater than the maximum curve of the references (Va, Vb and Vc) or smaller than the minimum of the references. The shoot-through duty cycle varies each cycle.It shows in the below figure 8.

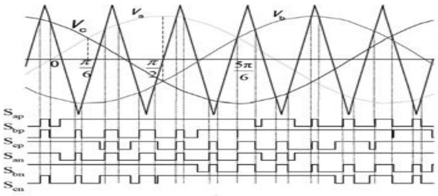

Figure 8. Maximum boost control wave forms

9, MODELLING OF Z-SOURCE INVERTER

A two port impedance network looks like symmetrical lattice network and it contains $L_1$and L_2 which is in series arm inductances, C_1 and C_2 which are diagonal arm capacitance is connected to the dc source and the converter. The dc source used here is the photovoltaic array. The full bridge consist of two legs and two switches in each leg are switched in such a way that when one of the arm is in off state, the other is in on state. The output current will flow continuously through load and the output voltage is solely dictated by the status of the switches. The z-source inverter will operate in two modes which have been discussed before. As we know in non-shoot through state it will act as traditional inverter whereas in shoot through state switching of two switches of one leg or two legs are turned on simultaneously. In this diode in the input side reverse biased and the capacitor C_1 and C_2 charges the inductors, $L_1$and L_2 and the voltage across the inductors are assumed as follows.

Assuming that the inductors ($L_1$and L_2) and capacitors (C_1 and C_2) and have the same inductance (L) and capacitance(C), respectively, the Z-source network becomes symmetrical. From the symmetry and the equivalent circuits, we have

$$V_{L1} = V_{L2} = V_L$$

$$V_{C1} = V_{C2} = V_C \qquad (1)$$

Given that the inverter bridge is in the shoot-through zero state for an interval of To, during a switching cycle T, and from the equivalent circuit

$$V_L = V_C \quad V_d = 2V_c \quad V_i = 0 \qquad (2)$$

Now consider that the inverter bridge is in one of the eight non shoot- through states for an interval of, during the switching cycle. From the equivalent circuit one has,

$$V_L = V_0 - V_C \quad V_d = V_0$$

$$V_i = V_L - V_C = 2V_c - V_0 \qquad (3)$$

Where V_0 dc source voltage and $T = T_0 + T_1$

The average output value of the inductor over one switching period should be zero in steady state from first two equations, thus we have

$$V_L = \frac{T_0 . V_c + T_1 . (V_0 - V_c)}{T} \qquad (4)$$

$$V_c / V_0 = T1 / T_1 + T_0 \qquad (5)$$

Similarly, the average dc link voltage across the inverter bridge can be found as follows

$$V_i = \overline{v}_i = \frac{T_0 \cdot 0 + T_1 \cdot (2V_C - V_0)}{T} = \frac{T_1}{T_1 - T_0} V_0 = V_C \qquad (6)$$

The peak dc-link voltage across the inverter bridge is expressed in (3) and can be rewritten as

$$\hat{v}_i = V_C - v_L = 2V_c - V_0 = \frac{T}{T_1 - T_0} V_0 = B \cdot V_0 \qquad (7)$$

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} \geq 1, \qquad (8)$$

B is the boost factor resulting from the shoot-through zero state. The peak dc-link voltage is the equivalent dc-link voltage of the inverter. On the other side, the output peak phase voltage from the inverter can be expressed as

$$\hat{v}_{\text{ac}} = M \cdot \frac{\hat{v}_i}{2} \qquad (9)$$

Where M is the modulation index. Using equations (7) and (9) can be expressed as

$$\hat{v}_{\text{ac}} = M \cdot B \cdot \frac{V_0}{2}. \qquad (10)$$

Equation 10 shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor B_B

$$B_B = M \cdot B = (0 \sim \infty). \qquad (11)$$

From equations (1), (5) and (8), the capacitor voltage can expressed as

$$V_{C1} = V_{C2} = V_C = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} V_0. \qquad (12)$$

The buck–boost factor is determined by the modulation index and boost factor. The boost factor as expressed in equation (8) can be controlled by duty cycle (i.e., interval ratio) of the shoot-through zero state over the non-shoot-through states of the Inverter PWM. Note that the shoot-through zero state does not affect the PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal.

10, THEORITICAL CALCULATION

The input voltage to the z-source is the output of the photovoltaic panel. The output voltage and current are taken from the simulation output of PV panel. The input voltage and current of z-source inverter be

V_{dc} = 55 volts
I_{dc} = 6

Modulation index $M = \frac{Ar}{Ac} = \frac{0.6}{1} = 0.6$

Duty ratio can also be find using Modulation index which is given by

$D_0 = 1\text{-}M$

$D_0 = 1\text{-}0.6 = 0.4$

Boost factor $B = \frac{1}{1-2Do} = \frac{1}{1-(2*0.4)} = 5$

Therefore using input voltage, modulation index and boost factor we can find the output voltage of the z-source inverter which is given by Output voltage $Vac = \mathrm{M.B.}\frac{\mathrm{Vdc}}{2} = 0.6 * 0.4 * \frac{55}{2}$

V_{ac}=82.5Volts

11, SIMULATION RESULTS

Simulations have been performed as shown in figure 9 and its corresponding results are listed below. The PV panel voltage is 55 volts with current rating of 6 A. The z-source network parameters are L_1= $L_{2=}$ 10 e^{-3} and C1 =C_2 =1000e^{-6}. Based on the boost factor the system is able to produce a three-phase 80 volts. In this case, the modulation index was set to 0.6, the shoot-through duty cycle was set to 0.4 and switching frequency was 10 kHz.

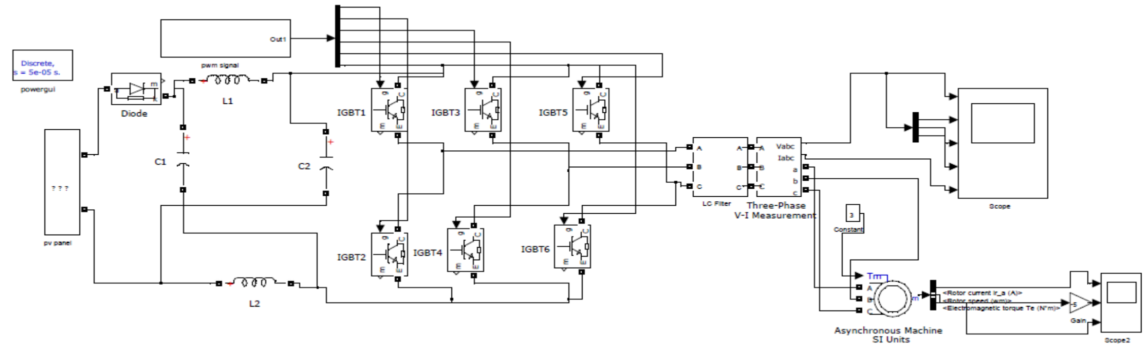

Figure 9. Simulation diagram of ZSI fed Induction Drive

The figure 10 shown below is the circuit diagram of PV panel. The input to the PV panel is depend on the two parameters namely, irradiance and the temperature which are given as constants, 1000 and 50 respectively. Based on the current and voltage equations of solar panel the PV panel is designed and the voltage generated is fed as input to the z-source inverter.

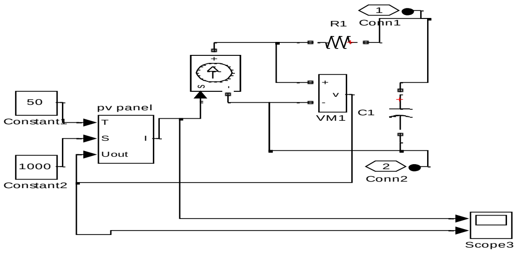

Figure 10.Simulation diagram of PV panel

The figure 11 gives the output voltage and current waveform of the PV panel with x axis of time and y axis of current and voltage. The output voltage of PVpanel is of 55 volts and current of 6A.

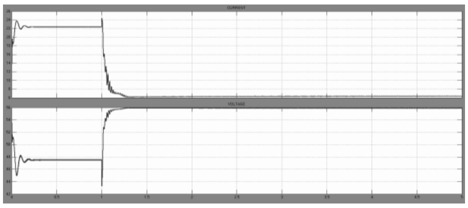

Figure 11.Voltage and current waveform of PV Panel Output

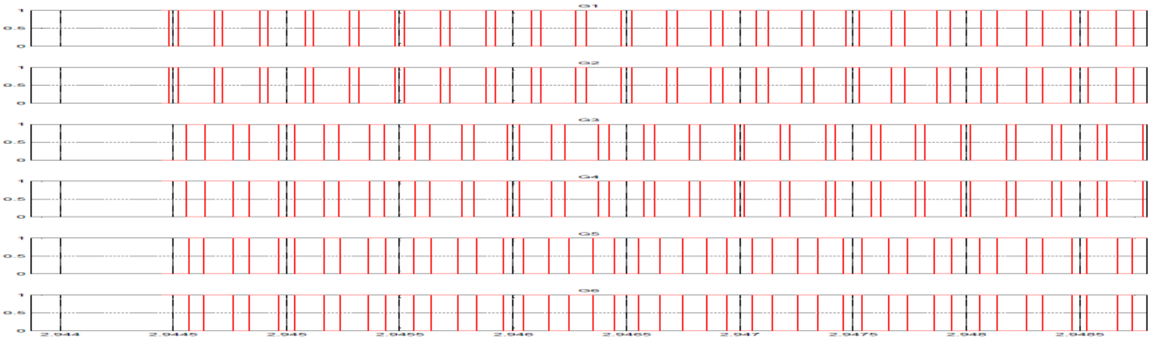

Figure 12. Waveform of pwm Gate signals of ZSI

The figure 12 gives the waveform of gate signals generated by boost control pulse width modulation technique. In this waveform we note the conduction of two gate signal at same time period.These are generated with modulation index of 0.6 and switching frequency 10KHz.Thus the short circuit condition occurs that is utilised by z-source inverter that utilies this as shoot through state that boost up the output voltage.

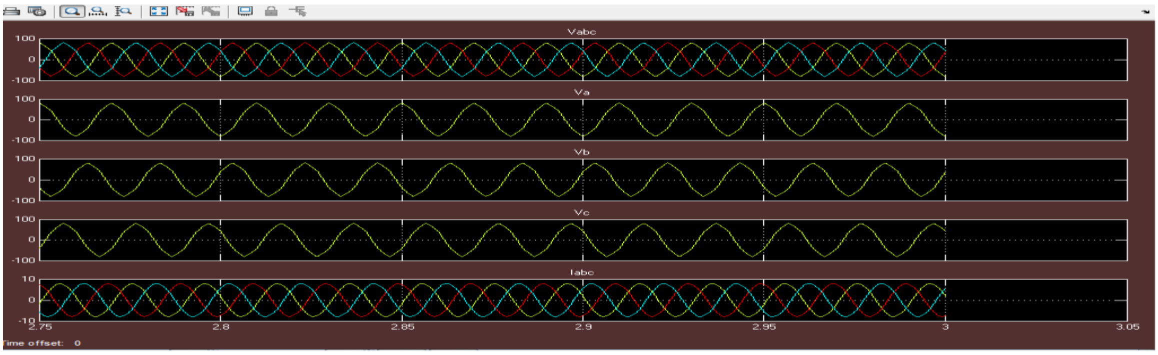

Figure 13. Voltage and current waveform of z-source inverter

The figure 13 gives the output voltage and current of the z-source inverter with input voltage of 55 volts which has been boosted to 80 volts with above mentioned system parameters. The below figure 14 shows the current , speed and torque characteristics of the 3φ induction motor to which the three output voltage of the z-source inverter is fed. The runs with speed of 992 rpm , load current of 6A and load torque of 2.4 N-m.

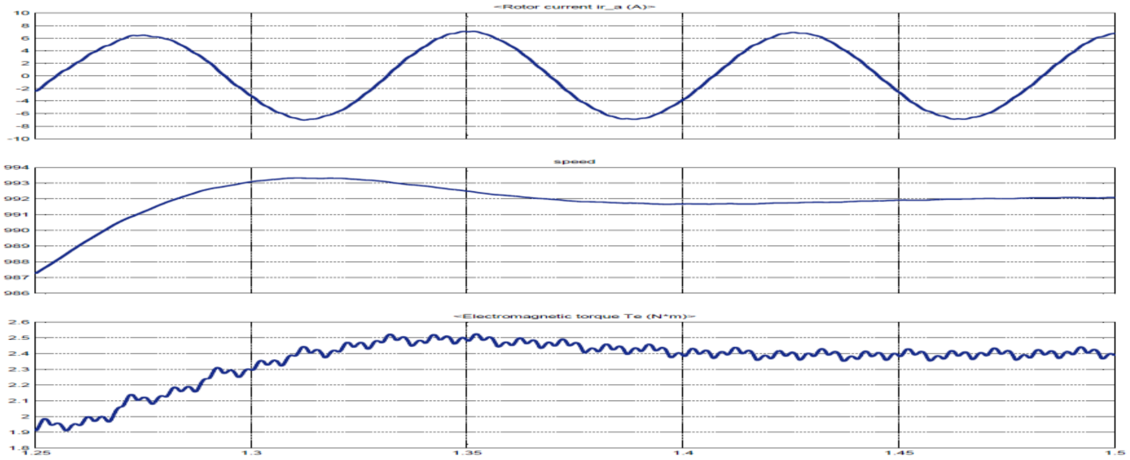

Figure 14. Motor characteristics waveforms

13, CONCLUSION

The implementation of boost control pulse width modulation technique has boosted the output of the z-source inverter to the desired level. The high power output of the z-source inverter has proven to be the flexible and reliable conversion which cannot be achieved with that of traditional current and voltage source inverter. This also shows that z-source inverter undergoes single stage power conversion which is of two stages in traditional inverters. Thus z-source inverter help in preventing the damage of inverter circuit during short circuit condition and also use it to boost the output voltage.

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BIOGRAPHY

Mr. RENGARAJAN**.**SELVA SANTHOSE KUMAR received the Bachelor's degree in Electrical and Electronics Engineering and Master's degree in Power Electronics and Drives from Anna University, Chennai. He is currently working as an Assistant Professor at VANDAYAR ENGINEERING COLLEGE.THANJAVUR in Electrical and Electronics Engineering. His research interests are in Z source inverter, Power Electronics based induction drives.
*Date of Birth: 24.05.1982
Email:santhosiyal@gmail.com