Sensorless Vector Control of a Wound Induction Motor Using MRAS with On-Line Stator Resistance Tuning

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Abstract

The wound induction motor can provide high starting torque and reduced starting current simultaneously by inserting large scale resistor. And this technique is one of the well known methods among the induction motor starting methods and generally used for heavy load starting such as Crain and Cement factories.

The conventional PI controller has been widely used in industrial application due to the simple control algorithm and in general, PI controller is used for control of current, torque, position, and speed for the wound induction motor drive system.

However, the system may result in poor performance since sensors have to be used, which in turn is limited by the environmental condition.

Recently, to overcome these problems, many sensorless vector control methods for the wound induction motor have been studied. This paper presents MRAS method with on-line stator resistance tuning for sensorless vector control of the wound induction motor drive.

In conventional MRAS method, in low frequency, stator resistance variation can result in poor performance. Therefore, to overcome several shortages of the conventional MRAS caused by parameter variation and enhance robustness of the sensorless vector control, this paper investigates a MRAS method with on-line stator resistance tuning for sensorless vector control of the wound induction motor.

The validity and effectiveness of the proposed method is verified through digital simulation.

1. Introduction

The wound induction motor has a complete set of three-phase windings on a rotor as well as a stator. Using this structure, It can provide high starting torque and reduced starting current simultaneously by inserting large scale resistor and can be generally used for heavy load starting such as a Crain and Cement factory. Speed control of the wound induction motor is usually obtained by using speed sensors.

However, the speed sensors require an additional mounting space, which results poor performance in harsh environments. [1]

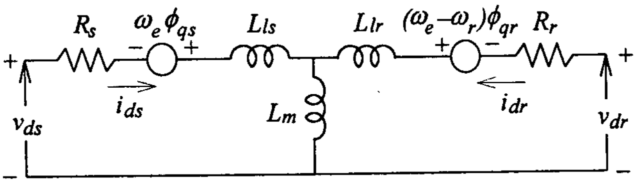
Recently, to overcome these problems, many sensorless vector control methods for the wound induction motor have been studied.

This paper presents MRAS method with on-line stator resistance tuning for the sensorless vector control of wound induction motor drive.

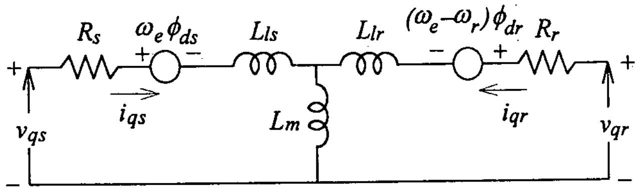
In conventional MRAS method, when a motor is running at high speed, the effect of error in stator resistance is usually quite negligible. However in low frequency, stator resistance variation can result in poor performance because the voltage drop on stator resistance becomes relatively large as frequency decreases.[2][3][4] Therefore, to overcome several shortages of the conventional MRAS caused by parameter variation and enhance robustness of the sensorless vector control, this paper investigates a MRAS method with on-line stator resistance tuning for the sensorless vector control of the wound induction motor. The proposed method is verified through digital simulation.

2. D, Q model of a wound induction motor

Fig. 1 shows a d-q equivalent circuit of the wound induction motor in the synchronously rotating reference frame with ω_e. Since the wound induction motor stator is connected to the power line and the rotor is connected to the PWM inverter, in the rotor voltage equation it is no longer a short winding. This is different from the squirrel cage induction motor.



(a) d-axis



(b) q-axis

Fig. 1 D-Q model of WRIM

From fig. 1, the wound induction motor voltage equations can be written as follows,

$$V^e_{ds} = R_s i^e_{ds} + p\Phi^e_{ds} - \omega_e \Phi^e_{qs} \tag{1}$$

$$V^e_{qs} = R_s i^e_{qs} + p\Phi^e_{qs} + \omega_e \Phi^e_{ds} \tag{2}$$

$$V^e_{dr} = R_r i^e_{dr} + p\Phi^e_{dr} - (\omega_e - \omega_r)\Phi^e_{qr} \tag{3}$$

$$V^e_{qr} = R_r i^e_{qr} + p\Phi^e_{qr} + (\omega_e - \omega_r)\Phi^e_{dr} \tag{4}$$

The linkage fluxes can be written, neglecting saturation effects as:

$$\Phi^e_{ds} = L_s i^e_{ds} + L_m i^e_{dr} \tag{5}$$

$$\Phi^e_{qs} = L_s i^e_{qs} + L_m i^e_{qr} \tag{6}$$

$$\Phi^e_{dr} = L_r i^e_{dr} + L_m i^e_{ds} \tag{7}$$

$$\Phi^e_{qr} = L_r i^e_{qr} + L_m i^e_{qs} \tag{8}$$

where, L_s, L_r, L_m are the winding inductances and the magnetizing inductance respectively.

Electromagnetic torque is

$$T_e = \frac{2P}{3}\frac{L_m}{L_r}(\Phi^e_{dr} i^e_{qs} - \Phi^e_{qr} i^e_{ds}) \tag{9}$$

Ideal decoupling control between d-and q-axis can be achieved by aligning the rotor flux vector to the d-axis and setting the rotor flux linkage to be a constant, which means.

$$\Phi^e_{qr} = \frac{d\Phi^e_{qr}}{dt} = 0 \tag{10}$$

$$\Phi^e_{dr} = \Phi_r = \text{constant} \tag{11}$$

Substituting (10) (11) into (1) (2) (3) (4) yields

$$\frac{L_r}{R_r}\frac{d\Phi_r}{dt} + \Phi_r = L_m \cdot i^e_{dr} \tag{12}$$

and the slip speed is given

$$\omega_{sl} = \omega_e - \omega_r = \frac{L_m}{\Phi_r}\frac{R_r}{L_r} \cdot i^e_{qs} \tag{13}$$

Therefore, the torque equation in (9) becomes

$$T_e = \frac{2P}{3} = \frac{L_m}{L_r}(\Phi^e_{dr} \cdot i^e_{qs}) \tag{14}$$

Thus, with the condition of (14), which can be achieved by setting i_{ds} command to be a constant when the motor is operating in its constant-torque region, the motor torque, with decoupling, can be controlled by the stator current i_{qs}.

3. Speed Estimation using MRAS system

The MRAS method is very effective in motor speed estimation.[3] The motor voltages and currents can be represented by the following equations in a stator frame of reference.

$$\Phi^s_{qr} = \frac{L_r}{L_m}\left[\int (V^s_{qs} - R_s i^s_{qs})dt - \sigma L_s I^s_{qs}\right] \tag{15}$$

$$\Phi^s_{dr} = \frac{L_r}{L_m}\left[\int (V^s_{ds} - R_s i^s_{ds})dt - \sigma L_s I^s_{ds}\right] \tag{16}$$

where $\sigma = 1 - \frac{L_m^2}{L_s L_r}$

$$p\Phi^s_{qr} = -\frac{1}{T_r}\Phi^s_{qr} + \omega_r \Phi^s_{dr} + \frac{L_m}{T_r} I^s_{qs} \tag{17}$$

$$p\Phi^s_{dr} = -\frac{1}{T_r}\Phi^s_{dr} + \omega_r \Phi^s_{qr} + \frac{L_m}{T_r} I^s_{ds} \tag{18}$$

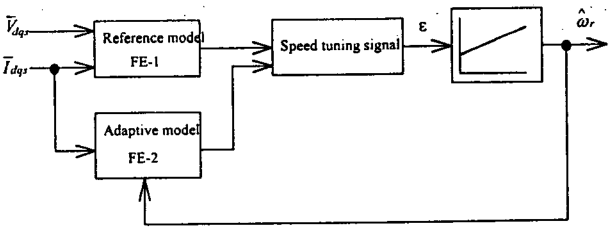


Fig. 2 Structure of MRAS system for speed estimation

Fig. 2 shows the structure for calculating the motor speed by means of MRAS technique.

There are two models, which consist of a reference model, an adjustable model - one, independent of the rotor speed(reference model) and the other dependent of the rotor speed(adjustable model).

The reference and adjustable models are used to estimate the rotor flux linkages and the angular difference of the outputs of the two estimators is used for the speed tuning signal. This tuning signal is the input to a linear controller(PI controller) which in turn outputs the estimated rotor speed.

When the estimated rotor speed ($\widehat{\omega}_r$)is changed in the adjustable model in such a way that the difference between the output of the reference model and that of the adjustable model becomes zero, then the estimated rotor speed is equal to the actual rotor speed ω_r

It follows from fig. 2 that the estimated speed can be expressed as

$$\widehat{\omega}_r = K_p\varepsilon + K_I\int \varepsilon dt \tag{19}$$

$$\varepsilon = \Phi^s_{qr}\Phi^s_{dr} - \Phi^s_{dr}\Phi^s_{qr} \tag{20}$$

where Φ^s_{qr}, Φ^s_{dr} are estimates of the d, q components of the rotor flux vector obtained from the reference model FE-1, while $\widehat{\Phi^s_{dr}, \Phi^s_{qr}}$ are these estimated by the adaptive model FE-2 in fig.2.

The effect of an error in R_s is usually quite negligible at high excitation frequency but becomes more serious as the frequency approaches zero.

Therefore speed estimation does not work well at low speed using conventional MRAS method. To overcome these problems, this paper adopts an on-line stator resistance tuning method as follows.[3]

$$\widehat{R}_s = \left(V'_q - \omega_e\Phi'_d\right)/I'_{qs} \tag{21}$$

4. Analysis Results

Fig. 3 shows a block diagram of the overall system. Table 1 shows wound induction motor parameters for the simulation.

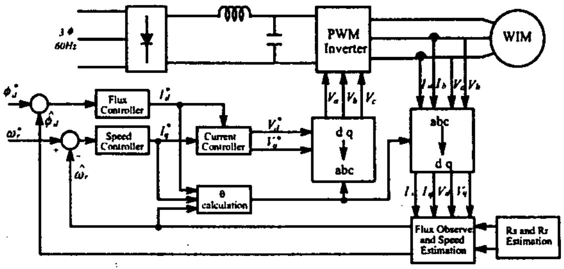
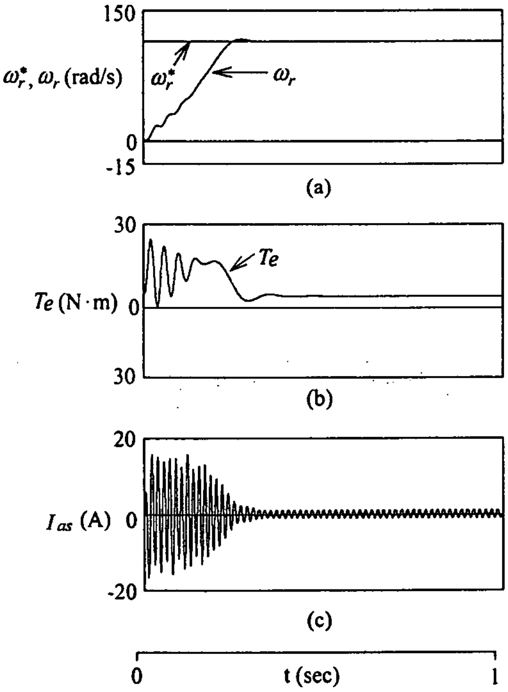


Fig. 3. Block diagram of the overall system

Table 1 : Wound induction motor parameters

$3(Phase), 10(Hp), 4(Pole), 60(Hz)$
$R_s = 0.3085(\Omega), R_r = 0.536(\Omega), L_s = 46.30(mH)$ L_r=46.30(mH),L_m=44.10(mH) $J = 0.036(Kg \cdot m^2), B = 0.000658(N \cdot m \cdot \sec/rad)$

Fig. 4 and fig.5 show simulation results. The simulation is carried out when speed command 100 [rad/s]. In these figures, (a) shows command speed, rotor speed and estimated speed, real speed is well estimated reference speed in MRAS. (b) is torque response. (c) shows current of a-axis. Fig.4 is a response of the conventional PI control to the command speed and fig.5 is a response of the MRAS to the command speed.



(a)

(b)

(c)

Fig. 4 Responses of conventional PI control to command speed

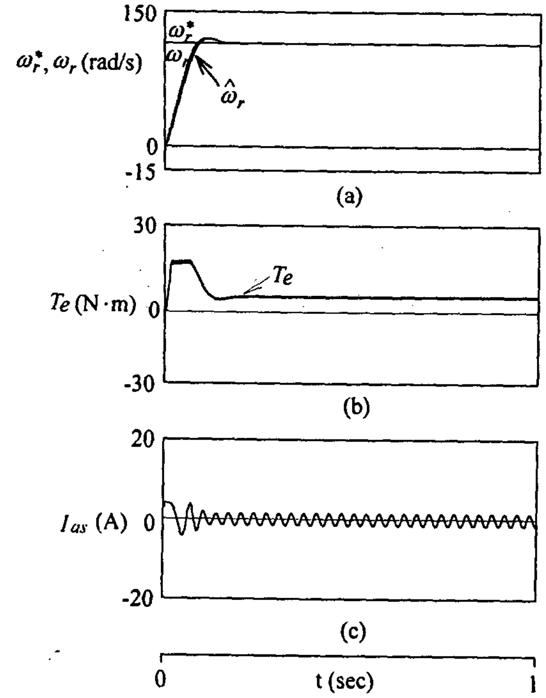


Fig. 5 Responses of MRAS to command speed

5. Conclusion

This paper presents MRAS method with on-line stator resistance tuning for the sensorless vector control of the wound induction motor drive.

The technique of MRAS applied in this paper, shows that an error of the estimated speed by on-line stator resistance tuning is educed even with parameter variation.

Computer simulation of the proposed control system shows the validity and effectiveness of the sensorless vector control with on-line stator resistance tuning of the wound induction motor using MRAS.

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