Study of Temperature in Five Phase Induction Motor with Z-Source Inverter and Traditional Inverter at Low Speed

Manjesh[1] A. S.Ananda[2]

Abstract–This paper presents the experimental study of temperature at various parts of five phase induction motor with PWM drive and compared the temperature at various parts of the five phase induction motor with Z-source inverter drive. It utilizes an exclusive Z-source network to link the main inverter circuit to the power source. The Z-Source converter employs a unique impedance network to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source and current-source converter where a capacitor and inductor are used, respectively. The Z-Source inverter system using MOSFETS provide ride through capability during voltage sags, reduce line harmonics, improves power factor and high reliability. Analysis and experimental results obtained by implementing the inverter circuit using Z-source inverter drivewill be presented in this paper.

Keywords–Induction motor drive, Z-source, five phase inverter drive.

I. INTRODUCTION

In electrical drive applications, three-phase drives are widely used in the industries. Now the interest in poly-phase motor drive system has been increased due to several advantages over a three phase drive system. The advantages are reducing the amplitude of harmonic currents, increasing the frequency of torque pulsations, reducing the rotor harmonic current losses, and lowering the dc link current harmonics [1-3].

Excessive thermal heat in the motor leads to machine failure therefore prevention of such a failure is crucial for increasing the motor's lifetime. By knowing the temperature at various parts of the induction motor prevention can be taken. Using different PWM technique heat generated at various parts in the Induction motor can be reduced.

For efficient power utilization various new PWM techniques are developed. Impedance-source inverter or Z-Source Inverter is an advanced PWM inverter topology is employed. The traditional inverters used for power control of Adjustable Speed Drives (ASD) are voltage source inverters (VSI) and current source inverters (CSI) which consists of a diode rectifier, dc link and inverter. The VSI and CSI are characterized by relatively low efficiency because of switching losses and considerable EMI generation.

The paper first received 2Jan2014 and in revised form 23Apr 2014.
Digital Ref: APEJ-2014-1-0431
[1]Department of Electronic Science, Bangalore University, Bangalore, India E-mail: manjesh1972@gmail.com
[2]Department of Electronic Science, Bangalore University, Bangalore, India E-mail: a.sanand@yahoo.com

The switches are used in the main circuit each is traditionally composed of power transistors or IGBT's and anti-parallel diode. It provides bi-directional current flow and unidirectional voltage blocking capability. Thus PWM inverter presents negligible switching losses and EMI generation at the line frequency.

The voltage source Inverters are widely used in various industrial applications. However it has the following limitations:

1. The upper and lower devices of each phase leg cannot be switched on simultaneously either by purpose or by EMI noise. A shoot through would occur and destroy the devices. Minimum dead time is provided to both upper and lower switches to avoid short circuit and distortion in the output voltage wave form to avoid the Inverter circuit failure.

2. The AC output voltage is limited below and cannot exceed the DC bus voltage or the DC bus voltage has to be greater than the AC input voltage. Therefore the voltage source inverter is a buck inverter for DC to AC power conversion and the voltage source converter is a boost rectifier for AC to DC power conversion. For applications where over drive is desirable and 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 lower the efficiency of the drive system.

3. An Output converter is needed for providing a sinusoidal voltage compared with the current source inverter, which causes additional power loss and control complexity.

The current source converter has the following conceptual and theoretical barriers and limitations.

1. Any one of the switch from the upper and one from the lower switch have to be maintained on at any time. Otherwise, an open circuit of the DC inductor would occur and destroy the devices. Overlap time for safe current commutation is needed in the current source converter, which also causes waveform distortion.

2. 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 current source inverter is a boost inverter for DC to AC power conversion and the current source converter is a buck rectifier for AC to DC power conversion[4]. For applications where a wide voltage

range is desirable, an additional DC-DC buck converter is needed.

The voltage source inverter is employed for driving the five phase Induction motor, the provisions are made in the inverter circuit that the upper and lower devices of each phase leg cannot be turned on simultaneously, furthermore the V-source inverter is a buck (step-down) inverter [2,6]. Therefore, the ac output voltage is limited and cannot exceed the DC-rail voltage. The Z-source inverter overcomes the conceptual and theoretical barriers and limitations of the V-source inverter and provides a novel power conversion concept[5,8].

A Z-source inverter could elevate most of the problems associated with traditional VSI and CSI. Z-source inverter circuit provides both voltage buck and boost properties, which cannot be achieved with conventional voltage source and current source inverters. Unique features of the Z-source inverter provide a simpler and single stage power conversion structure for induction motor drives. The Z-source concept can be applied to all DC-to-AC, AC-to-DC, AC-to-AC, and DC-to-DC power conversion.

A Z-Source based drive can:
1. Produce any desired output voltage, even greater than the line voltage, regardless of the input voltage, thus reducing motor ratings.
2.Provide ride-through during voltage sags without any additional circuits.
3.Improves power factor and reduces harmonic current and common mode voltage.
4. Reduction of harmonic content results in drastic minimization of rate of rise of heat in the induction motor.

II. Five Phase Induction Motor Drive with Traditional Inverter

The design of five phase induction motor drive with traditional PWM inverter is as shown in Fig. 1. By using Voltage frequency method speed can be controlled in five phase Induction motor by using microcontroller. Five Phase Signals are generated by microcontroller to drive the five phase Induction motor. Five phase signals are connected to Inverter drive circuit through Optoisolator (MCT2E) to provide isolation between high power and control signals generated by microcontroller. IGBT (Insulated-Gate Bipolar Transistor) switches are used to construct PWM five phase inverter drives [8,9].

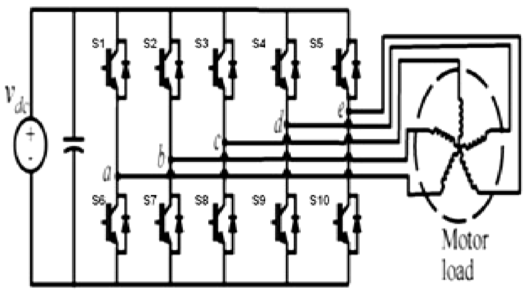

Fig.1: Five phase induction motor with traditional PWM inverter

The five phase control signals generated from microcontroller with 72° out of phase with each other is as shown in Fig.2.

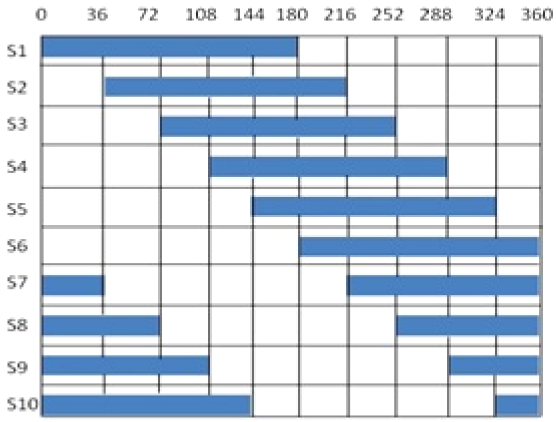

Fig. 2: Switching sequence of 180^0 conduction mode

The drive converts standard input power (230*V*, 50*Hz*) to adjustable voltage and frequency to power AC motor. V/f control method is employed to vary the speed of the five phase induction motor to operate at low speed and to study the temperature of five phase induction motor is recommended in this work experimentally.

The thermal network model for squirrel cage induction motor is developed according to the principles reported by Kessler [10]. It has been shown by Kylander [11], that a high level of accuracy can be achieved by modest sub division of the machine's geometrical parts. In building a thermal model, a machine part is identified as a node in the thermal network. A thermal capacitance and heat source is associated with each node.

A very simple, 3 node, 3 thermal resistance thermal network model has been developed for five phase induction motor. The corresponding thermal network is shown in Fig.3.

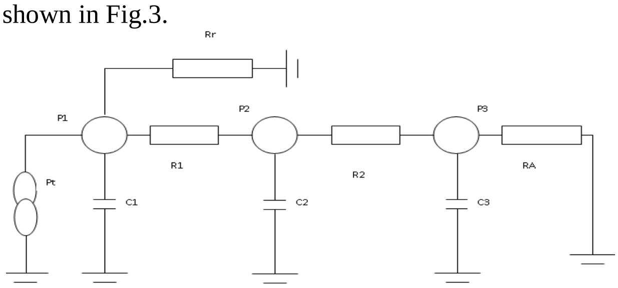

Fig.3: Thermal model of an induction motor

Table1 shows the thermal capacitances and thermal resistances of five phase induction motor at various parts. These parameters has been obtained by studying DC analysis of the five phase induction motor (the motor is in stall), the predicted temperature has been found by Powering DC to the five phase induction motor.

Table 1: Thermal resistances and thermal capacitances

Thermal Capacitance	Values in J/ ℃	Thermal Resistance	Values in W/ ℃
C1	6541	*R1*	0.0303
C2	6888	*R2*	0.0178
C3	7037	*RA*	0.1354

III. Five Phase Induction Motor Drive with Z-Source Inverter

The construction of Z-Source Inverter (ZSI) of a Five Phase Induction Motor Drive and it has a DC voltage Source, Z-Source network, Inverter and an AC load shown in Fig.4, the dc Source can be either a voltage source or a current source. The Z-Source network comprises split indictors *L1* and *L2*, and *X* connected capacitors *C1* and *C2* for coupling of the inverter network to the dc source.

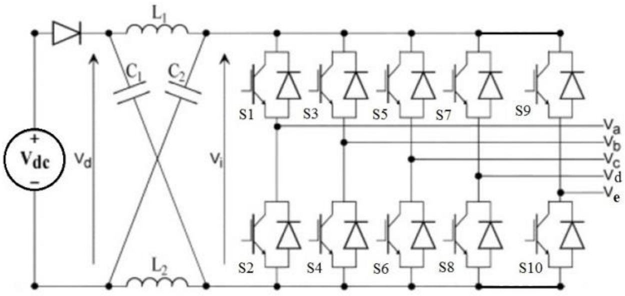

Fig. 4: Construction of Z source inverter for five phase induction motor drive

Equivalent circuit of Z-Source network A diode and Z-source network connected between the dc input voltage and inverter are the main differences in the power circuit, the equivalent circuit of Z-source inverter shown in Fig.5.

The diode function is to prevent discharging capacitor through the dc-input voltage. A special feature of ZSI operation is that it allows both power switches of a phase leg to be turned on simultaneously without damaging inverter network (a scenario called shoot-through). The inverter's performance can be analyzed via its equivalent circuits as shown in Fig.6.

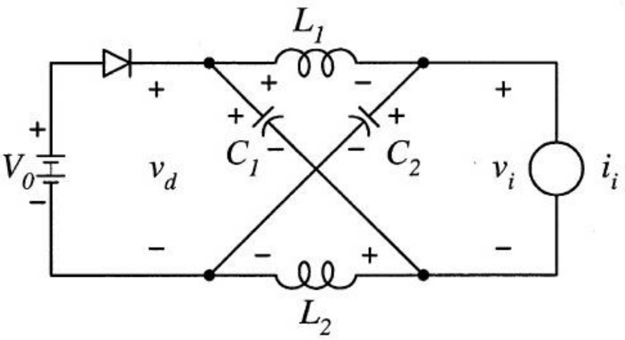

Fig. 5: Equivalent circuit of Z-source network

By assuming $C_1=C_2=C$, therefore

$$V_{L1}=V_{L2}=V_L=V_{C1}=V_{C2}=V_C$$

$$V_d=V_L+V_C$$

$$V_i=0$$

No energy is transferred to the load.

During non-shoot-through state, current flows from the Z-source network through the inverter network, to the connected ac load.

The following equations thus result:

$$V_L=V_{dc}-V_C$$

$$V_d=V_{dc}$$

$$V_i=V_C-V_L=2V_C-V_{dc}$$

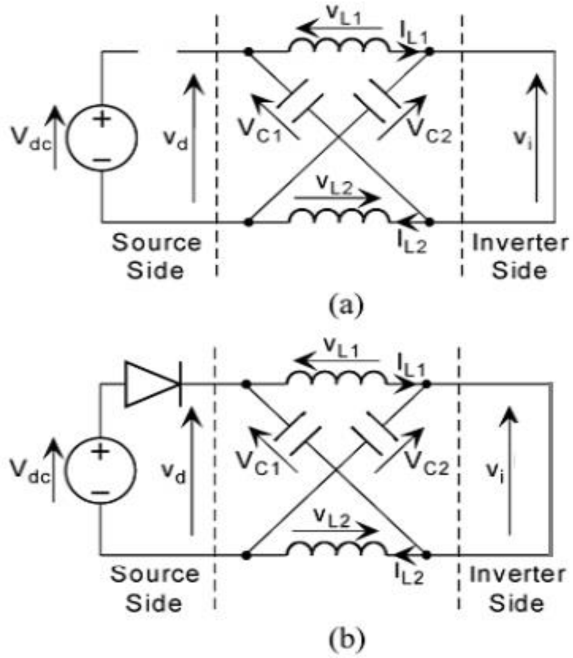

Fig.6: Equivalent z-source inverter circuits in (a) shoot-through state (b) non-shoot –through state

Inductor and capacitor requirements: Considering additional filtering and energy storage provided by the inductors, the Impedance source network should require less capacitance and smaller size compared with the traditional voltage source inverter. Similarly, when the two capacitors (*C1* and *C2*) are small and approach zero, the Impedance source network reduces to two inductors *(L1* and *L2)* in series and becomes a traditional current source. The two capacitors are small the Impedance source network reduces to two inductors in series and becomes a traditional current source. Considering additional filtering and energy storage by the capacitors, the Impedance source network should require less inductance and smaller size compared with the traditional current source inverters.

IV. Complete Setup

The complete circuit is constructed as shown in Fig. 7 and AC mains are connected to the autotransformer, then it is connected to the bridge rectifier. The rectifier converts AC to DC then it is connected to Z-source inverter. Five phase signals are generated using a microcontroller kit using the IC AT89S54. These phase signals are connected to the driver circuit. Drive circuitry is designed to isolate and to provide desired control signals, then these signals are connected to the inverter IGBT's gate terminals.

To measure the temperature of five phase induction motor, J-type thermocouples are inserted at various parts five phase induction motor[12]. The thermocouples are connected to the temperature module kit, the module kit is interfaced to personnel computer where the experimental data has been collected and used to draw the graph.

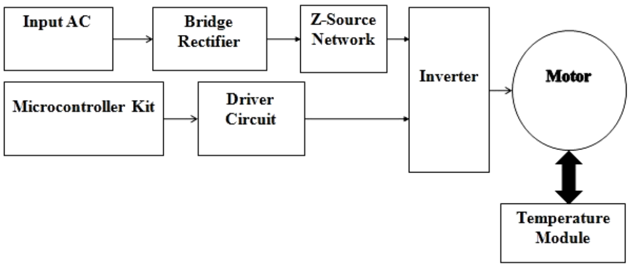

Fig.7: Complete setup of five phase induction motor drive with Z-source inverter

The Z-source network consists of inductors *L1* and *L2* and capacitors *C1* and *C2*. The values of *L1*=*L2*=18*mH*, and *C1*=*C2*=1000*uF*/450*V* is used for the experimental work, the experiment is studied at low speed. The motor will be running at the frequency of 5 *Hz* and 20 *V* based on v/f control method, speed is reduced to 143 *rpm*. Then the temperature is measured at various parts of the five phase induction motor. This experiment is done in two stages, one with traditional inverter and other with Z-Source Inverter. The experimental study of heat at various parts of the five phase induction motor is obtained for both normal PWM drive and Z-source inverter drive, powering the five phase induction motor for a period of 3 hours.

V. Experimental Result

The motor parameters ratings are used in this experimental work are

Voltage= 200*V*
Current= 3.4*A*
Horsepower= 1*Hp*
RPM= 1400
Frequency= 50*Hz*

The maximum temperature of PWM inverter and Z-source inverter are shown in the table2. The graph is plotted time versus temperature of PWM inverter and Z-source inverter is shown in Fig.8 and Fig.9 respectively.

Table 2: Comparison of Maximum temperature at various parts of five phase induction motor.

Induction motor parts	Temperature with PWM Inverter (^{o}C)	Predicted Temperature (^{o}C)	Temperature with Z-Source Inverter (^{o}C)
Top Stator Winding	33.50	28.74	30.51
Bottom Stator Winding	33.27	28.74	30.65
Inner Frame 1	32.80	28.44	30.45
Inner Frame 2	32.7	28.44	30.14
Body	31.93	27	29.8
Ambient	27.18	27	27.06

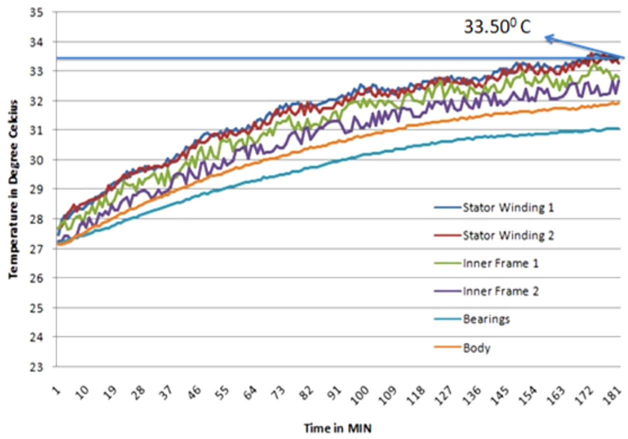

Fig.8:Measurement of temperature at various parts of five phase induction motor with PWM inverter at *V*=20*V*, *F*=5*Hz*, Torque load=0.15*Nm*

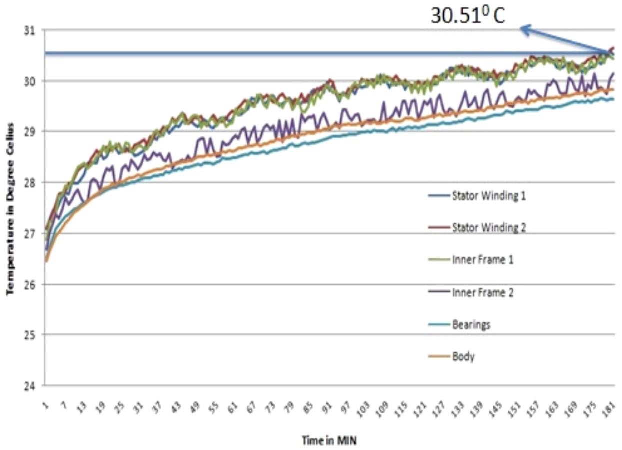

Fig.9: Measurement of temperature at various parts of five phase induction motor with Z-source inverter at *V*=20*V*, *F*=5*Hz*, Torque load=0.15*Nm*

VI. Conclusion

Study of stator windings of five phase induction motor with Z-source inverter, and traditional PWM inverter has been studied experimentally. It is concluded from the experimental results the rate of rise of temperature at various parts of five phase induction motor with Z-source filter is found to be less compared to normal PWM Inverter. In summary, the Z-source inverter system has several unique advantages, such as Z- source can be used both in Buck and Boost properties and Z-source concept can be applied to all DC-to-AC, AC-to-DC, AC-to-AC, and DC-to-DC power conversion. These advantages are very desirable for many Adjustable Speed Drive applications.

References

[1] Sk. Moin Ahmed andHaitham Abu-Rub “A Three-to-Five-Phase Matrix Converter Based Five-Phase Induction Motor Drive System,”*International Journal on Recent Trends in Engineering and Technology*, vol. 8, no. 2, Jan 2013.

[2] N. Kim and M. Kim, “Modified Direct Torque Control System of Five Phase Induction Motor,” *Journal of Electrical Engineering & Technology*,vol. 4, no. 2, pp. 266-271, 2009

[3] K. P. Prasad Rao, B. Krishna Veni and D. Ravithej, “Five-Leg Inverter For Five-Phase Supply,”*International Journal of Engineering Trends and Technology*,vol. 3, no. 2, 2012.

[4] PalakG.Sharma and S. Rangari, "Simulation of Inverter Fed Five Phase Induction Motor,"*International Journal of Science and Research (IJSR)*, India Online ISSN: 2319-7064, vol. 2,no. 2, February 2013

[5] Chomát Miroslav, S.Luděk and B. Jiri, "Measurement on Five-Phase IM Fed from Ten-Pulse Frequency Converter," *Transactions on Electrical Engineering*, vol. 1, no. 2, 2012.

[6] M. Jones and E. Levi, "A literature survey of state-of-the-art in multiphase ac drives," in Proc. 37th Int. UPEC, Stafford, U.K., 2002, pp. 505–510.

[7] E. Levi, R. Bojoi, F. Profumo, H. A. Toliyat, and S. Williamson, "Multiphase induction motor drives-A technology status review," *IET Elect. Power Appl.*, vol. 1, no. 4, pp. 489–516, Jul. 2007.

[8] E. Levi, "Multi-phase machines for variable speed applications," *IEEE Trans. Ind. Electron.*, vol. 55, no. 5, pp.1893–1909, May 2008.

[9] 'Five-phase induction motor drive for weak and remote grid system' International Journal of Engineering, Science and Technology,vol. 2, no. 2, pp. 136-154, 2010.

[10] 'Analysis of various PWM controls on single-phase Z-source inverter' Proceedings of 2010 IEEE Student Conference on Research and Development (SCOReD 2010), 13 - 14 Dec 2010, Putrajaya, Malaysia

[11] Kessler,A. VersucheinergenauerenVorausberechnung des zeitlichenErwarmungsverlaufesElektrischerMaschinenmittel sWarmequellennetzen.Archiv Fur Elektrotechnik, vol.45,no.1, pp.59-76, 1960.

[12] Kylander, G. Thermal modeling of small cage induction motors. Doctor of Technology Thesis, Chalmers University of Technology, Gothenburg, Sweden,1995.

[13] F. Z. Peng,"Z-Source Inverter,"*IEEE Trans. Ind.Appl.*,, vol. 39, no. 2, March/April 2003.

[14] S. Thangaprakash and A. Krishnan,"Z-source Inverter Fed Induction Motor Drives – a Space Vector Pulse Width Modulation Based Approach," *Journal of Applied Sciences Research*, vol. 5, no. 5, pp. 579-584, 2009.

[15] B. Justus Rabi and R. Arumugam,"Harmonics Study and Comparison of Z-source Inverter with Traditional Inverters,"*American Journal of Applied Sciences*, vol. 2 no. 10, pp. 1418-1426, 2005

[16] J. Singh,"Transient Analysis of Z-Source Inverter Fed Three-Phase Induction Motor Drive by Using PWM Technique,"*International Electrical Engineering Journal (IEEJ)*,vol. 4 , no. 1, pp. 856-863, 2013.

[17] S. M.Dehghan, M.Mohamadiany and Ali Yazdian, "Current-Type Nine-Switch Inverters," *Journal of Power Electronic*s, vol. 10, no. 2, March 2010.

[18] S.Rajakarunaand L.Jayawickrama, "Steady-State Analysis and Designing Impedance Network of Z-Source Inverters", *IEEE Trans. Ind.Electron.*,vol. 57, no.7, July 2010.

[19] P. C. Loh, D. M.Vilathgamuwa, Y.S Lai, G.T. Chua and Y. Li,"Pulse-Width Modulation of Z-Source Inverters," *IEEE Trans, Power Electron.*,vol. 20, no. 6, Nov. 2005.

[20] S. Thangaprakash and A. Krishnan, "Comparative evaluation of modified pulse width modulation schemes of Z-source inverter for various applications and demands", *International Journal of Engineering, Science and Technology*, vol. 2, no. 1, pp. 103-115, 2010.

BIOGRAPHIES

Manjesh obtained his Ph.D in Electronic Science, Bangalore University, presently working as Associate Professor, Electronic Science Department, Bangalore University, Karnataka, India. He is working on Power Electronics and Motor drives, Temperature analysis of motor drives having many publications in reputed journals, national and international conferences etc.

A. S. Ananda Obtained his M.Sc. Electronics from Department of Electronics, University of Mysore, Mysore. Presently Ph.D student under Dr. Manjesh, working on power electronics and motor drives.