Implementation of Sensorless Vector Control Technique based on MRAS Speed Estimator for Parallel Connected Induction Motors

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ABSTRACT
This paper reveals the effectiveness of sensor less vector control technique for two parallel connected induction motors fed by a single inverter. Speed and rotor fluxes of both drives are estimated by model reference frame adaptive system (MRAS), whereas PI controllers have been employed to match the speed between two induction motors. Complete system has been simulated for balanced and unbalanced conditions and results have been presented in this paper.

Keywords— PI controller, MRAS speed estimator, Sensor less vector control.

INTRODUCTION
The basic structure of modern AC drives is of inverter-motor type, where one inverter may be used to feed two or more motors connected in parallel such as electric railway traction system and steel process due to the cost effectiveness, compactness and lightness [2].

For balanced load conditions, when two induction motors of same rating are connected in parallel, the system is stable when the rotor speed and the current taken by both induction motors are same i.e. circulating current is zero. But if there is a deviation in the rotor angular velocity of induction motors, the current drawn by both induction motors differ and the circulating current increases. Thus difference in speed of induction motor can be due to mismatch between machine characteristics, or different slip characteristics or when working on full load there is mismatch between the wheel diameters.

Under unbalanced load conditions, if average currents flow through the stator windings and rotor fluxes are considered, the speed of one induction motor increases and the speed of other induction motor decreases continuously. This makes the system unstable. To make the system stable, average and differential currents flowing through the stator windings and rotor fluxes needs to be known to determine the reference currents. Also PI controllers are used in current control loop to generate the corresponding reference voltage signals, and which compares the reference speed and actual speed of the induction motors. Further any difference
between the two speeds of induction motors feedback may be fed to another PI controller which makes the system stable under unbalanced load conditions [3-4].

In this paper sensorless vector control technique is used in order to estimates speed of induction motor from the measured terminal voltages and currents. In controlling AC motor drive, speed transducers such as tacho-generators, resolvers or digital encoders are used to obtain speed information. They are usually expensive. In defective and aggressive environments, the speed sensor might be the weakest part of the system. And it degrades the system’s reliability. This led to speed sensor less vector control. This feature decreases the cost of drives system, reduces the size and there is no need of additional wiring for sensors or devices mounted on the shaft due to hostile environments such as high temperature, corrosive contacts, etc. In this method parameters of each motors are determined namely rotor speed, rotor flux, speed difference and different load torques [5-7].

The speed and rotor fluxes of both drives have been estimated by using model reference frame adaptive system (MRAS). Sensor less vector control is suitable from point of reliability of the equipment, cost effectiveness and less maintenance [8-10].

The topology corresponding to mentioned control technique and the drive system has been converted in to a mathematical model using MATLAB/SIMULINK Software.

OPERATING PRINCIPLE OF SPEED SENSORLESS VECTOR CONTROL AND MRAS SPEED ESTIMATOR

The schematic diagram of control strategy for a single induction motor with sensor less control is as shown in Fig.1 [1].

![Fig.1 Block diagram of speed sensor less vector control](image)

Sensorless vector control of IM drive essentially mean vector control without any speed sensor. The vector control technique can be used to vary the speed of an induction motor over a wide range. In the vector control scheme, a complex current is synthesized from two quadrature components, one of which is responsible for the flux level in the motor and another which controls the torque production in the motor. This vector control algorithm is based on two fundamental ideas. The first is the flux and torque producing currents. An induction motor can be modeled most simply using two quadrature currents rather than the familiar three phase currents actually applied to the motor [5-7].
In order to implement the vector control technique, the motor speed information is required. Model reference adaptive system is a speed estimation method having two models namely reference and adaptive model. The error between two models estimates induction motor speed. The model that does not involve the quantity to be estimated is considered as the reference model. The model that has the quantity to be estimated involved is considered as the adaptive model. The output of the adaptive model is compared with that of the reference model, and the difference is used to drive a suitable adaptive mechanism whose output is the quantity to be estimated the adaptive mechanism should be designed to assure the stability of the control system [8-10]. Model Reference Adaptive System (MRAS) for estimation of speed of induction motor is as shown in Fig.2 [8].

![Fig. 2 Block diagram of MRAS speed estimator](image)

The main advantages of MRAS are
1. The transient response of the drive is fast i.e we can attain steady state very quickly.
2. By using MRAS, we can estimate the speed, which is same as that of actual speed of Induction motor.

The governing equations used for MRAS estimator are given below:

Reference Model

\[ Q_{\text{ref}} = V_{ds} \cdot i_{ds} - V_{ds} \cdot i_{qs} \]  

Adaptive Model

\[ Q_{\text{est}} = W_{e} \cdot \sigma \cdot L_{s} \cdot (i_{ds}^{2} + i_{qs}^{2}) + W_{e} \cdot \frac{L_{m}}{L_{r}} \cdot i_{ds}^{2} \]  

Leakage Coefficient \( \sigma = 1 - \frac{L_{r}}{L_{m}} \)

Error

\[ \varepsilon = Q_{\text{ref}} - Q_{\text{est}} \]

Adaptive Mechanism

\[ \text{PI} = K_{p} + \frac{K_{i}}{\varepsilon} \]
system configuration
The complete system configuration for speed control of parallel connected IM Drive system fed by a single IGBT Inverter is as shown in Fig.3.
The main blocks of the system are given below.
a) PI controller and Torque calculation block
b) Rotor flux estimator block
c) Average rotor flux and theta calculation block
d) \(i_{ds}\) ref calculation block
e) \(i_{qs}\) ref calculation block.
f) 2 to 3 conversion block

Fig.3 Configuration of parallel connected induction motor drive system

The above mentioned blocks have been designed by using following equations.
a) For PI controller and Torque calculation block
Torque for induction motor1 and induction motor2 is calculated by equation (6)

\[
T = \bar{T}_0 - \frac{\Delta T_s}{m} \frac{\Delta T_e}{(1 - \frac{5mT^2}{m^2})}
\]  

.........(6)
Where
\[ \overline{T_e} = \frac{(T_{e1} + T_{e2})}{2}; \Delta M' = \frac{(M'_{\alpha} - M'_{\beta})}{2}; \]
\[ \Delta T_e = \frac{T_{e2} - T_{e1}}{2}; \quad M'' = \frac{M''_{\alpha} + M''_{\beta}}{2}; \]

b) Rotor flux for flux estimator block is calculated by using following equations

i) \[ i_{qF}^e = i_{dF} \quad \text{and} \quad i_{qF}^e = -\frac{1}{\sqrt{3}} [i_{dF} + 2i_{bF}] \quad \text{.........(7)} \]

ii) \[ v_{qF}^d = \frac{1}{\sqrt{3}} (v_{dF} + v_{bF}) \quad \text{and} \quad v_{dF}^d = -\frac{1}{\sqrt{3}} v_{bF} \quad \text{.........(8)} \]

iii) \[ \omega_{r1} = \frac{d\theta_{r1}}{dt} - \frac{l_m}{r_r} \left[ \frac{\varphi_{r1}^d - \varphi_{r1}^q - \varphi_{r1}^\phi}{\varphi_{r1}^2} \right] \quad \text{.........(9)} \]

\[ \frac{d\theta_{q1}}{dt} = \frac{\varphi_{r1}^d - \varphi_{r1}^q - \varphi_{r1}^\phi}{\varphi_{r1}^2}; \quad \theta_{r1} = \int \frac{\varphi_{r1}^d - \varphi_{r1}^q - \varphi_{r1}^\phi}{\varphi_{r1}^2}. \]

iv) \[ \varphi_{dr1} = \frac{l_m}{r_r} i_{dF} - \omega_{r1} \varphi_{qF}^d - \frac{1}{r_r} \varphi_{dF}^d \quad \text{.........(10)} \]

c) Average calculation for rotor flux and theta is calculated by using equations

i) \[ \overline{\varphi_{r1}} = \frac{\varphi_{r1}^d + \varphi_{r1}^q}{2} \quad \text{.........(11)} \]

ii) \[ \overline{\theta_{r1}} = \frac{\theta_{q1} + \theta_{d1}}{2} \quad \text{.........(12)} \]

d) \[ i_{ds}^f = \frac{\varphi_{dF}}{l_m} \quad \text{.........(13)} \]

e) \[ i_{qs}^f = \sqrt{\overline{T''}/pM''/(\overline{\varphi_{dr1}^d})} \quad \text{.........(14)} \]
IV. SIMULATION DIAGRAM AND CONFIGURATION

The discussed topology has been simulated in MATLAB and is presented in Fig.4.

![Simulation Diagram of Speed Sensorless Vector Control of Parallel Connected Induction Motor Drive](image)

Fig. 4 Simulation diagram of speed sensorless vector control of parallel connected Induction Motor drive

The presented model is simulated for parameters of Induction Motors as given in Table-I

<table>
<thead>
<tr>
<th>Parameters of Induction Motors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor Rating</strong></td>
</tr>
<tr>
<td>Nominal power</td>
</tr>
<tr>
<td>Voltage</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Poles</td>
</tr>
<tr>
<td>Stator resistance (Rs)</td>
</tr>
<tr>
<td>Rotor resistance (Rr)</td>
</tr>
<tr>
<td>Stator Inductance (Ls)</td>
</tr>
<tr>
<td>Rotor Inductance (Lr)</td>
</tr>
<tr>
<td>Mutual Inductance (Lm)</td>
</tr>
<tr>
<td>Inertia (J)</td>
</tr>
<tr>
<td>Friction factor (F)</td>
</tr>
</tbody>
</table>
V. SIMULATION RESULTS

The simulated condition for balanced and unbalanced loads technique is presented below in Table-II to Table-V

<table>
<thead>
<tr>
<th>Simulation Values For Constant Load Torque Under Balanced Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time(s)</td>
</tr>
<tr>
<td>Speed(rpm)</td>
</tr>
<tr>
<td>Torque (Nm) for M1</td>
</tr>
<tr>
<td>Torque (Nm) for M2</td>
</tr>
</tbody>
</table>

For balanced conditions, the load torque values for the two motors are kept same, the model is simulated with reference speed as 1100rpm

1). Balanced Load Condition

a) When constant load torque of 20Nm is applied to both the induction motors, Ref speed=1100rpm

It can be seen from the output graphs that when constant torque of 20Nm is applied to both the induction motors with reference speed as 1100rpm, the speed of IM₁ slowly rises from 0 to 600 rpm and finally obtains the value of 1100rpm. Similarly speed of IM₂ is seen to rises from 0 to 600rpm and finally settles at 1100rpm.
Table-III Simulation Values For Variable Load Torque Under Balanced Condition

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>0.5 sec</th>
<th>1 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed(rpm)</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Torque (Nm) for M1</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Torque (Nm) for M2</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

b) Variations of torque in steps (step time=0.5sec, initial value of load torque for IM1 is 10Nm and final value of load torque for both IM1 and IM2 is 20Nm)

Fig.5 (b)

In this case load torque of IM1 is varied with step time as 1sec (10 to 20Nm) and with ref speed as 1100rpm. It can be observed that speed of IM1 steadily rises from 0 rpm to 1100 rpm.

2) Unbalanced Load Condition

Table-IV. Simulation Values For Constant Load Torque Under Unbalanced Condition

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>0 sec</th>
<th>1 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed(rpm)</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Torque (Nm) for M1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Torque (Nm) for M2</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
a) When constant load torque of 10Nm is applied to IM\(_1\) and constant load torque of 20Nm is applied to IM\(_2\).

![Graph showing load torques and speeds for IM1 and IM2 under variable load conditions.](image)

**Fig.5 (c)**

The output graphs shown, that the load torques for the two induction motor is different with ref speed as 1100rpm. Even though the load torque on the two induction motors are varied, the actual speed of the both motors rises from 0 rpm to 1100rpm. It shows the stability of the proposed technique.

**Table-V. Simulation Values For Variable Load Torque Under Unbalanced Condition**

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>0.5 sec</th>
<th>1 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed(rpm)</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Torque (Nm) for M1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Torque (Nm) for M2</td>
<td>5</td>
<td>20</td>
</tr>
</tbody>
</table>

b). Variation of torque in steps [step time=0.5sec, initial load torque for IM1 is varied (5Nm to 20Nm)].

![Graph showing load torques and speeds for IM1 and IM2 under variable load conditions.](image)

**Fig.5 (d)**
As load torque for IM₁ is varied from 5Nm to 20Nm, the actual speed of the motors slowly rises from 0 to 600rpm and settles down to 1100rpm. Similarly for IM₂.

The finally it concludes that during both constant and variable loads, it matches speed of two induction motors and obtain stable operation for balanced and unbalanced loads. The above graphs drawn speed verses time and torque verses time.

**VI. CONCLUSION**

In this paper, model reference frame adaptive system has been used to estimate the speed and rotor fluxes of induction motors. The simulation results obtained reveals the stability of the proposed technique for both balanced and unbalanced conditions.

**VII. REFERENCES**

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