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A Comparison of V/f and Field Oriented Control of Three Phase Induction Motors Employed in Load Sharing

Roopa Nayak[1*], Andhe Pallavi[2]

[1]Department of Electrical and Electronics, RNSIT, VTU, Bangalore, India
[1]Department of Electronics and Instrumentation, RNSIT, VTU, Bangalore, India

[*]Corresponding Author: Roopa Nayak_nayakru@yahoo.com, Tel.: 9741175518

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Abstract— There are various applications in industries where it has become essential to employ multiple motors to drive a common load. This necessity of multiple motor employment has aroused due to several reasons such as the presence of large loads, lack of space for a large motor, need for redundancy and process requirements. Also, there are some of the processes such as conveyor belt and mills which cannot operate with merely one motor. Any process that necessitates the employment of multiple motors to drive a common load will have to adopt load sharing arrangement which is essentially the usage of multiple motor-drive set. With the advancements that has happened in Power Electronics and Electric Drive streams, the user has a wide range of motors and drives to choose from, for load sharing. However, a study of behavior of these motors and drives when employed for load sharing is of utmost importance, as this helps the user to choose the appropriate motor -drive set for the required application. Induction motors are used in majority of the applications in industry. Scalar control and vector control are adopted for induction motor control. Understanding the behavior of induction motor under scalar and vector control in a load sharing arrangement will ease the selection of appropriate control strategy. Therefore, a comparative study of V/f and Field Oriented Control strategies for controlling induction motor in a load sharing arrangement is carried out and results are discussed

Keywords— Load Sharing, Multiple Motor Drive, Torque sharing, V/f control, Field Oriented Control

I. INTRODUCTION

In a load sharing arrangement, multiple motors are used to share the torque requirements of the load[1]. Load sharing arrangement should satisfy the following conditions.

(i) There should be equal or proportionate torque sharing among the motors, so that none of the motors get overloaded.
(ii) The motors sharing the common load should run at a common speed as per the process requirement.

While employing Load sharing arrangement, two prime factors to be considered are[1]

(i) Choice of Motors
(ii) Choice of Control Strategy for controlling the motor

One of the quite widely used motors in industries are three phase induction motors. The popularity of these motors is owed to their ruggedness and their characteristics. Also, very well developed, sophisticated and proven control strategies are readily available for controlling the speed and torque of three phase induction motors. Hence three phase induction motors are suitable for load sharing [2][3].

The control strategies that can be used for controlling an induction motor are

(i) Scalar Control or V/f Control
(ii) Vector Control or Field Oriented Control

In V/f control of induction motor, the speed and torque of the motor is controlled by varying the magnitude and frequency of the input voltage of the motor. The voltage and frequency is varied such that the ratio of rated voltage to frequency remains constant. Whereas in Field Oriented Control, the torque and flux are independently controlled to obtain the desired speed and torque at the output of the motor.

These control strategies that are used for controlling induction motors can be extended to load sharing arrangements[2][3][4].

However, the behaviour of induction motor in load sharing arrangement will vary with the variation in control strategies adopted. A thorough understanding of how the motors behave in a load sharing arrangement when different control strategies are used will make it easier in choosing the right kind of motor-drive arrangement for load sharing. Hence a comparison of behaviour of V/f and Field Oriented Control in load sharing arrangements with two motors is made in this paper.

II. Related Work

A modified V/f control for torque sharing is discussed in [2], where equal torque sharing between two unidentical induction motors sharing a common load is obtained by comparing the torque component of the stator currents for the two motors. The two induction motors under study in [2] have unidentical rotor resistances. The speed reference of the two motors is varied based on the variation of torque component of the stator current of the two motors. This modified V/f control strategy is applied to vehicular wheels under slippery ground conditions in[3].

V/f control strategy has the disadvantage of sluggish torque response. Hence other control strategy for three phase induction motor such as Field Oriented Control can be explored.

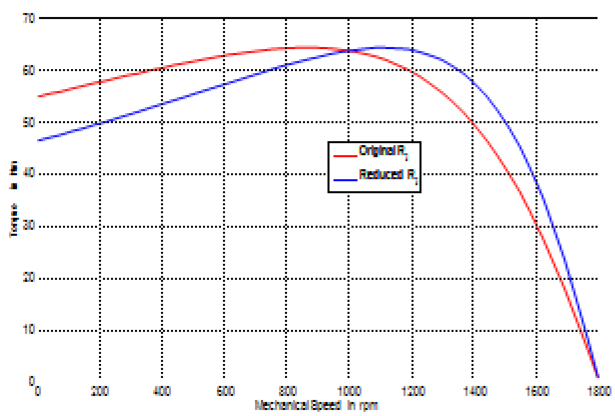

Figure.1 Torque-Speed characteristics of motors under study

III. LOAD SHARING WITH V/F CONTROL STRATEGY

When three phase induction motors are used for load sharing, it is found that the torque contribution of the motors running at a common speed will vary and may not be as desired. The variation in torque contribution can be seen even with motors of identical power rating [2]-[4]. This is because no two motors can be exactly identical. Even with same power ratings, the parameters of the motors such as stator and rotor resistances and inductances might vary from motor to motor [5]. The rotor resistance of the induction motor varies largely due to heating, wear and tear [6]-[7]. Since the characteristics of a three-phase induction motor is heavily dependent on the motor parameters such as rotor resistance, motors of same power rating with different parameters will have distinctive characteristics [2][3]. As a result, the torque imparted by the three phase induction motors running at a common speed would differ.

The behaviour of the V/f control strategy in load sharing arrangement is studied using two induction motors with same ratings of 3HP, 220V, 60Hz. The other considerations are:

- ➢ The variation in rotor resistance is considered to study the effect on load sharing as the torque of the motor is most affected by the rotor resistance and least affected by the other equivalent circuit parameters.
- ➢ It is also found that the rotor resistance varies with the variation in temperature [6]-[7]. Rotor resistance is found to decrease with the increase in temperature.

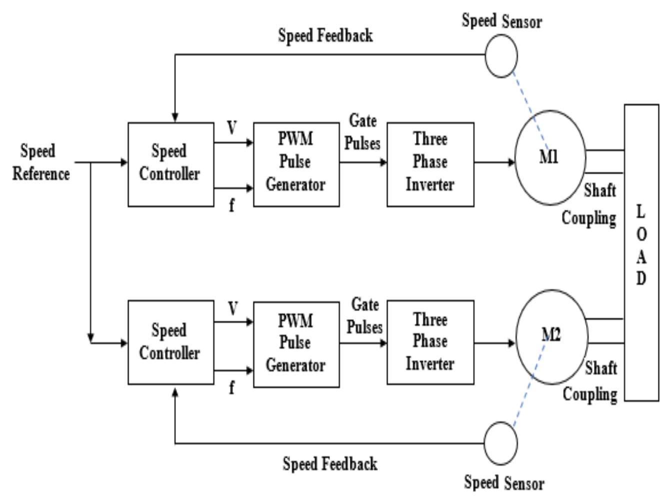

Figure.2 Block diagram of V/f control of induction motors employed in load sharing

- ➢ A lower resistance is taken for second motor, M2 to account for variation in rotor resistance of motors due to manufacturing tolerances.
- ➢ The rotor resistance of the first motor M1 is 0.816Ω and that of the second motor M2 is 0.616Ω. The other equivalent circuit parameters of the motors are assumed to be identical.

- ➢ A load of 20Nm is applied to the load sharing arrangement with reference speed set to 105rad/s.

The gate pulses to the inverter is generated using a vector control block. The modelling of vector control block is discussed in the following section.

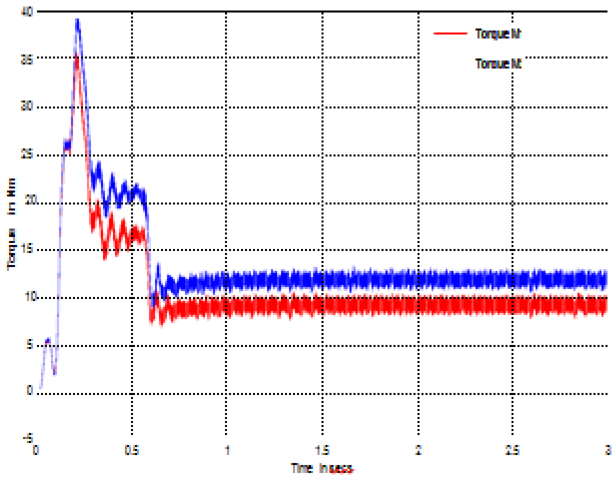

Figure. 3 Contribution of motor torque under load load sharing arrangement (V/f control, different rotor resistance)

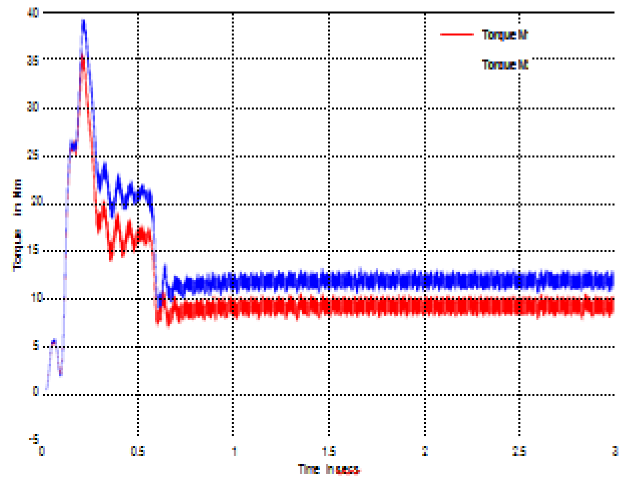

Figure. 4 Motor speeds under load sharing arrangement (V/f control, different rotor resistance)

Two identical motors with same ratings can have identical torque speed characteristics only when their equivalent circuit parameters are identical. The two motors under study has different performance characteristics as their rotor resistance values are different. The torque speed characteristics of the two motors under study is as shown in Figure.1

V/f control strategy used to control a single motor is extended to two motors as shown in Figure.2. Simulation is carried out in MATLAB/SIMULINK. The simulation results shown in Figure.3 and Figure.4 indicates that the torque contributed by the two motors is unequal, although the speed is same. The two induction motors under study have different values of rotor resistances and hence results in unequal torque sharing. Distinctive torque speed characteristics of M1 and M2 causes the motors to contribute different values of torque when running at same speed.

IV. LOAD SHARING WITH FIELD ORIENTED CONTROL STATEGY

Modelling of Field Oriented Control drive [8] is done in order to compare its performance with V/f control strategy in load sharing arrangement. The block diagram for Field Oriented Control is as shown in Figure.5. Reference speed (ref_speed) and reference flux (ref_flux) are the input signals. Rotor speed, (rotor_speed) and three phase stator line currents (I_A, I_B, I_C, denoted as stator_ currents) are the feedback signals. A three-phase current controlled inverter is employed to supply the motor.

The vector control block employs the Rotor speed, (rotor_speed), three phase stator line currents (I_A, I_B, I_C, denoted as stator_ currents) and reference flux (ref_flux) as input signals. A current regulator generates the gate pulses to the inverter which depends on the input line currents of the motor and the reference current signals generated (I_{A_ref}, I_{B_ref} and I_{C_ref}). These three-phase reference current signals are generated from direct axis reference current (I_{dir_ref}) and quadrature axis reference current (I_{quad_ref}). Modelling of each sub block of vector control block is described in the following sections

IV.I Modelling Of Vector Control Block

The components of vector control block is as shown in Figure 6. The vector control block employs the Rotor speed, (rotor_speed), three phase stator line currents (I_{A_ref}, I_{B_ref} I_{C_ref}). These three-phase reference current signals are generated from direct axis reference current (I_{dir_ref}) and quadrature axis reference current (I_{quad_ref}). Modelling of each sub block of vector control block is described in the following sections:

IV.I.I Torque Reference Generator

Torque reference signal is generated through comparison of reference speed and rotor speed. A speed controller is employed for the processing of error signal and generation of reference torque signal (torque_ref)

Speed error,

$$N_e = ref\_speed - rotor\_speed \quad (1)$$

$$torque\_ref = \frac{2\pi N_e}{60}\left[K_p + \frac{K_i}{s}\right] \quad (2)$$

where

K_p - proportionality constant

K_i - integral constant

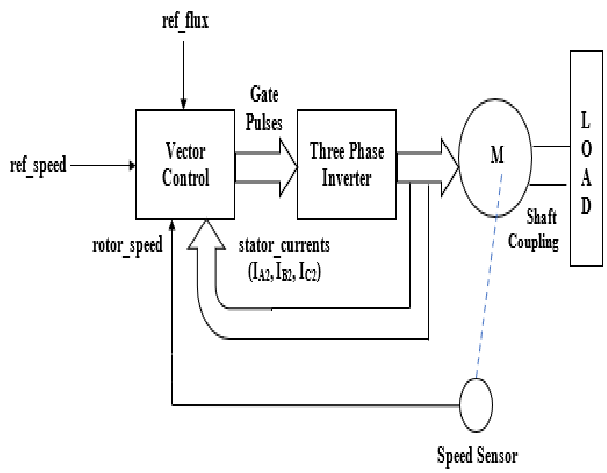

Figure.5 Block diagram of Field Oriented Control of induction motor

IV.I.II 3-Phase To 2-Phase Converter

The three phase stator currents (I_A, I_B, I_C, denoted as stator_ currents) are converted to two phase currents known as direct axis current (I_{dir}) and quadrature axis current (I_{quad}) applying Park's transformation as shown in equation (3)

$$\begin{bmatrix} I_{dir} \\ I_{quad} \\ I_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} \quad (3)$$

where

I_A, I_B and I_C are three phase stator currents

θ is rotor position angle

IV.I.III Flux Calculator

L_r -rotor inductance

L_m -mutual inductance of the motor

R_r -rotor resistance

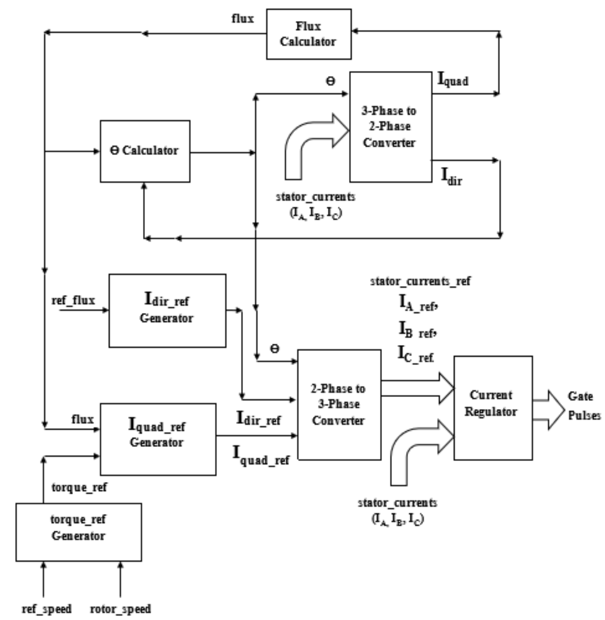

Figure.6 Block diagram of Vector Control block of Field Oriented Control

IV.I.IV ϴ Calculator

Angle of rotor position (θ) is required for Park's and Inverse Parks's transformation. It is estimated using stator currents, motor parameters, rotor speed and flux. The slip speed is calculated as shown in equation (6) which is used to arrive at rotor position angle as shown in equation (7)

$$slip\_speed = \frac{L_m R_r I_{quad}}{flux\ L_r} \quad (6)$$

$$\theta = \int (rotor\ speed + slip\_speed)\,dt \quad (7)$$

IV.I.V I_{dir_ref} and I_{quad_ref} Generator

Direct axis reference current(I_{dir_ref}) and quadrature axis reference current (I_{quad_ref}) are generated using the reference flux. Direct axis reference current is calculated using the equation(8)

The flux in the motor is estimated using motor parameters as shown in equation (4)

$$flux = \frac{L_m I_{dir}}{1+\tau_r s} \quad (4)$$

$$\tau_r = \frac{L_r}{R_r} \quad (5)$$

where

τ - rotor time constant

where

$$I_{dir\_ref} = \frac{ref\_flux}{L_m} \quad (8)$$

where

$_m$ - mutual inductance of the motor

Quadrature axis reference current, I_{quad_ref} is calculated using the equation

$$I_{quad\_ref} = \frac{2}{3}\frac{2}{P}\frac{L_r}{L_m}\frac{torque\_ref}{flux} \quad (9)$$

$_m$ - mutual inductance

- rotor inductance

P- number of poles

$$\begin{bmatrix} I_{A_{ref}} \\ I_{B_{ref}} \\ I_{C_{ref}} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & -\sin(\theta) & \sqrt{\frac{1}{2}} \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & \sqrt{\frac{1}{2}} \\ \cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) & \sqrt{\frac{1}{2}} \end{bmatrix} \begin{bmatrix} I_{dir_{ref}} \\ I_{quad_{ref}} \\ 0 \end{bmatrix} \quad (10)$$

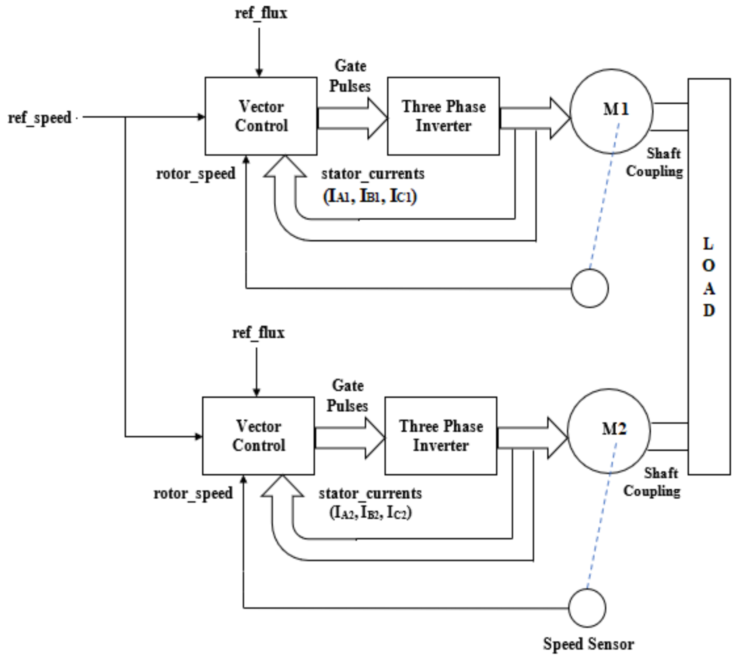

Figure.7 Block diagram of Field Oriented Control of induction motors employed in load sharing

IV.I.VII Current Regulator

Comparison of the actual stator currents taken as feedback signals and stator reference currents I using current regulator generates gate pulses to the three- phase inverter.

IV.I.VIII Simulation Results Of Load Sharing With FOC

Field Oriented Controller modelled for one motor is extended to two motors in a load sharing arrangement as shown in Figure.7. The motors employed have same ratings and parameters as the motors employed for load sharing with V/f control. A load of 20Nm is applied with a reference speed of 105rad/s to study the effect of torque sharing with Field Oriented Control as shown in Fig.7. Simulation is carried out using MATLAB/SIMULINK. Simulation results are shown in Figure.8 and Figure.9
Figure.8 shows that with Field Oriented Control strategy, each motor contributes equal torque of 10 Nm unlike V/f control strategy. Modelling of Field Oriented Control is done using equivalent circuit parameters of the motor.

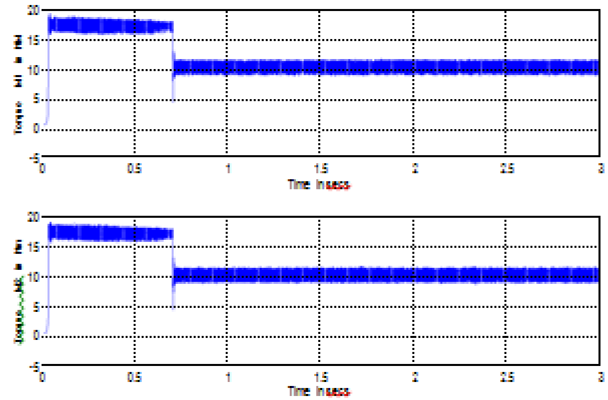

Figure.8 Contribution of motor torque under load load sharing arrangement (Field Oriented control, different rotor resistances- top R = 0.816 Ω; Bottom – R = 0.62Ω)

IV.I.VI 2-Phase To 3-Phase Converter

Direct and quadrature axis reference currents I_{dir_ref} and I_{quad_ref} are converted to three phase stator reference currents I_{Aref} , I_{Bref} and I_{Cref} applying Inverse Park's transformation as shown in equation (10)

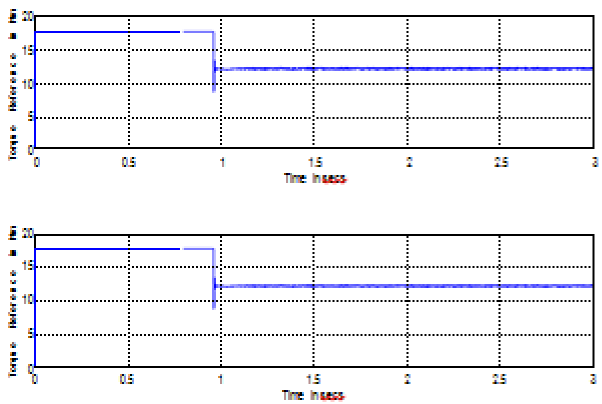

Figure.9 Motor speeds under load sharing arrangement (Field Oriented control, different rotor resistances- top R = 0.816 Ω; Bottom – R = 0.62Ω)

Hence this control strategy accounts for unidentical rotor resistance of the two motors. There is also an added advantage of torque and flux being individually controlled. Both the motors run at a common speed of 105 rad/s as shown in Figure.9

V. CONCLUSION AND FUTURE SCOPE

A comparison of speed and torque contribution of each motor with V/f and Field Oriented Control strategy is outlined in the Table 1 and 2.

Table 1. A comparison of torque shared with V/f and Field Oriented Control Strategy

Control Strategy	Load on the Motor	Torque Contributed by M1	Torque Contributed by M2
V/f	20 Nm	8.5 Nm	11.5 Nm
Field Oriented Control	20 Nm	10 Nm	10 Nm
Inference Torque contributed by individual motors is unequal due to variation in rotor resistance of the motors in V/f control, whereas in FOC, the same two motors contribute equal torque which is a requirement in load sharing arrangement.			

Table 2. A comparison of speed of motors during load sharing with V/f and Field Oriented Control Strategy

Control Strategy	Load on the Motor	Speed of M1	Speed of M2
V/f	20 Nm	105 rad/s	105 rad/s
Field Oriented Control	20 Nm	105 rad/s	105 rad/s
Inference Speed is maintained constant in both control strategies irrespective of parameter changes. Hence both the control strategies meet the requirement of common speed in load sharing arrangement.			

Hence, we can conclude that, Field Oriented Control is more suitable for torque sharing as compared to V/f control. However, Field Oriented Control is more complex as it involves many feedback signals in contrast to V/f control. Signals such as flux of the motor and rotor position signals are estimated using feedback signals. This necessitates the employment of estimators. Hence the cost of a Field Oriented Control drive is higher than the cost of V/f control drive.
As the modelling of Field Oriented Control strategy is done using motor equivalent circuit parameters, a thorough measurement of these parameters is of utmost importance. Deviation in motor parameters from the values used to model the Field Oriented Controller will lead to unequal torque sharing.
Load sharing arrangement with Field Oriented Control can be enhanced by including motor parameter estimators to track any deviations in the equivalent circuit parameters with changing operating conditions. This will avoid unequal torque sharing among the load sharing motors that can result due to the variations in the operating conditions of the motor. However, this would increase the complexity and further increase the cost. An alternate way out would be to develop a methodology that takes care of variation in parameters of the motors and ensures equal torque sharing among motors.

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Authors Profile

Roopa Nayak obtained her B.E degree in Electrical and Electronics Engineering in 2003 and M.Tech in VLSI Design and Embedded Systems in 2007. She has a teaching experience of 15 years and is currently working as Assistant Professor in the Department of Electrical and Electronics Engineering at RNSIT, Bangalore. She is pursuing part-time PhD in the field of electric drives under VTU at EIE Department research centre of RNSIT.

Dr. Andhe Pallavi is heading the Department of Electronics and Instrumentation at RNSIT, Bangalore. She has 22 years of teaching experience. Her areas of research interest include Information Theory and Error Control Coding, Digital Signal Processing, Microcontrollers, Industrial Drives and Cryptography. She is also a life member of ISTE and ISOI societies. She has chaired sessions at several National and International Conferences. She has delivered talks at several Faculty Development Programs sponsored by UGC and TEQUIP. She is a BOS and BOE member at VTU and reputed autonomous colleges such as RVCE, BMSCE and Dr. AIT.

