I J C T A, 7(2) December 2014, pp. 175-182

Performance Study of two Motor Single Inverter Sensorless Drive with Unequal Ratings

R. Gunabalan[*] and V. Subbiah[**]

ABSTRACT

This paper describes the performance study of two induction motors of unequal ratings connected in parallel and controlled by a single inverter. The speed of the motors under unbalanced load conditions is maintained constant by employing PI controllers. Average and differential current flowing through the motors are considered to make the system stable under unbalanced load conditions. To perform sensorless control operation, natural observer is employed to estimate the stator currents, rotor fluxes and speed. In addition, the load torques of both the motors are estimated. The performance of the drive system is validated using MATLAB simulations.

Keywords: induction motor, observer, parallel connection, sensorless control, simulation

1. INTRODUCTION

Induction motors are preferred in most of the industries because of its simple structure, ruggedness, reliability and less maintenance. In the start, induction motors were controlled by scalar control techniques and were characterised by the complications in execution because of the computational burden. For control purpose, the speed of the motor was sensed by encoders or tacho-generators. It increases the cost of the sensor, cabling, the connectors and interfaces, and all related expenses [1]. In addition, the speed sensor is not suitable for hollow shaft motors, high temperature environment, high speed range and unfavourable environmental conditions. With the advancement of digital signal processors, power electronics and modern digital control schemes, speed sensorless ac motor drives were developed. To reduce the problems associated with speed sensors in industries, sensorless control of induction motor drive is preferred. In sensorless control, motor current and voltages are measured and speed is estimated from the measured quantities using mathematical relations.

Parallel connected induction motor drives are widely used in electric traction drives because of the advantages of low cost, light weight, compact structure and less number of power semiconductor switches. Conversely, voltage source inverter (VSI) fed induction motors in parallel has different motor speeds and load torques caused by different slip torque characteristics of motors, change in motor parameters and different wheel diameters between front and rear wheels.

In the past, parallel connected induction motors were treated as one large motor and speed sensor was attached to only one motor. However, in these methods unbalances of torque and current make the system unstable. It is overcome by the average and differential currents flowing into stator windings and rotor fluxes of induction motors [2] - [3]. To improve the performance of the parallel connected drive system, four leg [4] and five leg inverter [5] were used and induction motors were controlled with different voltage vectors. Nonlinear programming method was applied [6]-[7] to calculate the optimal voltage and frequency and load torque of each motor was estimated by disturbance observer. Inoue et al [8] presented the simulation

---

[*] Department of EEE, Dr. Sivanthi Aditanar College of Engineering, Tiruchendur-628215, Tamilnadu, INDIA, *E-mail: gunabalanr@yahoo.co.in*

[**] Department of EEE, PSG College of Technology, Coimbatore-641 004, Tamilnadu, INDIA, *E-mail: Subbiah42@yahoo.com*

results for equal and unequal ratings of induction motors and the speed difference between the induction motors is 125 to 150 rpm. PI controllers were used to generate the voltage references from current references. The system was stable in either case of equal and unequal ratings. The effects of radial difference, curve radius and parameter difference based on weighted voltage vector were discussed in [9]. The effects of deviation of the wheel diameters on motor current, rotor speed and torque were considered for parallel operation [10]. When the deviation was 6mm, the speed difference is less. Under worst case of 50mm deviation, the speed difference between the motors is high and it affects the traction effort.

Multiphase, multi motor vector controlled drive system fed by a single inverter was discussed in detail [11]. Multiphase induction motors such as six phases (double star) and nine phases (triple star) are preferred in electric locomotives because of fault tolerant features. The main drawbacks in multiphase drive system are it increases the cost of the drive system and size of the inverter. It is not suitable for existing three phase motors and special design methodologies to be adopted for manufacturing the motors.

To improve the control performance of unbalanced load, weighted vector control was applied [12] and the speed of the motors was controlled by PI and P controller, respectively. Mean and master slave field oriented control was applied to study the performance of multi motor control [13]. Small signal analysis was performed to compare the various control methods and speed sensor was used to measure the speed.

In most of the literatures, adaptive observers were used to estimate the speed and rotor fluxes. It needs some correction term in order to follow speed changes and the estimations always lagging the actual values. To avoid such difficulties, natural observer based parallel connected induction motors of same rating with fuzzy PI controllers were discussed in [14]. The primary focus of this paper is to study the performance of dissimilar ratings motors in parallel under unbalanced load conditions and to reduce the speed difference amongst the motors and employ natural observer to estimate the speed, rotor fluxes and load torque.

2. SINGLE-INVERTER TWO-MOTOR DRIVE

Current flowing in each motor are unbalanced if there is a difference between the motor speeds or the machine parameters. Under unbalanced load conditions, i_{s1} does not equal to i_{s2} and the average current $\bar{i}_s$ is compared with the reference current i_s^* to produce the required control voltage for the inverter. Figure 1 shows the block diagram of single inverter fed two-motor drive in parallel. The major blocks are adaptive load torque estimation with natural observer, Current Regulated Pulse Width Modulated (CRPWM) voltage source inverter, Park and Clarke transformation blocks, reference current calculation blocks and, average and differential currents, fluxes and speed calculation blocks. The torque reference is derived from the output of PI controllers. The reference current $\bar{i}_{ds}^{e*}$ and $\bar{i}_{qs}^{e*}$ are derived from space vector model of induction motor and are as follows:

$$\overline{I_{ds}^{e*}} = \frac{\overline{s_r}\,\overline{\varphi_{dr}^{e*}} + \Delta\overline{\widehat{\omega_r}}\,\Delta\overline{\widehat{\varphi_{qr}^{e}}} + \Delta\overline{S_r}\,\Delta\varphi_{dr}^{\overline{\widehat{e}}} - \Delta_1{}_{ds}^{\overline{\widehat{e}}}}{\bar{\bar{U}}} \tag{3}$$

$$\bar{I}_{qs}^{e*} = \frac{\dfrac{\bar{T}}{p\bar{M}'} - \Delta\,\bar{\hat{\imath}}_{ds}^{e} \times \Delta\bar{\hat{\varphi}}_{dr}^{e} + \Delta\,\bar{\hat{\imath}}_{qs}^{e} \times \Delta\bar{\hat{\varphi}}_{qr}^{e}}{\bar{\hat{\varphi}}_{dr}^{e*}} \tag{4}$$

$$\bar{T} = \frac{\bar{T}_{e^-}\left(\dfrac{\Delta\overline{M'}}{M'}\right)\Delta\bar{T}_e}{1-\left(\dfrac{\Delta\overline{M'}}{M'}\right)^2} \tag{5}$$

where,

$$U = S_r L_m \quad \bar{U} = \frac{U_1+U_2}{2} \quad \Delta\bar{U} = \frac{U_2-U_1}{2}$$

$$\bar{M} = \frac{1}{2}\left(\frac{L_{m1}}{L_{r1}}+\frac{L_{m2}}{L_{r2}}\right) \qquad \overline{\Delta M} = \frac{1}{2}\left(\frac{L_{m2}}{L_{r2}}-\frac{L_{m1}}{L_{r1}}\right)$$

$$\overline{I_s^e} = \frac{i_{s1}^e+i_{s2}^e}{2} \quad \overline{\Delta I_s^e} = \frac{i_{s2}^e-i_{s1}^e}{2}$$

$$\overline{\widehat{\omega_r}} = \frac{\hat{\omega}_{r1}+\hat{\omega}_{r2}}{2} \quad \overline{\Delta\widehat{\omega_r}} = \frac{\hat{\omega}_{r2}-\hat{\omega}_{r1}}{2} \quad \overline{S_r} = \frac{s_{r1}+s_{r2}}{2} \quad \overline{\Delta S_r} = \frac{s_{r2}-s_{r1}}{2}$$

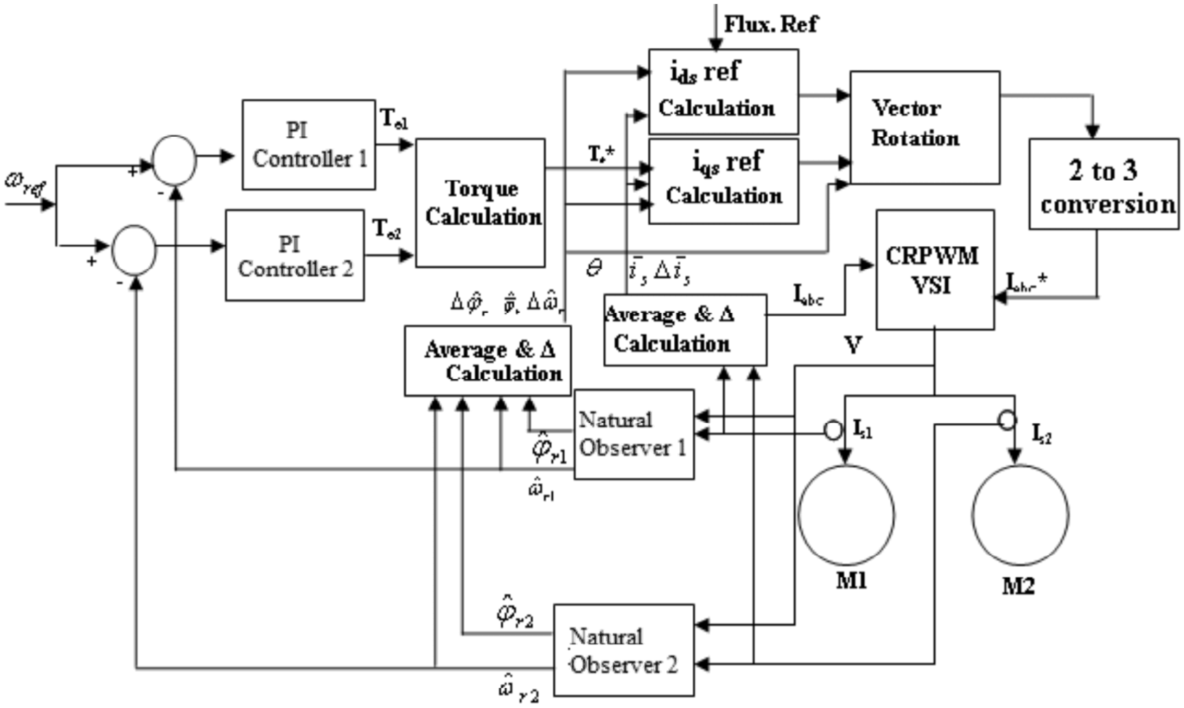

Figure 1: Single-inverter Fed two-motor Drive System

3. MATLAB SIMULATION RESULTS AND DISCUSSIONS

Two induction motors of dissimilar ratings are connected in parallel and their parameters are given in Table 1. The simulation conditions at different time intervals are given in Table 2. Initially, both motors run at a speed of 900 rpm and at t = 2s, a step command is given and the speed of the motor increases from 900 rpm to 1100 rpm. At no load, both the motors follow the command speed and the estimated and actual speed remains same. At t = 4s, a load of 2.5 Nm is applied to both motors and it results that the speed difference among the induction motors is 20 rpm and is steady. At t = 6s, load of motor 2 is disconnected and motor 1 runs continuously at load condition. The speed difference with respect to the command speed is 90 rpm and both run at constant steady speed. In literature [8], the speed difference among the induction motors is 125 to 150 rpm for dissimilar ratings of induction motors for a set speed of 700 rpm. The speed difference is reduced in this work for dissimilar ratings at unbalanced load conditions. The individual speed responses of motor 1 and motor 2 are depicted in Figure 2 and Figure 3 respectively. This indicates that, the PI controller and the estimator makes the system stable for unbalanced load conditions. For comparison, the estimated and actual speed responses are plotted separately and are illustrated in Figure 4 and Figure 5 in that order. The estimated and actual torque responses of both the motors are shown in Figure 6 and Figure 7 respectively. The estimated torque is free from ripple and it shows that the natural observer estimates the load torque correctly under noisy environment conditions.

Table 1
Rating and Parameters of Induction Motors

Ratings	*Motor 1*	*Motor 2*
Output	559.2 W	745.6 W
Poles	4	4
Speed	1420 rpm	1415 rpm
Voltage	415 V	415 V
Current	1.8 A	1.8 A
Frequency	50 Hz	50 Hz
R_s	14.775 Ω	19.355 Ω
R_r	4.767 Ω	8.43 Ω
L_s	0.8075 H	0.715 H
L_r	0.8075 H	0.715 H
L_m	0.7485 H	0.689 H

Table 2
Simulation Conditions

Time (s)	*0-2*	*2-4*	*4-6*	*6-8*
Speed (rpm)	900		1100	
Load torque – motor 1(Nm)	0	0		2.5
Load torque – motor 2 (Nm)	0	0	2.5	0

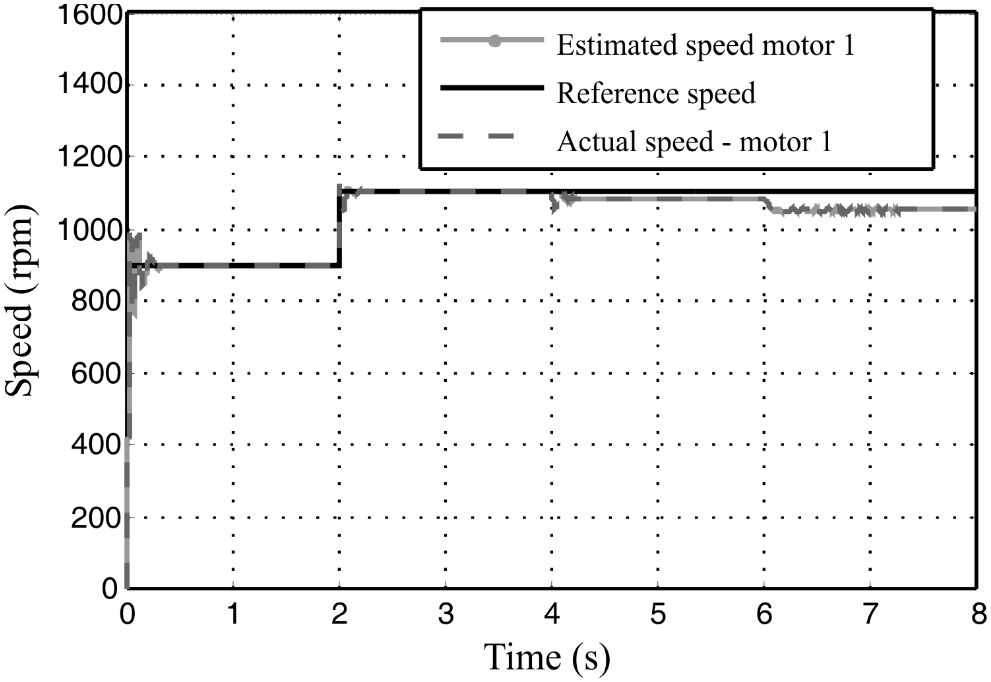

Figure 2: Speed Response of Induction Motor 1

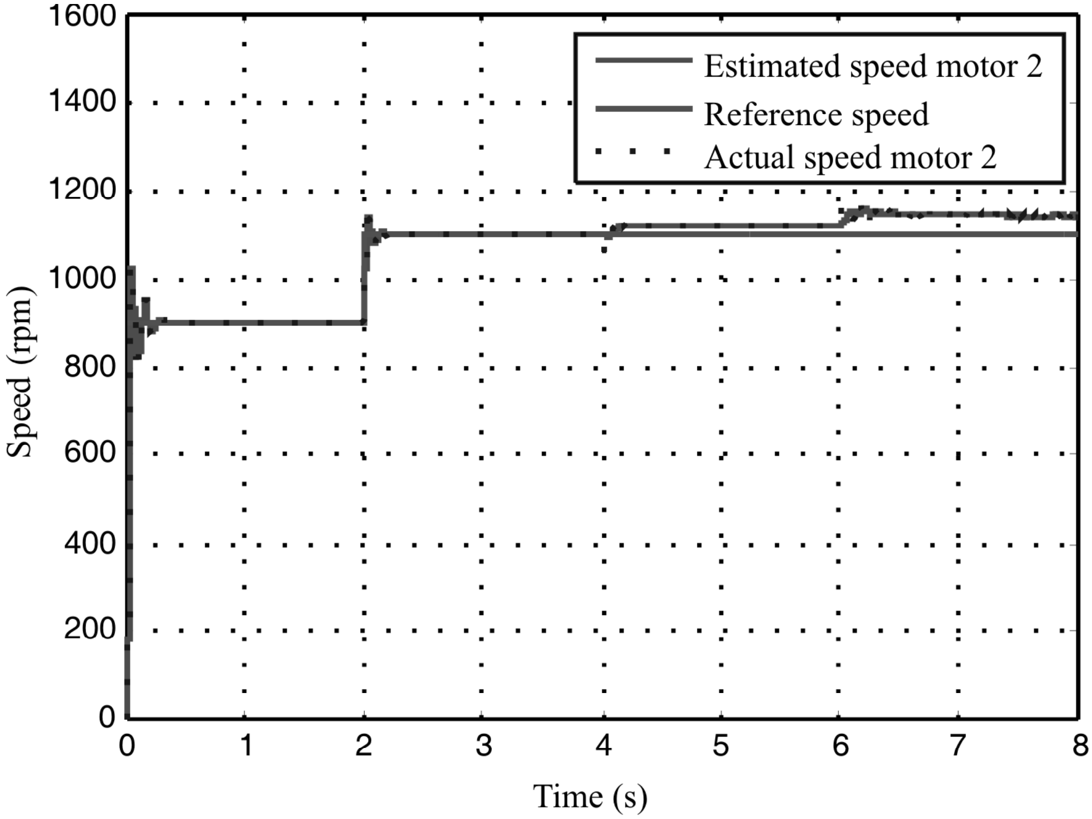

Figure 3: Speed Response of Induction Motor 2

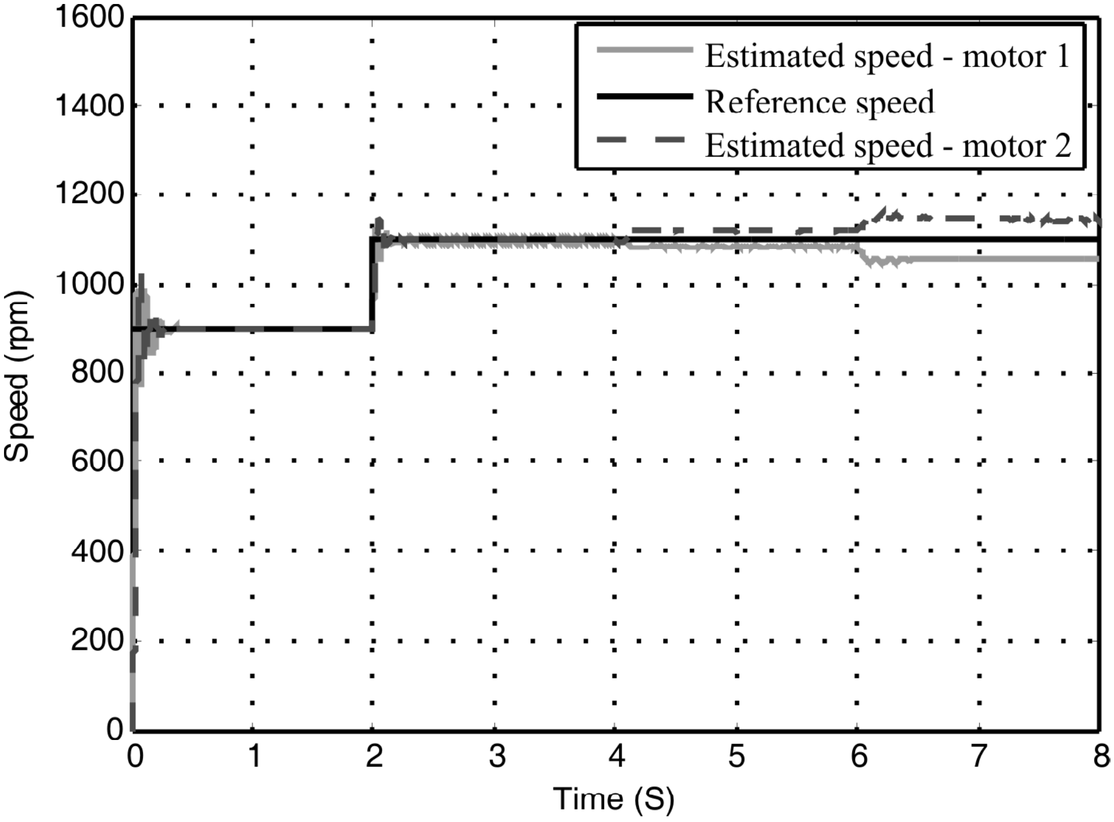

Figure 4: Estimated Speed Response of Motor 1 and Motor 2

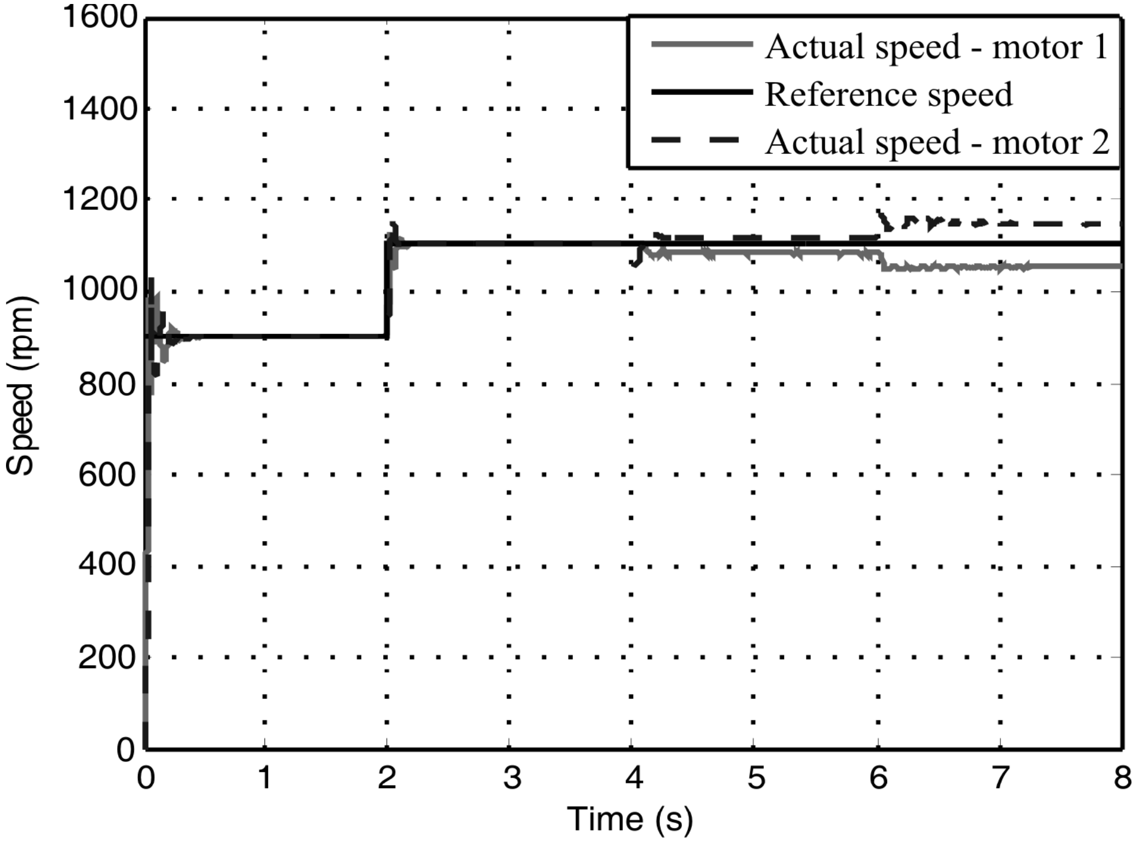

Figure 5: Actual Speed Response of Motor 1 and Motor 2

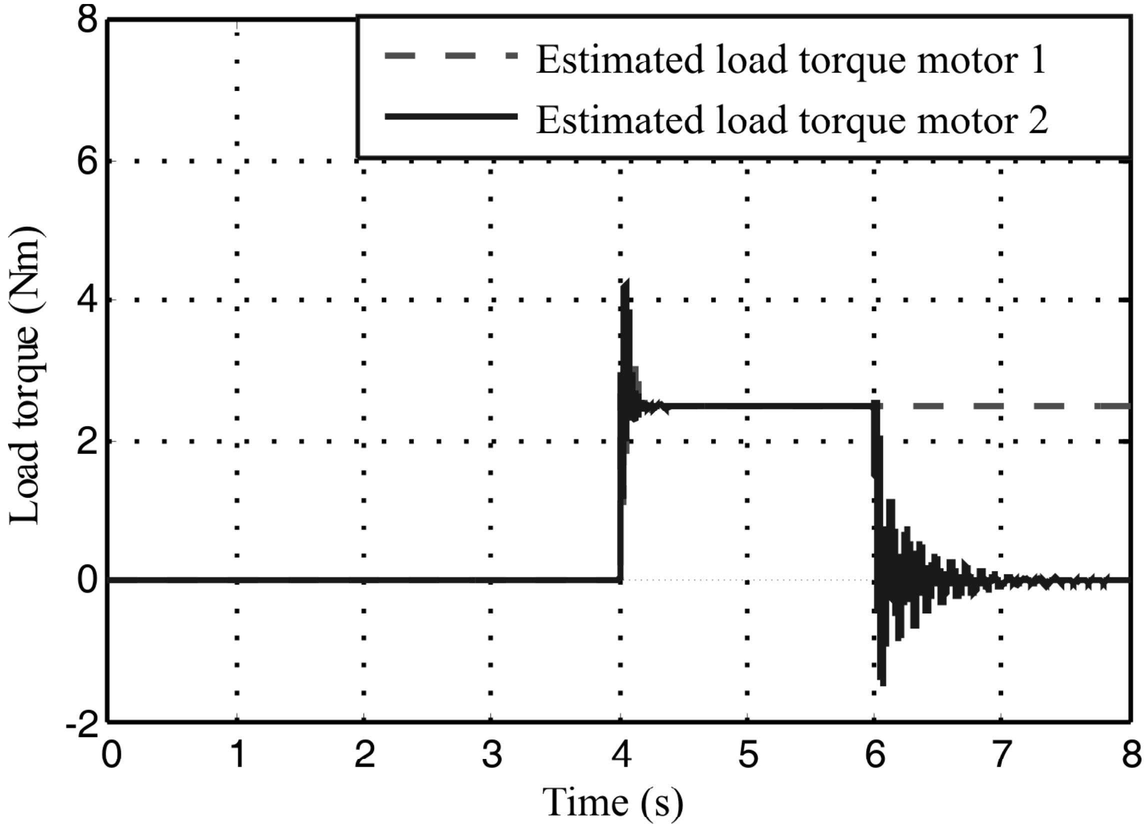

Figure 6: Estimated Torque Response of Motor 1 and Motor 2

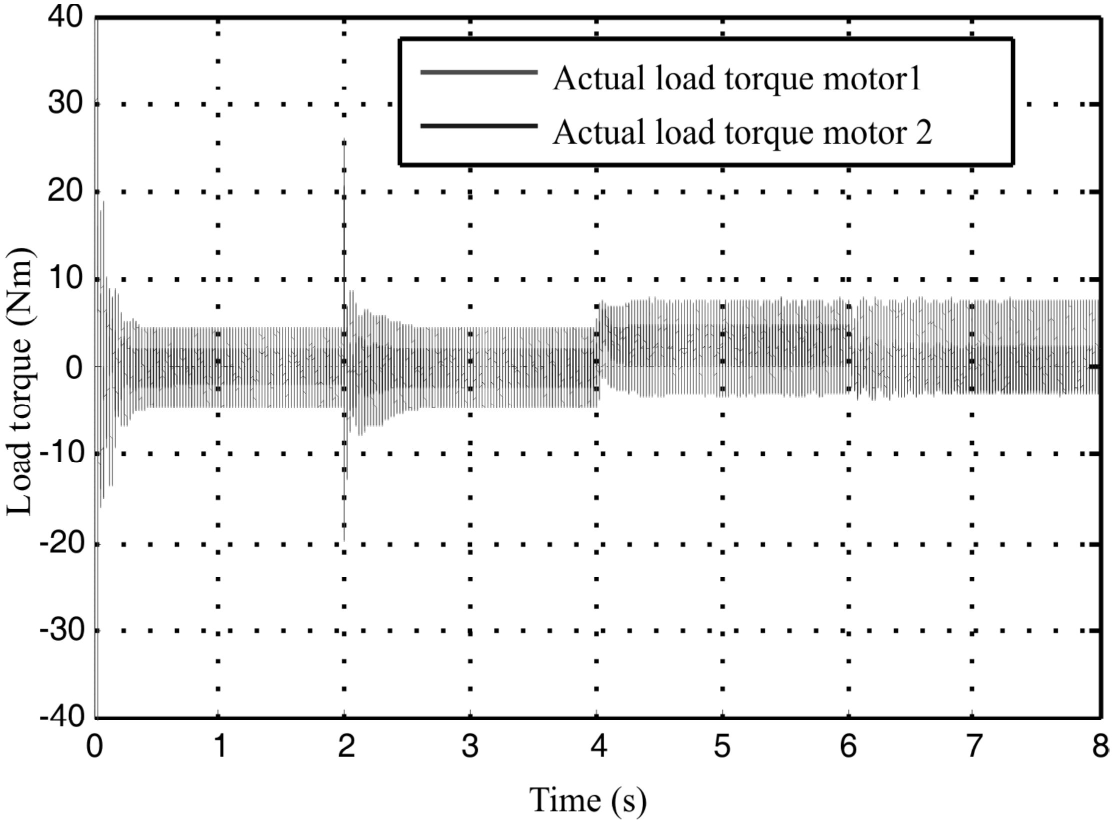

Figure 7: Actual Torque Response of Motor 1 and Motor 2

4. CONCLUSION

The performances of two induction motors of dissimilar ratings connected in parallel and driven by a single inverter are studied. The speed of the motors for various loads are maintained a constant value irrespective of motor ratings by employing PI controllers and the speed difference is minimum amongst the motors. Rotor speeds, load currents, rotor fluxes and load torques are estimated using natural observer. The performances of the controllers and natural observer are validated using MATLAB simulations.

REFERENCES

[1] Mario Pacas, "Sensorless drives in industrial applications- advanced control schemes", *IEEE Industrial Electronics Magazine*, pp. 16-23, June 2011.

[2] K. Matsuse, Y. Kouno, H. Kawai and J.Oikawa, "Characteristics of speed sensor-less vector controlled dual induction motor drive connected in parallel fed by a single Inverter", *IEEE Trans. Industry Applications.*, Vol. 40, pp. 153-161, Jan./Feb. 2004.

[3] K. Matsuse, Y. Kouno, H. Kawai and S. Yokomizo, "A Speed-sensor-less vector control method of parallel-connected dual induction motor fed by a single inverter," *IEEE Trans. Industry Applications*, Vol. 38, pp. 1566–1571, Nov./Dec. 2002.

[4] K. Matsuse, N. Kezuka and K. Oka, "Characterisitcs of independent two induction motor drives fed by a four-leg inverter", *IEEE trans. Industry Applications*, Vol. 47, No. 2, pp. 2125-2134, Sep. 2011.

[5] M. Jones, S. N. Vukosavic, and D. Dujic, "Five-leg inverter PWM technique for reduced switch count two-motor constant power applications", *IET- Electric Power Applications*, Vol. 2, pp. 275-287, 2008.

[6] Ando I., Sato M., Sazawa M and Ohishi K., "High efficient parallel connected induction motor speed control with unbalanced load condition using one inverter", in Proc. *IEEE*, *IECON'03*, 2003, pp. 162-167.

[7] Ando I., Sazawa M. and Ohishi K., "High efficient speed control of parallel connected induction motors with unbalanced load condition using one inverter", in Proc. *IEEE*, 2004, pp.1361-1366.

[8] Inoue T., Azegami K., Matsuse K., Ito S. and Nakajima Y., "Characteristics of sensorless vector controlled multiple induction motor drive connected in parallel fed by a single inverter", *in Proc. IEEE- Power Engineering Conference*, 2011.

[9] Fei Xu, Liming Shi, "Unbalanced thrust control of multiple induction motors for traction system", *in Proc. IEEE- Industrial Electronics and Applications*, pp. 2752-2757, 2011.

[10] Hyung-Woo Lee, "Study on Motor Characteristics due to Deviation of the Wheel Diameters with Parallel Operation", *Journal of Electrical Engineering Technology*, Vol. 8, No. 1, pp. 106-109, 2013.

[11] Martin Jones, Vukosavic S. N. and Emil Levi, "Parallel connected multiphase multi drive systems with single inverter supply", *IEEE Trans. Industrial Electronics*, Vol. 56, No. 6, pp. 2047-2057, June 2009.

[12] Levi E., Jones M., Vukosavic S. N. and Toliyat H. A., "A novel concept of a multi-phase, multi-motor vector controlled drive system supplied from a single voltage source inverter", *IEEE Trans. Power Electronics*, Vol. 19, No.2, pp. 320-335, March 2004.

[13] Fei Xu, Liming Shi and Yaohua Li, "The Weighted Vector Control of Speed-Irrelevant Dual Induction Motors Fed by the Single Inverter", *IEEE trans. Power Electronics*, Vol. 28, No.12, pp. 5665-5672, 2013.

[14] R. Gunabalan, V. Subbiah, "Speed sensorless vector control of parallel connected induction motor drive with fuzzy controller", *in Proc.of IEEE conference (ICCIC'12),* 2012, pp. 473-478.