

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

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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.

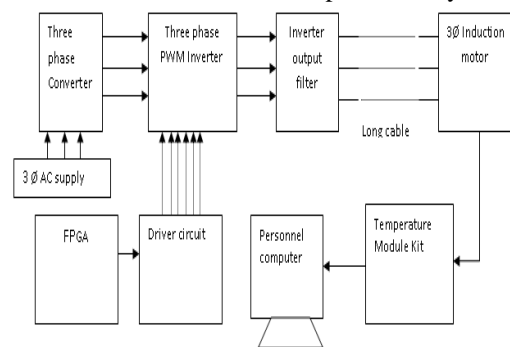


Fig.1: Experimental setup three phase motor drive

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 $\alpha\beta$ 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

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

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

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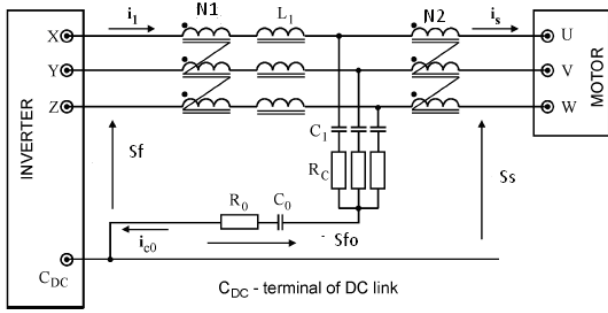


Fig.2. Inverter output filter with common mode and differential mode

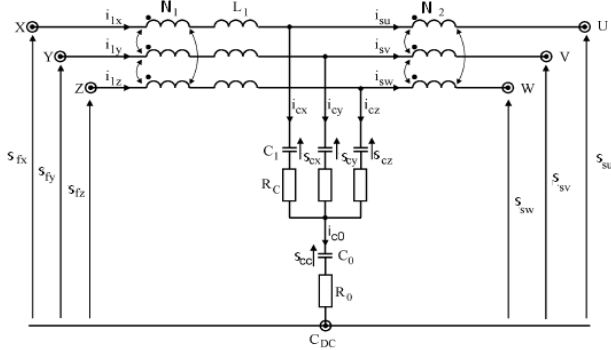


Fig.3. Equivalent filters circuit in ABC references

$$C_1 \frac{d}{d\tau} \begin{bmatrix} S_{cx} \\ S_{cy} \\ S_{cz} \end{bmatrix} = \begin{bmatrix} i_{1x} \\ i_{1y} \\ i_{1z} \end{bmatrix} - \begin{bmatrix} i_{sx} \\ i_{sy} \\ i_{sw} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} i_{1x} \\ i_{1y} \\ i_{1z} \end{bmatrix} = \begin{bmatrix} i_{sx} \\ i_{sy} \\ i_{sw} \end{bmatrix} + \begin{bmatrix} i_{cx} \\ i_{cy} \\ i_{cz} \end{bmatrix} \quad (4)$$

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

$$i_{co} = i_{cx} + i_{cy} + i_{cz} \quad (6)$$

Filter model (1) to (6) has been transformed to the $\alpha\beta$ orthogonal frame of reference:

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

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

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

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

$$C_0 \frac{dS_{cc}}{d\tau} = i_{c0} \quad (11)$$

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

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

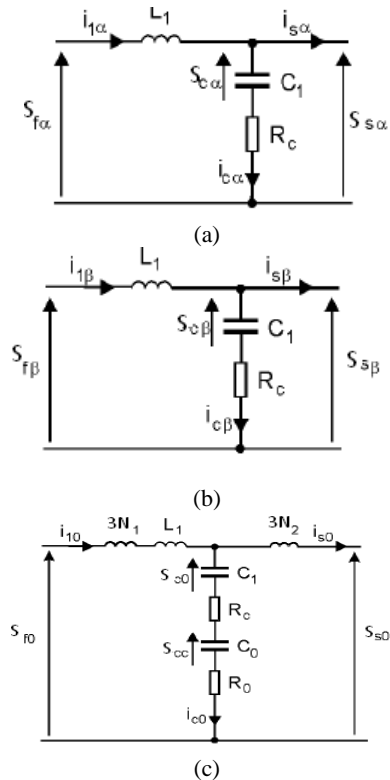

 Fig.4. Filter model circuit in $\alpha\beta$ references: (a), (b) differential mode, (c) common mode.

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	11.12 Ω	Stator resistance
L_l, L_2	0.23H	Stator inductance (leakage + mutual)
L_m	0.3	Mutual inductance
L_f	6.3mH	Filter inductor
C_f	3.3 μ F	Filter capacitor
R_c	3 Ω	Damping resistance
N_1, N_2	14mH	C M choke inductance
F_r	1kHz	Filter resonance frequency
C_o	4.7 μ F	Capacitor
R_o	33 Ω	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.

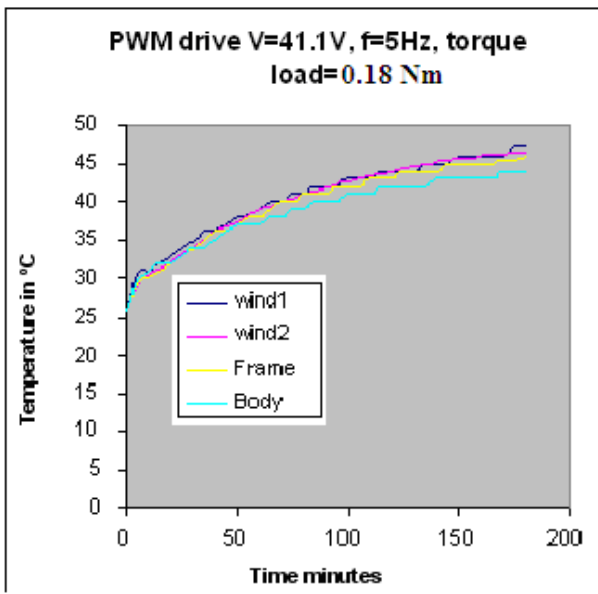


Fig.5: Measurement of temperature V=41V, f=5Hz, torque load=0.18Nm

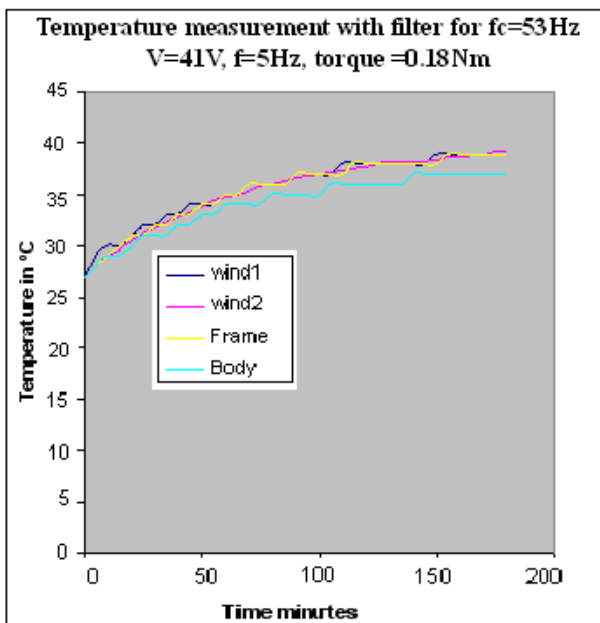


Fig.6: Measurement of temperature V=41, f=5Hz, torque load=0.18Nm with filter

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

Measurements at various parts	Temperature values at normal PWM Drive in °C	Temperature values with filter =1kHz in °C	Predicated Temperature values with filter =1kHz in °C
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.

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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.



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