TZ- Source Inverter For The Speed Control Of Three Phase Induction Motor

S. B. Ron Carter, L. P. Sivakumar, K. Premkumar, A.Selvaraj, M. Vishnu Priya

Abstract: TZ-source inverter is a new boost voltage source inverter, designed by replacing the inductors with two transformers in the classical Z source inverter. This new topology inverter uses transformers with low number of turns in order to minimize the size and weight of the model without compromising the voltage gain at output. The voltage boosts up ability can be achieved with very low shoot-through duty ratio which helps in improving the modulation index. By improving the modulation index the main circuit output power quality can be improved. In this, speed control is possible by controlling the gate pulse given to the inverter. The PWM method is used for controlling the pulse width given to the inverter switches.

Keywords: Induction motor, adjustable speed drives, voltage and frequency control, rectifier, inverter, boost inversion ability, transformer, Z- source inverter.

1 INTRODUCTION

Irrespective of the type of industry the usage of rotary machines has find its application in one form or the other [1]. So, the process of controlling the rotary motion either in the form of torque or in the form of speed becomes an inevitable thing. To achieve this DC motor and AC motor drives have been used widely. In olden days DC motors were used widely because of the easiness to control the speed [2,3]. Whereas controlling an Induction motor was considered as the tedious task as the technology used in those days to control the IM was very less efficient [4]. The modern inventions in the areas of drives has changed the way that the industry operate. New control techniques developed to control the speed and torque of asynchronous machines has improved the efficiency of the motor and the drive system considerably [5, 6]. Induction motors are motors which work on the principle of mutual induction [7]. Induction motors are broadly classified into two; first one is slip ring induction motor and second one is squirrel cage induction motor [8]. The working principle of motor is, whenever the magnetic field cuts the current carrying conductor and the current carrying conductor experiences the torque [9]. Three phase induction motor s used in this work. In this the stator consists of three phase balanced winding and these windings are supplied with balanced three phase AC supply [10]. Whenever the stator winding is energized, a rotating magnetic field is produced and will rotate at synchronous speed along the stator periphery [11]. Here the rotor windings are closed winding, so by generator action, rotor winding induced with electro motive force. Since the rotor windings are closed some current will start flowing through the rotor circuit [12]. According to Lenz's law the current will flow in such a direction to oppose the cause. Here the cause for the current flow is the relative speed difference of the rotor flux and stator flux. Hence the rotor will starts rotating in the direction same as that of stator flux to reduce the relative speed. But one thing we have to keep in mind in case of induction motor is that it won't works at synchronous speed. This is because of the reason that there will not be any torque production at synchronous speed [13]. Various control techniques for controlling the speed of IM is available at our disposal. The common techniques like changing the pole pair count in the stator, changing the supply frequency, rotor resistance technique etc., has its own advantages and disadvantages. The pick of the lot is V/f control as the ratio is maintained constant the torque will be maintained constant throughout the operation. This is the resultant of constant magnetizing flux at the stator [16-28]. The conventional Variable speed VSI uses a inverter to supply the voltage to the motor from the generic dc bus system. The major drawback of this system is that under the condition of voltage sag, required voltage may not be available at the dc bus to maintain the speed and torque this again further deteriorate the characteristics of the system. To conquer these issues the idea of using a Z-source came into existence, this uses two capacitors and two inductors to provide the required voltage to the VSI during voltage sags. Z-source inverter offers the advantage of improved power quality by reducing the harmonics and improving the power factor of the overall system.

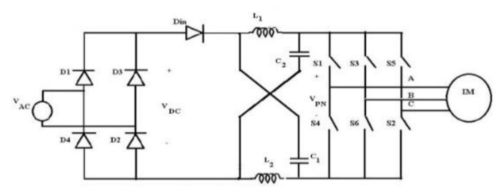

Fig.1 *Circuit diagramforZ-source inverter fed IM*

The boosting factor (B) of classical Z- source inverter [1] is given by

$$B = \frac{1}{1-2\frac{T_0}{T}} = \frac{1}{1-2D} \quad (1)$$

Where T0 is shoot through time
D is shoot through duty ratio.

From (1) it is clear that Boosting factorclearly depends on the value of duty ratio D, so the boosting capabilityhas some limitations because it will affect the modulation index [14]. Modulation index is an important factor which determines the power quality. To overcome the aforementioned problem, we go for another inverter called TZ-source inverter.

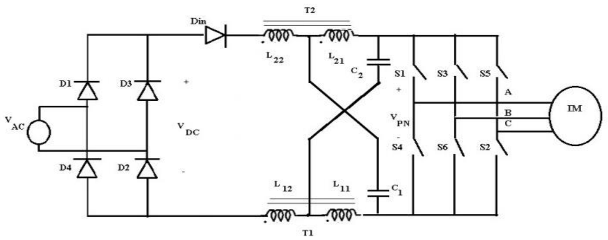

Fig.2 *Circuit diagramforTZ-source inverter fed IM*

The boosting factor (B) of TZ- source inverter is given by

$$B = \frac{1}{[1-(2+N_1+N_2)D]}$$

$$= \frac{1}{[1-(2+N_1+N_2)\frac{T_0}{T}]} \qquad (2)$$

Where N_1 and N_2 are turns ratios of the corresponding transformers T_1 and T_2.

As far as the TZ-sourced inverter is concerned its boosting factor depends on the values of the number of turns N1 & N2 (2) and slightly on the value of duty ratio D [15]. The effect of D on the output can be effectively reduced with the induction of transformer at the input side of inverter as discussed below. This will result in improved modulation Index and output power quality.

2 PROPOSED MODEL

Fig.2 shows the circuit diagram for the proposed TZ- source inverter fed induction motor. It mainly consists of diode bridge rectifier, TZ- network and 120° mode voltage source inverter. The main difference between normal inverter and TZ- source inverter is the presence of shoot through state, which helps in obtaining high boosting ability. It has 12 modes of operation [4], and it can be classified into two 1. Active state, 2. Shoot through state. The gate pulse should be given in such a way that a shoot through interval should come after every active sate.

2.1 Active state

Fig.3 shows the equivalent circuit for one of the six active states.

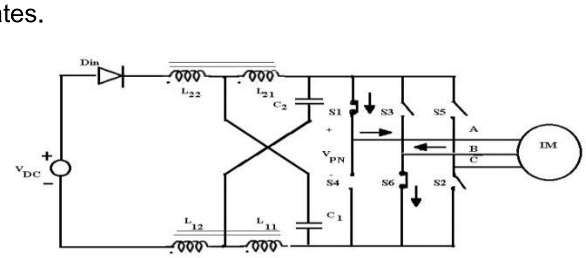

Fig.3Equivalent *circuit for active state*

In this state switches S6, S1 and the input diode Din are in conduction. At this condition, the inductor voltage is added to the input voltage and this resultant voltage is given as input to the inverter. Since the input to the inverter is boosted, the output of the inverter will also get boosted up. From the equivalent circuit it is clear that there is no current flow through the C phase winding.

2.2 Shoot through state

Fig.4 shows the equivalent circuit for one of the shoot through state. Shoot through state is nothing but switches in the same leg will conduct at same state.

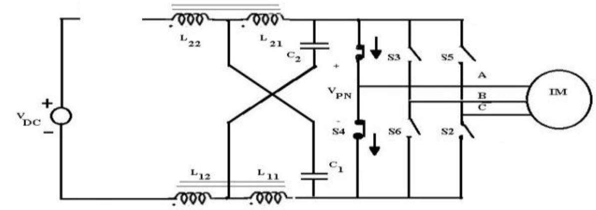

Fig.4 *Equivalent circuit for shoot through state*

In this state switches S1 and S4 are in conduction. It is to be noted that here switches from the same leg is in conduction, which is not possible in the traditional inverter. It is clear from the equivalent circuit that the input to the TZ-network gets interrupted, since the input diode Din is in off condition. Here the inverter terminal is short circuited and through this path the stored energy in the capacitors gets discharged to the inductor.

3 DESIGN METHODOLOGY

To perform the operation in the Simulink environment of MATLAB, the following ratings has been assumed for further study.

Motor: 3 phase Induction motor.
Connection: Star
Power: 0.75 KW
Speed: 1390 rpm
Voltage: 415 V
Current: 1.8 A
Frequency: 50 Hz
Efficiency: 75%
Duty ratio 'D' is assumed to be 5% of T.

Boosting factor can be calculated from the inverters required input and the output of rectifier and the correlation is found to be,

V_0=Boost factor (B) *V_d(3)

The corresponding turns ratio can be found out from the boosting factor, the calculation of B value from the corresponding input and output values of inverter and rectifier will enable easy calculation of N1 and N2.The capacitance value of the capacitor at the input side of inverter has to be designed based on the ripple value of the voltage. The ripple voltage of capacitor should be less than 10% of the voltage available across the capacitor. i.e) ΔV_{c1} and ΔV_{c2} should be around 1% of the voltages V_{c1} and V_{c2} correspondingly. Voltage is calculated by the application of KVL and can be written as below.

$$V_{c1} = V_{c2} = \frac{(1+N_1+N_2)D}{1-(2+N_1+N_2)D} * V_{DC} \qquad (4)$$

From the identified voltages the values of capacitors are being calculated using the following equations.

$$C_1 = I_{m1}.D.\frac{T}{\Delta V_{c1}} \quad (5)$$

$$C_2 = I_{m2}.D.\frac{T}{\Delta V_{c2}} \quad (6)$$

Where the sum of the magnetizing currents$I_{m1}$and I_{m2}will give the value of load current. The used circuit is considered to be symmetrical in nature and so the values of capacitors is assumed to be the same. The equation to calculate the magnetizing inductance of a transformer is given below.

$$L_{m1} = \frac{D(1-D)TV_{DC}^2}{(1+N_1)[1-2ND]P_0} \quad (7)$$

$$L_{m2} = \frac{D(1-D)TV_{DC}^2}{(1+N_2)[1-2ND]P_0} \quad (8)$$

The inverter circuit gets its input from the newly designed TZ- source network. The inverter circuit has the provision to be operated at different modes like $120°$, $180°$ and SPWM. In this case the $120°$ mode of conduction has been chosen. With the addition of TZ- network there will be one more switching state calle shoot through state when compared with normal VSI. The conduction sequence of switches in normal VSI is 61, 12, 23, 34, 45, 56. This will repeat for each cycle and this state is called active state. In TZ- source inverter both active state and shoot through state will be there.

4 SIMULATION DIAGRAM FOR THE PROPOSED SYSTEM

The MATLAB/Simulink has been the simulation package for this inverter. Fig.5 shows the simulation diagram for the proposed speed control system. For the simulation purpose different parameters used were $C_1 = C_2 = 3.2\,mF$and$L_{m1} = L_{m2} = 6.27mH$.

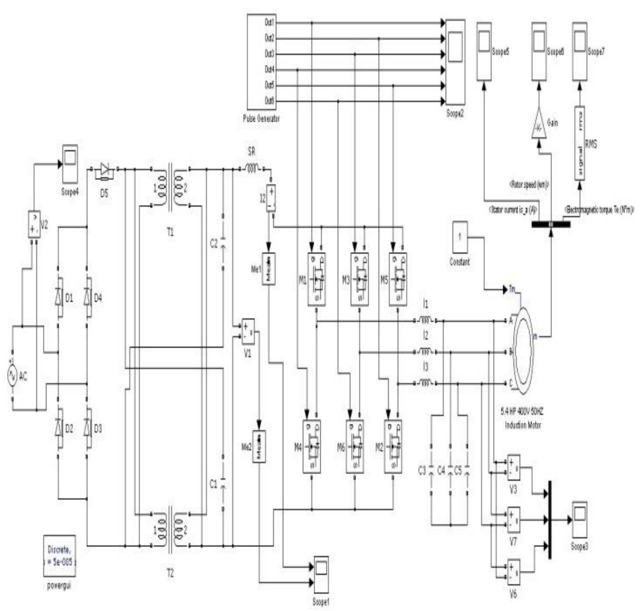

Fig.5 *Simulation diagram for TZ- source inverter fed IM*

5 EXPERIMENTAL RESULTS

The simulated output has been shown below for validation with valuesD = 0.1 and $N_1 = N_2 = 3$.

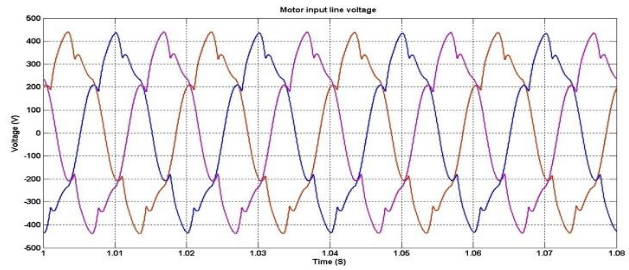

Fig.6 *Stator input line voltage*

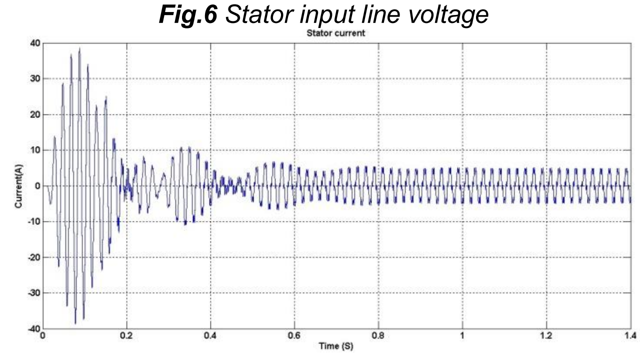

Fig.7 *Stator current*

Fig.6 & Fig.7 depicts the line voltages and currents given to the IM from the inverter.

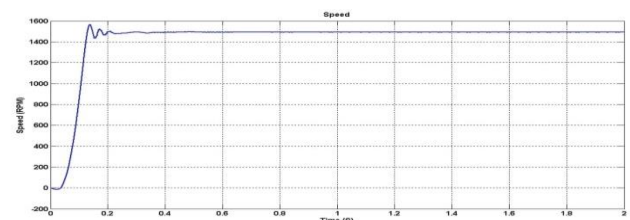

Fig.8 *Speed variation*

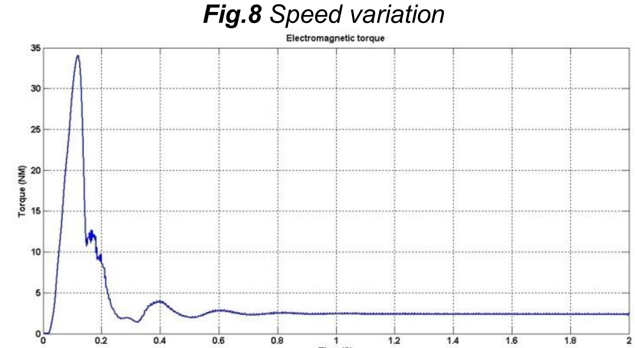

Fig.9 *Torque variation*

Fig.8 and Fig.9 shows the speed and torque variation of the proposed speed control system. From the figure it is clear that at starting torque will be high and at steady state it will be less. From the simulation result it is clear that it is possible to obtain the desired output voltage by adjusting the turn's ratios of the transformer and shoot through duty ratio. Since the turns ratio is greater than one the TZ- sourceinverter has high boosting up capability when compared with classical Z- source inverter.

6 COMPARATIVE STUDY BETWEEN PROPOSED AND EXISTING SYSTEM

With the same shoot through duty ratio and filter various parameters like DC- link voltage, output current and Total

Harmonic Distortion (THD) of the proposed and existing systems were compared.

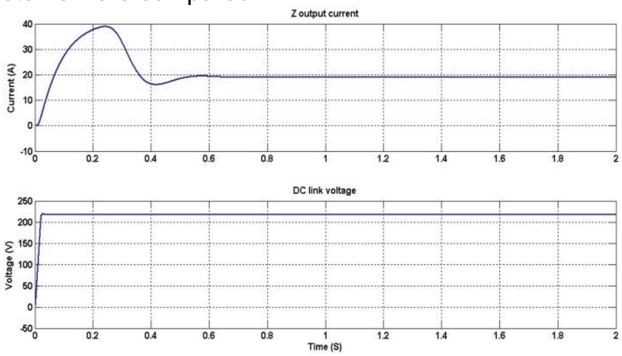

Fig.10 *Z network output current and DC- link voltage*

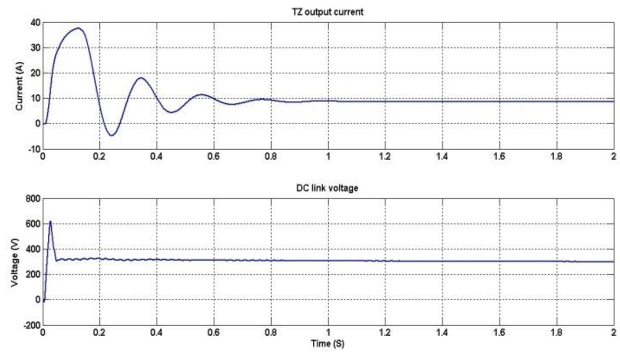

Fig.11TZ *network output current and DC- link voltage*

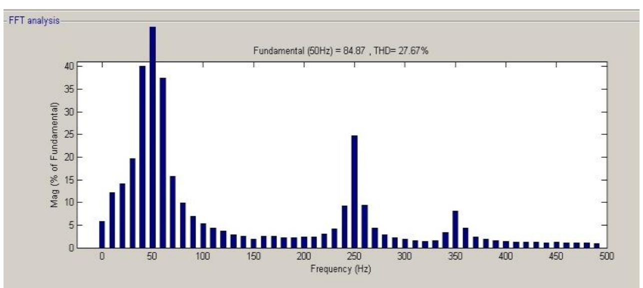

Fig.12 *THD for existing system*

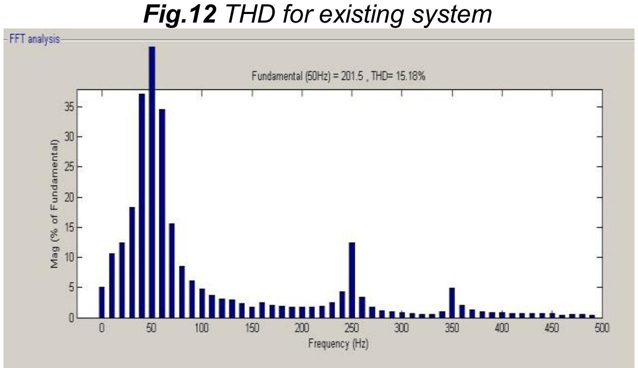

Fig.13 *THD for proposed system*

From the comparative study it is clear that the proposed inverter is capable of producing a high output voltage with less shoot through duty ratio when compared with classical Z- source inverter.

7 CONCLUSION

A new TZ-source inverter has been proposed to drive the 3-phase induction machine and has been simulated in MATLAB/Simulink environment. The disadvantage of the conventional Z-source inverter based on inductor has been rectified with the advent of transformer-based input to inverter. The size of transformer is made tiny because of low turns ratio Also significant boosting factor was attained by changing the shoot through duty and turns ratios. For the same power rating the usage of proposed design is found to be smaller than the conventional system and has clear advantages over other systemsfor the purpose of driving the induction motors.

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