# Study of Heat at Various Parts of the Three Phase Induction Motor with Inverter Output Filter

Manjesh [1] B. Rajesh [2]

**Abstract–The experimental work focuses on the temperature study of three phase induction motor at various parts using inverter output filters. Various filters are used in industrial PWM drives. These filters reduce the bearing current and shaft voltage, and also smoothes the motor supply voltage approximately a sinusoidal voltage. The induction motor driven by PWM drive inverter for long time heat generated in the windings of the induction motor is high, since the copper loss in the windings is more compared to other losses in the induction motor, also various harmonics at the output of the inverter, common mode voltage and differential mode voltage is also added the cause of heat in the induction motor. In this paper the temperature of the three phase induction motor is experimentally studied with v/f control method. The heat in the induction motor has been observed with PWM inverter drive and compared with the heat produced when the filter is used**

**Keywords–PWM inverter, stator copper loss, common mode voltage, differential mode voltage.**

## I. Introduction

In the recent research works PWM drive with high frequency is commonly used. The high dv/dt supply voltage gives the disadvantageous consequences, high motor insulation stress, bearing current [2, 8] will deteriorates motor efficiency, EMC noises etc. the problem may be severe if a long cable is used to connect the motor and an inverter. To avoid these problems various methods are proposed [3, 5]. A preferred method to minimize these problems by using output filters at the output of the inverter is employed in this paper. This uses a passive filter with the combination of inductors and capacitors connected very close to the inverter shown in the Fig.1

A literature survey presents the analysis of the motor model for CM current [4, 6] flow gives information that the CM filter has no influence on motor torque. Motor torque is dependent only on differential mode. Therefore a differential mode filter adds an extra voltage drop and phase shift between voltages and currents on the input and output of the filter [1,6,11,12].

A V/f control method is employed to control the speed of the three phase induction motor; the motor used for the experimental purpose is a class-F motor whose specifications are shown in the Table1. A thermo couple is inserted at various parts of the induction motor to measure the temperature of the induction motor through temperature module kit. A temperature module kit collects the data and passes this temperature data to personnel computer for record. The PWM drive is constructed with six IGBT modules, to control the PWM drive six control signals are generated from the FPGA kit through the drive circuit. The experiment is conducted for 3 hours for the low voltage and low frequency, the temperature at various parts in the induction motor is recorded with a load of 0.18Nm. The experiment is repeated for the same load and same V/f control with filter, the heat in the various parts of the induction motor is measured experimentally.

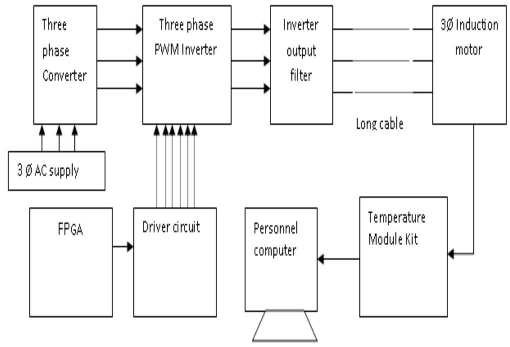



Fig.1: Experimental setup three phase motor drive

### A. Filter Model

A filter is proposed in this paper has a structure similar to that proposed by Akagi in [3]. Fig.2. three capacitors *C1* and three inductors *L1* are the parts of the differential filter for *αβ* components. *RC* is used for transients damping. The common mode filter elements are coupled choke *N1* capacitor *C0* and *R0*. The circuit is closed by capacitors in the DC link of the inverter. By contrast with the filter [3], the second CM choke *N2* is used to limit the flow of zero component of current in the external circuit relative to the filter and inverter shown in the Fig.3. It is assumed that both chokes *N1* and *N2* as well as inductor *L1* are ideal elements, resistances and leakage inductances were neglected.

The equations of the filter for the ABC frame and related to the $C_{DC}$ terminal is given by

$$\begin{bmatrix} S_{fx} \\ S_{fy} \\ S_{fz} \end{bmatrix} = \frac{d}{d\tau}\begin{bmatrix} N_1 & N_1 & N_1 \\ N_1 & N_1 & N_1 \\ N_1 & N_1 & N_1 \end{bmatrix}\begin{bmatrix} i_{1x} \\ i_{1y} \\ i_{1z} \end{bmatrix} + L_1\frac{d}{d\tau}\begin{bmatrix} i_{1x} \\ i_{1y} \\ i_{1z} \end{bmatrix} + \frac{d}{d\tau}\begin{bmatrix} N_2 & N_2 & N_2 \\ N_2 & N_2 & N_2 \\ N_2 & N_2 & N_2 \end{bmatrix}\begin{bmatrix} i_{su} \\ i_{sv} \\ i_{sw} \end{bmatrix} + \begin{bmatrix} S_{su} \\ S_{sv} \\ S_{sw} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} S_{su} \\ S_{sv} \\ S_{sw} \end{bmatrix} = \begin{bmatrix} S_{cx} \\ S_{cy} \\ S_{cz} \end{bmatrix} + R_c\begin{bmatrix} i_{cx} \\ i_{cy} \\ i_{cz} \end{bmatrix} + \begin{bmatrix} S_{cc} \\ S_{cc} \\ S_{cc} \end{bmatrix} R_0\begin{bmatrix} i_{cx}+i_{cy}+i_{cz} \\ i_{cx}+i_{cy}+i_{cz} \\ i_{cx}+i_{cy}+i_{cz} \end{bmatrix} - \frac{d}{d\tau}\begin{bmatrix} N_2 & N_2 & N_2 \\ N_2 & N_2 & N_2 \\ N_2 & N_2 & N2 \end{bmatrix}\begin{bmatrix} i_{su} \\ i_{sv} \\ i_{sw} \end{bmatrix} \quad (2)$$

The paper first received 4 Nov 2010 and in revised form 17 Dec 2012.
Digital Ref: APEJ-2012-12-308

[1] Department of Electronic Science, Bangalore University, Karnataka India. E-mail: manjesh1972@gmail.com

[2] Department of Electronic Science, Bangalore University, Karnataka, India. E -mail: rajeshb0201@gmail.com

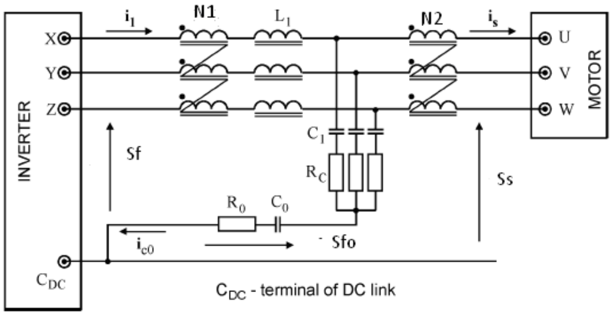



Fig.2. Inverter output filter with common mode and differential mode

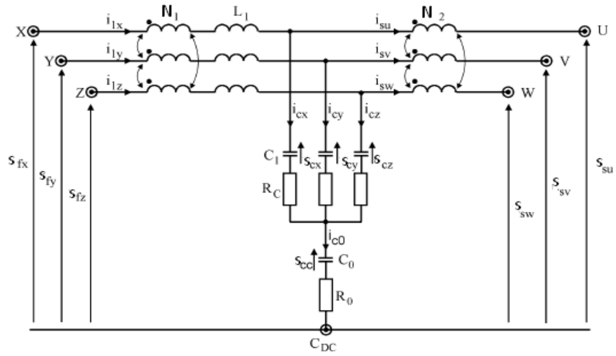



Fig.3. Equivalent filters circuit in ABC references

$$C_1 \frac{d}{d\tau}\begin{bmatrix} S_{cx} \\ S_{cy} \\ S_{cz} \end{bmatrix} = \begin{bmatrix} i_{1x} \\ i_{1y} \\ i_{1z} \end{bmatrix} - \begin{bmatrix} i_{su} \\ i_{sv} \\ i_{sw} \end{bmatrix}. \tag{3}$$

$$\begin{bmatrix} i_{1x} \\ i_{1y} \\ i_{1z} \end{bmatrix} = \begin{bmatrix} i_{su} \\ i_{sv} \\ i_{sw} \end{bmatrix} + \begin{bmatrix} i_{cx} \\ i_{cy} \\ i_{cz} \end{bmatrix} \tag{4}$$

$$C_0 \frac{dS_{cc}}{d\tau} = i_{cx} + i_{cy} + i_{cz} \tag{5}$$

$$i_{co} = i_{cx} + i_{cy} + i_{cz} \tag{6}$$

Filter model (1) to (6) has been transformed to the *αβ0* orthogonal frame of reference:

$$\begin{bmatrix} S_{f0} \\ S_{f\alpha} \\ S_{f\beta} \end{bmatrix} = \frac{d}{d\tau}\begin{bmatrix} 3N_1 & & \\ 0 & & \\ 0 & & \end{bmatrix}\begin{bmatrix} i_{10} \\ i_{1\alpha} \\ i_{1\beta} \end{bmatrix} + L_1 \frac{d}{d\tau}\begin{bmatrix} i_{10} \\ i_{1\alpha} \\ i_{1\beta} \end{bmatrix} + \frac{d}{d\tau}\begin{bmatrix} 3N_2 & & \\ 0 & & \\ 0 & & \end{bmatrix}\begin{bmatrix} i_{s0} \\ i_{s\alpha} \\ i_{s\beta} \end{bmatrix} + \begin{bmatrix} S_{s0} \\ S_{s\alpha} \\ S_{s\beta} \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} S_{s0} \\ S_{s\alpha} \\ S_{s\beta} \end{bmatrix} = \begin{bmatrix} S_{c0} \\ S_{c\alpha} \\ S_{c\beta} \end{bmatrix} + R_c\begin{bmatrix} i_{c0} \\ i_{c\alpha} \\ i_{c\beta} \end{bmatrix} + \begin{bmatrix} S_{c0} \\ 0 \\ 0 \end{bmatrix} + R_0\begin{bmatrix} i_{c0} \\ 0 \\ 0 \end{bmatrix} - \frac{d}{d\tau}\begin{bmatrix} 3N_2 & & \\ 0 & & \\ 0 & & \end{bmatrix}\begin{bmatrix} i_{s0} \\ i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \tag{8}$$

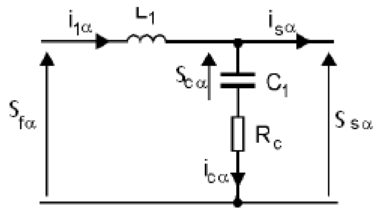
$$C_1 \frac{d}{d\tau}\begin{bmatrix} S_{c0} \\ S_{c\alpha} \\ S_{c\beta} \end{bmatrix} = \begin{bmatrix} i_{10} \\ i_{1\alpha} \\ i_{1\beta} \end{bmatrix} - \begin{bmatrix} i_{s0} \\ i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} i_{10} \\ i_{1\alpha} \\ i_{1\beta} \end{bmatrix} = \begin{bmatrix} i_{s0} \\ i_{s\alpha} \\ i_{s\beta} \end{bmatrix} + \begin{bmatrix} i_{c0} \\ i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \tag{10}$$

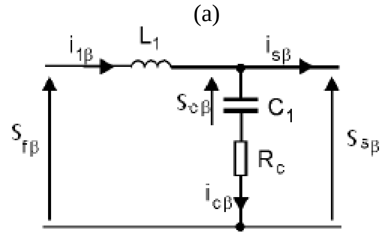
$$C_0 \frac{dS_{cc}}{d\tau} = i_{c0} \tag{11}$$

where $\tau$ is time per unit = $2\pi f_o t$, and $f_o$ is the electrical grid frequency. The αβ0 are presented in the Fig.4

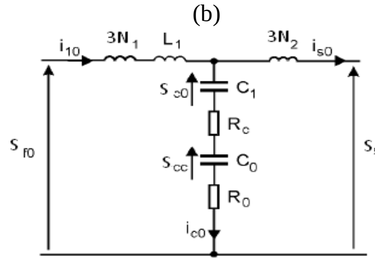
One can observe that for the *αβ* components the parameters of the differential mode filter exist [9, 10]. For the 0 component, only common mode filter elements are present.




(a)




(b)




(c)

Fig.4. Filter model circuit in αβ0 references: (a), (b) differential mode, (c) common mode.

Table 1: Filter and Induction Motor Parameter

| Parameter | Value | Description |
|---|---|---|
| $P_n$ | 0.75kW | Nominal |
| $S_n$ | 415V | Phase Voltage |
| $I_n$ | 3.5A | Nominal current |
| $N_n$ | 1390 | Nominal speed |
| $P$ | 50Hz | Supply frequency |
| $f_n$ | 11.12Ω | Stator resistance |
| $L_l, L_2$ | 0.23H | Stator inductance (leakage + mutual) |
| $L_m$ | 0.3 | Mutual inductance |
| $L_i$ | 6.3mH | Filter inductor |
| $C_i$ | 3.3 µF | Filter capacitor |
| $R_c$ | 3Ω | Damping resistance |
| $N_1, N_2$ | 14mH | C M choke inductance |
| $F_z$ | 1kHz | Filter resonance frequency |
| $C_o$ | 4.7 µF | Capacitor |
| $R_o$ | 33Ω | Resistor |

## II. Results

a) The experiment is carried with PWM drive at low speed with V/f control and a common load is employed throughout the experiment. Distribution of temperature of the induction motor is done.

b) Experiment is repeated with same V/f control and same load with filter is also studied. Distribution of temperature of induction motor is done.

c) Distribution of temperature at various parts of the induction motor is also studied with DC test, the thermal resistance, thermal capacitances are calculated at various parts of the induction motor, these parameters are used to determine the predicted temperature of the induction motor.

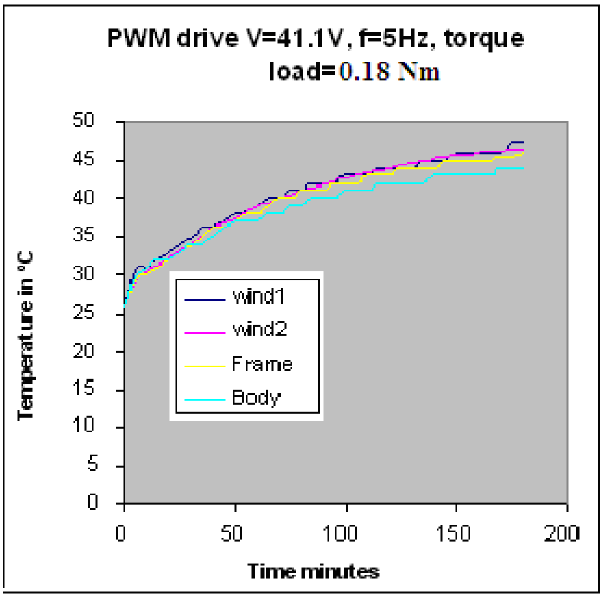



Fig.5: Measurement of temperature V=41V, f=5Hz, torque load=0.18Nm

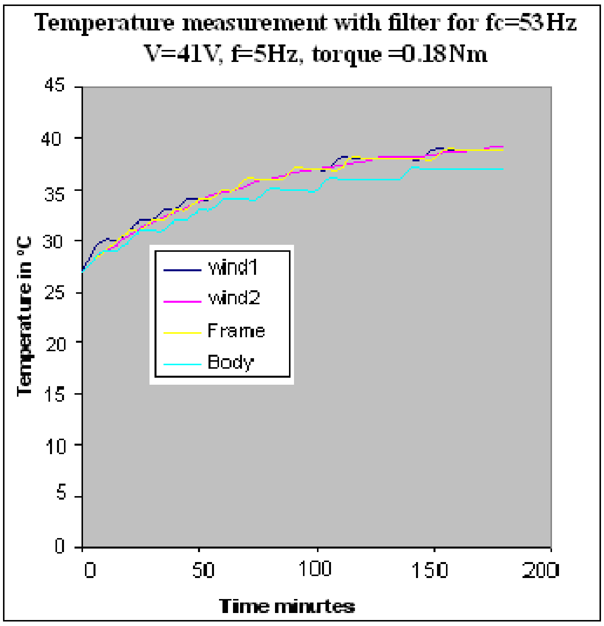



Fig.6: Measurement of temperature *V*=41, *f*=5Hz, torque load=0.18Nm with filter

Table 2: Measurement of temperature at various parts of the induction motor

| **Measurements at various parts** | **Temperature values at normal PWM Drive in ℃** | **Temperature values with filter =1kHz in ℃** | **Predicated Temperature values with filter =1kHz in ℃** |
|---|---|---|---|
| Left-Winding-1 | 47 | 39 | 38 |
| Right-Winding-2 | 46.6 | 39.2 | 38 |
| Frame(Yolk) | 46 | 39 | 37 |
| Outer body | 44 | 37 | 35 |
| Ambient | 26 | 27 | 27 |

## III. Conclusions

The effect of *dv/dt*, bearing current, and EMC noise are the major issues in induction motor. These parameters have adverse effect on windings of the induction motor that deteriorates the life time of the induction motor. The experimental work has been carried out to study the temperature at various parts of the induction motor with PWM drive, the results obtained using PWM inverter is compared with common mode filter connected between inverter and motor. The rise in temperature has been subsequently reduced at various parts of the induction motor is presented. The thermal model of three phase Induction motor is also constructed to determine the predicted temperature of the Induction motor.

## References

[1] A. Binder and A. Muetze, "Scaling effects of inverter-induced bearing currents in ac machines", *IEEE Trans. Ind. Appl.*, vol. 44, no.3, May/June 2008.

[2] D.F. Busse, J. Erdman, R. Kerkman, D. Schlegel and G. Skibinski, "The effects of PWM voltage source inverters on the mechanical performance of rolling bearings", Eleventh Annual Applied Power Electronics Conference, APEC'96, 3-7 March 1996, San Jose,(California), USA.

[3] H. Akagi, H. Hasegawa and T. Doumoto, "Design and performance of a passive EMI filter for use with a voltage-source PWM inverter having sinusoidal output voltage and zero common-mode voltage", *IEEE Trans. Power Electron.*, vol.19, no. 4, July 2004.

[4] M. Cacciato, A. Consoli, G. Scarcella and A. Testa. "Reduction of common-mode currents in PWM inverter motor drives", *IEEE Trans. Ind. Appl.*, vol. 35, no. 2, March/April 1999.

[5] S-J. Kim and S-K Sul, "A novel filter design for suppression of high voltage gradient in voltage-fed PWM inverter", Twelfth Annual Applied Power Electronics Conference and Exposition, APEC'97, February 1997, Atlanta, USA.

[6] H.T. Mouton "Natural balancing of three-level neutral-point-clamped PWM inverters", *IEEE Trans. on Ind. Electron.*, vol 49, no. 5, October 2002, pp.1017-1025.

[7] A.L. Julian and T.A. Lipo, "Elimination of common mode voltage in three phase sinusoidal power converters", IEEE PES Conference Rec., pp. 1968-1972, 1996.

[8] S. Chen, T.A. Lipo, and D. Fitzgerald, "Modeling of motor bearing currents in PWM inverter-fed ac motor drive system", *IEEE Trans. Ind. Appl.*, vol.33, no.4, pp. 1019-1026, 1997.

[9] J. Guziński, "Closed loop control of AC drive with LC filter", 13th International Power Electronics and Motion Conference EPE–PEMC, September 2008, Poznan, Poland.

[10] J. Guziński, "Sensorless AC drive control with LC filter", 13th European Conference on Power Electronics and Applications EPE'09, September 2009, Barcelona, Spain.
[11] T. Kawabata, T. Miyashita and Y. Yamamoto, "Digital control of three phase PWM inverter with LC filter", *IEEE Trans. Power Electron*., vol. 6, no. 1, January 1991.
[12] W. Koczara and R. Seliga, "High quality sinusoidal voltage inverter for variable speed ac drive systems", The Third International Power Electronics and Motion Control Conference, IEEE IPEMC 2000. vol. 3, August 2000, Beijing, China.

## BIOGRAPHY

**Dr. Manjesh** obtained his Ph.D in march 2012, presently working as Assistant 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.

**Mr. Rajesh B** Obtained his M.Sc. Electronics from Department of Electronic Science, Bangalore University, Bangalore. Presently Ph.D student in the same department under Dr. Manjesh. working on power electronics and motor drives.