Novel V/f Strategy Using Command Speed Compensator for Improved Load Sharing With Dual Induction Motor

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Abstract

Large torque demand in industries can be supplied by using multiple induction motors. Usage of multiple induction motor is not only useful in supplying higher torque demands, but also provides an added advantage of ease of maintenance and reliability. However, while using multiple induction motors care should be taken to ensure that all the motors share load equally or proportionately. In practice variation in motor parameters leads to unequal load sharing. To overcome this problem an improved V/f strategy to ensure equal load sharing is discussed in this paper.

Keywords: *Load Sharing, Torque Sharing, Speed Command Compensator.*

1. Introduction

Induction motors are the most widely used motors for industrial applications due to their simple and rugged construction. They are available in wide range of power, torque and speed ratings. Also the output torque and speed of the motor can be easily controlled using variable frequency drives. For industrial applications that demand higher magnitude of power, it would be wise to supply the demand using two or more induction motors of smaller power ratings than a single induction motor drive of larger rating. Usage of multiple motor drives to supply a load offers some of the advantages, such as ease of maintenance and assured reliability. However, while using multiple motor drives to run a common load it becomes very essential to ensure that all the motors are sharing the load equally or proportionately. Also the speed of the motor should be synchronized as per the load demand. In the event of uneven or disproportionate load sharing , one of the motors will get overloaded resulting in the other motor being underutilized. Therefore, there should be some means to monitor and control the load sharing among the motors.

2. Load Sharing Using existing Conventional V/F Controlled Induction Motors

The existing motor drive arrangement for sharing a common load using V/f scheme is shown in Fig.1

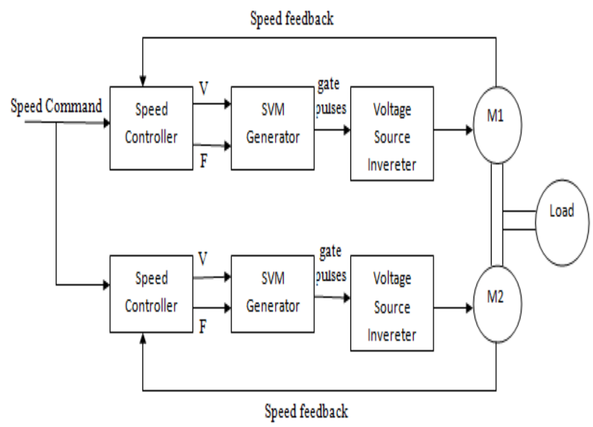

Fig.1 Block diagram for existing load sharing scheme using V/F control of induction motors

Both the induction motors are controlled using a voltage source inverter fed from a pulse generator which is space vector pulse width modulated. The votage and frequency control signals to the pulse generator are generated using a PI speed controller.

In order to analyse load sharing using this existing V/f control scheme, two induction motors , sharing a common mechanical load of 10Nm at a speed of 1700rpm was simulated using MATLAB/SIMULINK. The motors chosen are assumed to have

- same power rating of 3HP, 220V, 60Hz
- identical parameters: $r_s = 0.435\ \Omega$, $r_r' = 0.816\ \Omega$, $L_s = 0.002H$, $L_r' = 0.002H$ and $L_m = 69.31 \times 10^{-3}\ H$

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The simulation results for load sharing using existing load sharing schemes with identical induction motors is shown in Fig.2. It can be inferred from Fig.2 that

- The motors which are assumed to be identical in all respects share load equally
- Each motor is found to contribute a torque of 5Nm to the load.

Table 1: Torque developed by M1 and M2 with identical parameters using existing load sharing scheme

MOTOR	Torque	Rotor Resistance	Speed
M1	5 Nm	0.816Ω	178 rad/sec
M2	5 Nm	0.816Ω	178 rad/sec

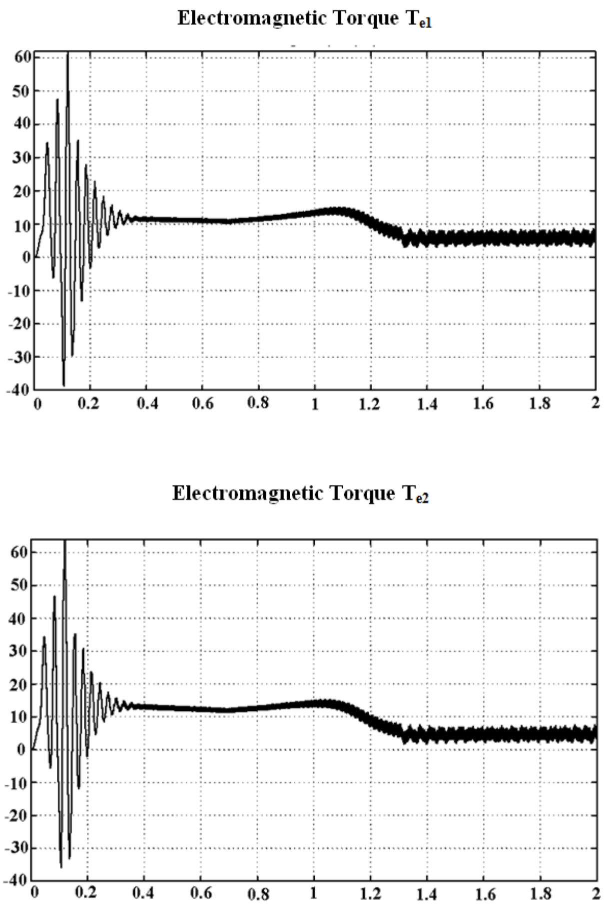

Fig. 2 Load sharing between two induction motors M1 and M2 with identical parameters

However, in practice, induction motors of common power rating may not have identical parameters. Let us now consider two un-identical induction motors sharing a common mechanical load of 10Nm at a speed of 1700rpm. The two motors are assumed to have

- same power rating of 3HP, 220V, 60Hz
- different values of rotor resistance. Rotor resistance r_r' of M1 is 0.816Ω and M2 is 2.816Ω.

Variation of rotor resistance is considered here as the torque developed by the induction motor is most dependent on the rotor resistance. The simulation results using existing load sharing scheme for un-identical motors is shown in Fig. 3 and is tabulated in Table 2. Though the motors are of same power rating, it is found from Fig. 3 that the motor with lower rotor resistance develops higher torque than the motor with the higher rotor resistance.

Table 2: Torque developed by M1 and M2 with different rotor resistances using existing load sharing scheme

MOTOR	Torque	Rotor Resistance	Speed
M1	7.2Nm	0.816Ω	178rad/sec
M2	2.8 Nm	2.816Ω	178 rad/sec

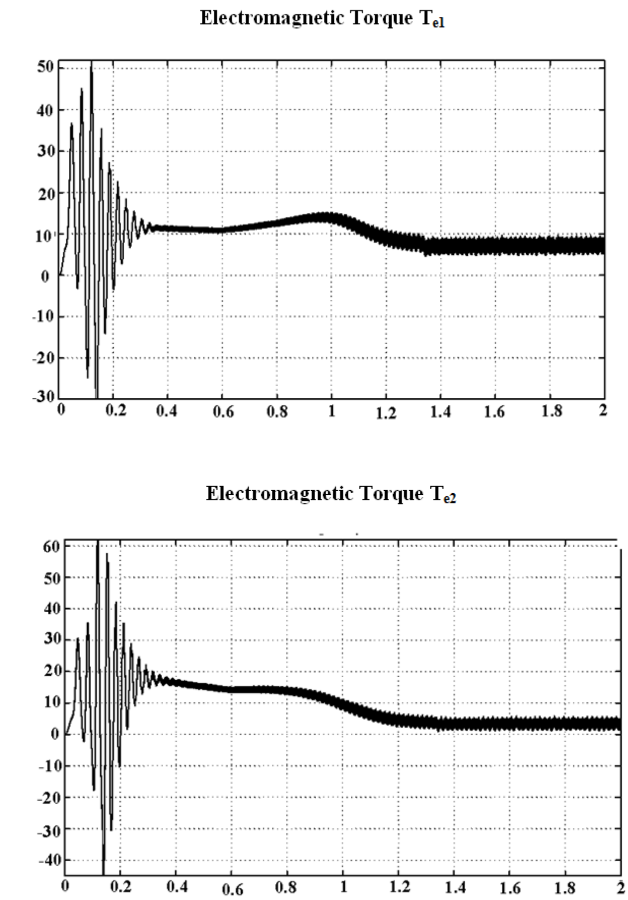

Fig. 3 Load sharing between two induction motors M1 and M2 with variation in rotor resistance using existing load sharing scheme

From the tabulated results it can be inferred that

- it is not possible to obtain symmetric torque sharing using the existing conventional V/f scheme of load sharing, which determines the developed torque based on the torque speed characteristics of the induction motor.

- M1 is overloaded and M2is underutilised due to variation in machine parameters.

In order to compensate for the changes in the motor parameter, the speed command signal to the second motor should be changed accordingly.

To achieve this, the speed command to the second motor should be fed through a command speed compensator. The design of command speed compensator is discussed in the following section.

3. Design of command speed compensator

The steady state equivalent circuit of an induction motor[4] is shown in Fig. 4

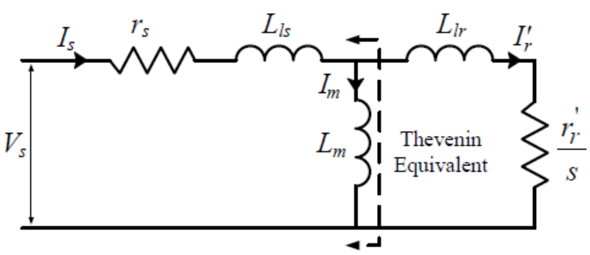

Fig 4. Steady state equivalent circuit of induction motor

For V/f control of induction motor, the relationship between voltage and frequency[5] is expressed as follows

$$\frac{V_r}{\omega_{rated}} = \frac{V_s}{\omega_e^*} \quad (1)$$

$$V_s = \left[\frac{V_r}{\omega_{rated}}\right] \omega_e^* \quad (2)$$

V_r is the rated voltage

ω_{rated} is the rated electrical frequency

ω_e^* is the commanded electrical frequency

The steady state electromagnetic torque developed by induction motor is given as [4]

$$T_e = 3\frac{P}{2}\frac{V_{th}^2}{\omega_e} \times \frac{\frac{r_r'}{s}}{\left(R_{th} + \frac{r_r'}{s}\right)^2 + \left(X_{th} + X_{lr}'\right)^2} \quad (3)$$

where V_{th}, R_{th} and X_{th} can be determined from steady state equivalent circuit of induction motor.

$$V_{th} = \frac{V_s \times jX_m}{[r_s + j(X_{ls} + X_m)]} \quad (4)$$

$$R_{th} = \frac{r_s X_m}{(X_{ls} + X_m)} \quad (5)$$

$$X_{th} = \frac{X_{ls} X_m}{(X_{ls} + X_m)} \quad (6)$$

Since the slip in the motoring region is very low, the above electromagnetic torque equation can be approximated as

$$T_e = 3\frac{P}{2}\frac{V_{th}^2}{\omega_e} \times \frac{\frac{r_r'}{s}}{\left(\frac{r_r'}{s}\right)^2} \quad (7)$$

$$T_e = 3\frac{P}{2}\frac{V_{th}^2}{\omega_e} \times \frac{s}{r_r'} \quad (8)$$

The electromagnetic torque developed by M1 and M2 is indicated using T_{e1} and T_{e2} respectively. The suffixes 1 and 2 are being used for parameters of M1 and M2 respectively

$$T_{e1} = 3\frac{P}{2}\frac{V_{th1}^2}{\omega_{e1}} \times \frac{s}{r_{r1}'} \quad (9)$$

$$T_{e2} = 3\frac{P}{2}\frac{V_{th2}^2}{\omega_{e2}} \times \frac{s}{r_{r2}'} \quad (10)$$

For equal load sharing

$$T_{e1} = T_{e2}$$

Using Eq (2), (4), (5) and (6) we can obtain an expression for the command speed of the second drive as follows

$$\omega_{e2} = \left[(\omega_{e1} - \omega_r)\left(\frac{X_{M1}}{X_{M2}}\right)^2 \left(\frac{r_{r2}}{r_{r1}}\right)^2 \left(\frac{X_{M1} + X_{ls1}}{X_{M2} + X_{ls2}}\right)^2\right] + \omega_r \quad (11)$$

The speed command compensator for the second drive can be designed using the Eq (11).

4. Load sharing using Improved V/f scheme with command speed compensator

Improved V/f scheme employing command speed compensator for equal load sharing among motors is shown in Fig 5. The command speed compensator is formed using Eq(11). The first motor drive system is unchanged whereas the drive for the second motor is modified. The PI speed controller that generates the voltage and frequency control signals to the pulse generator is eliminated. The command speed to the second drive is fed through the speed compensator block. The actual speed of the second motor is taken as a feedback signal to the command speed compensator block. The compensator varies the command speed to the second drive as per the variation in the rotor resistance of the machine

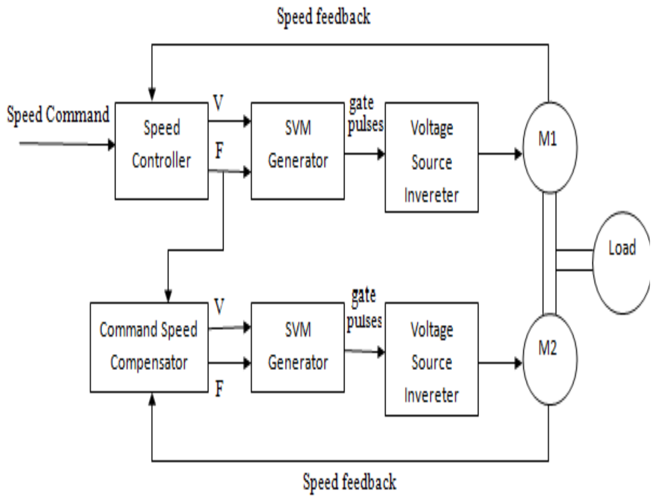

Fig 5. Block diagram for load sharing using proposed modified V/f scheme with a command speed compensator

In order to analyse the effect of the proposed modified V/f scheme using a command speed compensator on load sharing, two un-identical induction motors sharing a common mechanical load of 10Nm at a speed of 1700rpm is simulated using MATLAB/SIMULINK. The two motors are assumed to have

- same power rating of 3HP, 220V, 60Hz
- different values of rotor resistance. Rotor resistance r_r' of M1 is 0.816Ω and M2 is 2.816Ω

The simulation results obtained after employing the command speed compensator using MATLAB/SIMULINK is shown in fig 6. The torque developed by the motors are tabulated in Table 4. It can be inferred form Fig 6 that load sharing among the motors have improved

Table: 4 Torque developed by M1 and M2 with different rotor resistances using proposed modified V/f scheme with command speed compensator

MOTOR	Torque	Rotor Resistance	Speed
M1	5.2 Nm	0.816Ω	178 rad/sec
M2	4.8 Nm	2.816Ω	178 rad/sec

The voltage and frequncy control signals fed to the pulse generator of the drives of the two motors for achieving this load sharing using command speed compensator is as follows:

M1: $V = 219\ \ V;\ \ f = 59.7\ \ Hz;\ \ \frac{V}{f} = 3.66$

M2: $V = 206.5\ \ V;\ \ f = 56.4\ \ Hz;\ \ \frac{V}{f} = 3.66$

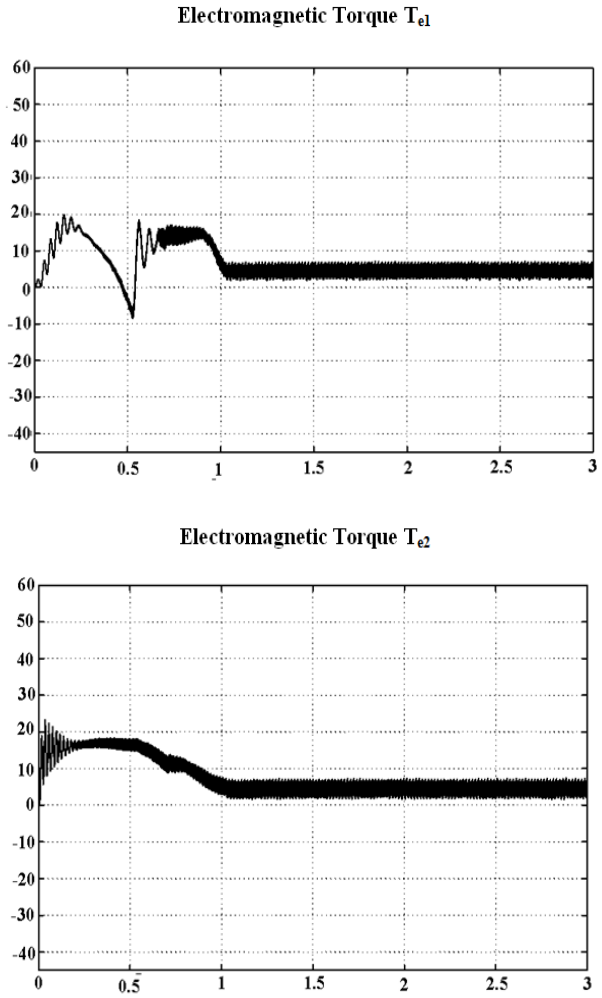

Fig. 6 Load sharing between two induction motors M1 and M2 with variation in rotor resistance employing proposed modified V/f scheme with command speed compensator

5. Conclusions

This paper addresses the problem of asymmetrical load sharing using two induction motors of same power rating with un-identical parameters. In order to overcome this problem the command speed to the second drive is varied in accordance with the variation in machine parameters. The existing V/f speed control scheme wass modified by including a command speed compensator for the second drive. The simulation of the proposed scheme shows that symmetrical load sharing can be obtained with two induction motors of varying parameters sharing a common load. Also it is found that both the motors are running at a speed of 178rad/sec(1700rpm). Comparison of load sharing between two motors with same power rating and different rotor resistances for conventional scheme and the proposed scheme is shown in Table 5.

Table: 5 Comparison between the developed torques by M1 and M2 using conventional scheme and proposed scheme

		M1	M2
Load sharing using existing scheme	Rotor resistance	0.816Ω	2.816Ω
	Torque	7.2Nm	2.8Nm
Load sharing using the proposed scheme	Rotor resistance	0.816Ω	2.816Ω
	Torque	5.2Nm	4.8Nm

With the inclusion of command speed compensator the torque contributed by the first motor M1 running at a speed of 178 rad/secs (1700rpm) is reduced to 5.2Nm from 7.2Nm. The deviation in the torque contribution by M1 is reduced as shown in Table 6

Table: 6 Comparison of M1 performance before and after inclusion of command speed compensator

Required Torque	5 Nm
Torque Without Compensator	7.2 Nm
Torque With Compensator	5.2 Nm
% Deviation without Compensator	44
% Deviation with Compensator	4
Inference	With the inclusion of command speed compensator the the torque contribution of the M2 has reduced.

With the inclusion of command speed compensator the torque contributed by the second motor M2 running at a speed of 178rad/sec (1700rpm) is increased to 4.8Nm from 2.8Nm. The deviation in the torque contribution by M2 is reduced as shown in Table 7

Table: 7 Comparison of M1 performance before and after inclusion of command speed compensator

Required Torque	5 Nm
Torque Without Compensator	2.8Nm
Torque With Compensator	4.8 Nm
% Deviation without Compensator	-78.5
% Deviation with Compensator	-4.16
Inference	With the inclusion of command speed compensator the the torque contribution of M2 has increased.

This method can also be extended to obtain proportionate load sharing when induction motors of different power ratings are used.

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