Robust Vector Control of Wound-Rotor Induction Motor without Speed Sensor

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ABSTRACT - This paper describes a simple vector control scheme for the wound rotor type induction motors(WRIM) without the additional speed sensor in order to remove the external resistor bank which is usually adapted for the WRIM speed control. The motor angular speed is obtained indirectly from the slip angular speed and the slip angular speed is estimated by detecting the rotor currents only. Because the motor parameters are not included in the estimation algorithm, the proposed algorithm is free from the variation of the motor parameters and the robust sensorless vector control can be achieved. The performance of the proposed scheme is verified through the digital simulation.

I. Introduction

The wound rotor type induction motors (WRIM) are usually driven in the crane or the hoist system. The efficiency of these motors is very poor because of the external resistor bank which is used for the speed control. Furthermore, they have to be maintained periodically because of their mechanical contact such as the resister contactors and the magnetic contactors.

Usually, the motors used in the crane or the hoist need a good dynamic performance and wide speed control range. These constraints can be removed with the aid of the vector control algorithm which can be achieved using the rotor speed or position information. But, it is very hard to mount the speed sensor to the already equipped motor and it is not economic to change the driving motor. So, it is important to implement the vector control algorithm for WRIM without the traditional speed sensors. Recently, many researchers have made a significant effort toward improving the performance of the vector control without the traditional speed sensors which are usually called as sensorless vector control. As a result, many sensorless speed control algorithm have been proposed[1]-[5]. Most of these are about the squirrel caged induction motors. Of cause, the sensorless algorithm for the squirrel caged IM can be applied to WRIM also. But, the accuracy and the reliability of the sensorless algorithms have some problems because the information to estimate the motor speed is obtained indirectly from the stator currents and the voltages using the stator and rotor resistance which are varied with the load condition and the temperature[6]-[7].

In WRIM, we can detect the rotor current directly through the slip ring and the rotor current is used to estimate the rotor speed. We estimate the slip angular speed using the rotor current only and the rotor speed is obtained indirectly from the slip angular speed. Because the motor parameters are not included in the estimation algorithm, the proposed algorithm is free from the variation of the motor parameters and the robust sensorless vector control can be achieved. The performance Sensorless algorithm for WRIM of the proposed scheme is verified through the digital simulation.

II. Sensorless Algorithm for WRIM

The equivalent circuit of the induction motor is shown in Fig. 1. We usually use the two-axis components instead of the three-phase components to analyze the machine simply.

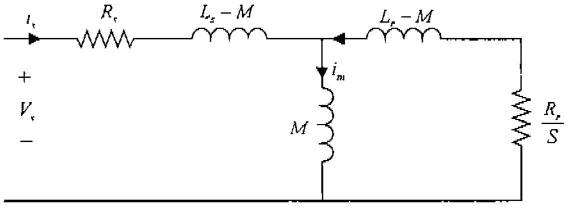


Fig.1. The equivalent circuit of Induction Motor

In Fig. 1, R_s and R_r are the stator and rotor resistance, L_s and L_r are the stator and rotor self inductance, L_m is mutual inductance.

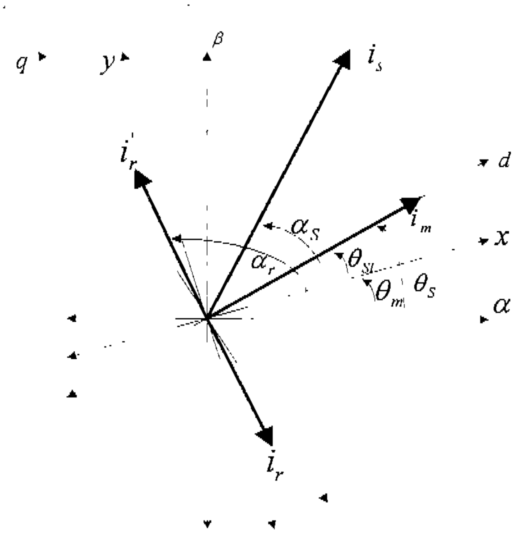


Fig. 2. Two-axis coordinates and Current Vectors

The Fig. 2 describes the two-axis coordinates used in this paper and the relations of the current vectors including the stator current, rotor current and magnetizing current. In Fig.2, $\alpha - \beta$ is the stationary axis on the stator, $x - y$ is the stationary axis on the rotor and $d - q$ is the rotating axis with the synchronous speed. i_s, i_m and i_m mean the stator current, rotor current and magnetizing current, respectively. The relationship between i_r and i_r' is shown as

$$\vec{i}_r' = -\frac{L_r}{M}\vec{i}_r \tag{1}$$

Also, in the rotor flux oriented reference frame, the relationship between the rotor magnetizing current to stator and rotor current is given as

$$\vec{i}_m = \frac{\lambda_r}{L_m} = \vec{i}_s + \frac{L_r}{M}\vec{i}_r \tag{2}$$

where $\lambda_r = Mi_s + L_r i_r$ is the rotor linkage flux.

From Eq.(1) and Eq.(2), we can obtain the following equation.

$$\vec{i}_s = \vec{i}_r' + \vec{i}_m \qquad (3)$$

In Fig.(2), the direction of the magnetizing current i_m coincides with the d-axis, it is also possible to express the relationship of the current vectors in Eq.(3) in terms of their real and imaginary axis components in d-q axis:

$$i_{rx}\cos\theta_{sl} + i_{ry}\sin\theta_{sl} + i_m = i_{sd} \qquad (4)$$

$$i_{ry}\cos\theta_{sl} - i_{rx}\sin\theta_{sl} = i_{sq} \qquad (5)$$

where i_{rx}, i_{ry} are x, y component of the rotor current and i_{sd}, i_{sq} are d, q component of the stator current, respectively.

Because the magnetizing current i_m and the rotor current i_r are perpendicular to each other in case of the vector control[8], the following conditions must be satisfied.

$$i_{rx}\cos\theta_{sl} + i_{ry}\sin\theta_{sl} = 0 \qquad (6)$$

and $i_r = i_{sq}$

where $i_r = \sqrt{i_{rx}^2 + i_{ry}^2}$ (7)

By utilizing Eq.(5) and Eq.(6), the sine and cosine value for the slip angle θ_{sl} can be defined as

$$\sin\theta_{sl} = -\frac{i_{rx}}{i_r}, \quad \cos\theta_{sl} = \frac{i_{ry}}{i_r} \qquad (8)$$

The slip angular frequency ω_{sl} can be found by differentiating Eq.(8) and the results are given as

$$\omega_{sl} = \frac{i_{rx} p i_r - i_r p i_{rx}}{i_r i_{ry}} \qquad (9)$$

where $p = d/dt$ is differential operator.

The denominator in Eq.(9) becomes to zero periodically if sinusoidal currents and voltages are assumed. Thus, Eq.(9) is transformed using the derivative of Eq.(7), and the result equation is given as

$$\omega_{sl} = \frac{i_{rx} p i_{ry} - i_{ry} p i_{rx}}{i_r^2} \qquad (10)$$

As is shown in Eq.(10), the slip angular frequency can be obtained from the rotor current only and any other motor parameters are not included. Because the synchronous speed ω_s is the stator input frequency which is known, the rotor speed ω_r can be derived from the slip angular speed and the synchronous speed.

$$\omega_r = \omega_s - \omega_{sl} = \omega_s - \frac{i_{rx} p i_{ry} - i_{ry} p i_{rx}}{i_r^2} \qquad (11)$$

III. Sensorless Drive System for WRIM

The proposed sensorless vector control algorithm is implemented by the current controlled PWM inverter. Fig.3 shows the block diagram of the sensorless drive system.

The current components used in Fig.3 can be given as follows:

The stator currents on the $d-q$ axis is

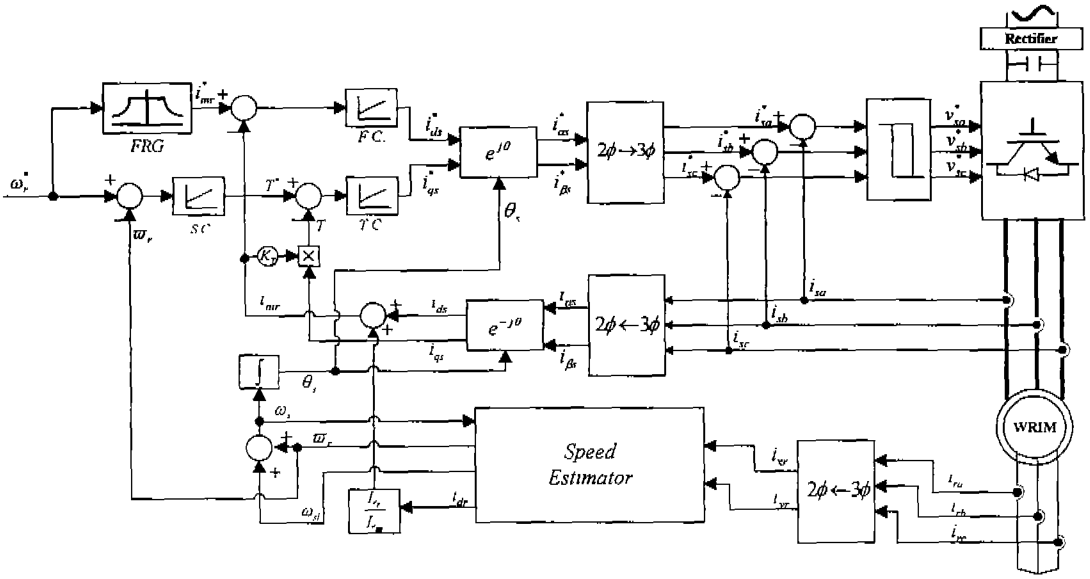


Fig. 3 Sensorless Drive System

$$\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} = \begin{bmatrix} \cos\theta_s & \sin\theta_s \\ -\sin\theta_s & \cos\theta_s \end{bmatrix} \begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \end{bmatrix} \qquad (12)$$

where $\theta_s = \int \omega_s ds$, $i_{\alpha s} = \frac{2}{3}(i_{sa} - \frac{1}{2}i_{sb} - \frac{1}{2}i_{sc})$

and $i_{\beta s} = \frac{1}{\sqrt{3}}(i_{sb} - i_{sc})$.

The rotor currents on the $d-q$ axis is

$$\begin{bmatrix} i_{dr} \\ i_{qr} \end{bmatrix} = \begin{bmatrix} \cos\theta_{sl} & \sin\theta_{sl} \\ -\sin\theta_{sl} & \cos\theta_{sl} \end{bmatrix} \begin{bmatrix} i_{xr} \\ i_{yr} \end{bmatrix} \qquad (13)$$

where $\theta_{sl} = \int \omega_{sl} ds$, $i_{xr} = \frac{2}{3}(i_{ra} - \frac{1}{2}i_{rb} - \frac{1}{2}i_{rc})$

and $i_{yr} = \frac{1}{\sqrt{3}}(i_{rb} - i_{rc})$.

The magnetizing current i_m and the developed motor torque T are expressed as follows:

$$i_m = \frac{L_r}{L_m} i_{dr} + i_{ds} \qquad (14)$$

$$T = K_T i_m i_{qs} \qquad (15)$$

where $K_T = \frac{3}{2}\frac{P}{2}\frac{L_m^2}{L_r}$

IV. Simulation Results

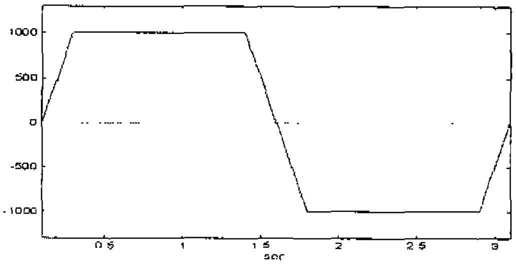
The Proposed sensorless algorithm is verified through the digital simulation.

The motor parameters used in this simulation are shown in Table 1.

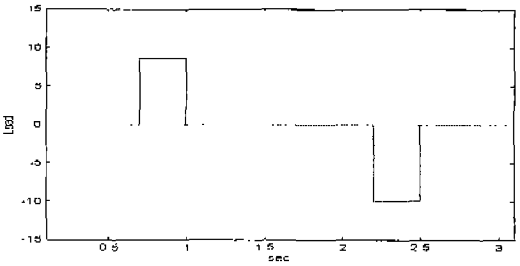
Fig.4 shows the performance of the proposed sensorless scheme by using Eq.(11) according to the speed reference and the load change with the

Table 1. Motor Specification and Parameters

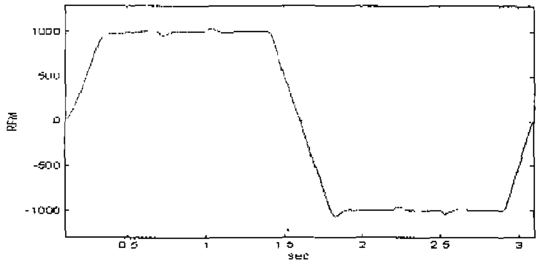
Frequency	60Hz	Rr	0.6460 Ω
# of poles	4 Poles	Ls	83.97mH
Voltage	220V	Lr	85.28 mH
Output	2.2Kw	Lm	81.36 mH
Rate speed	1733rpm	J	0.0367Kg-M^2
Rs	0.6865 Ω	B	0.003Kg-M^2/sec



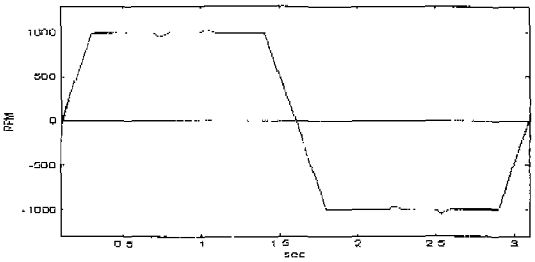
(a) Speed Reference



(b) Torque Reference



(c) Vector control with conventional speed sensor



(d) Vector control with sensorless algorithm

Fig.4. Characteristics of the sensorless algorithm

real rotor speed feedback. Fig.4(a) and (b) is the speed reference and the torque reference applied to the motor, respectively. Under these conditions, IM is controlled with the traditional speed sensor and the motor speed is shown in Fig.4(c). Fig.4(d) shows the characteristics of the proposed sensorless algorithm under the same condition as in Fig.4(c) when the estimated rotor speed is used in stead of the real speed. The estimated speed follows the real speed very well even though the reference speed and the load torque are changed and the proposed algorithm is good for the sensorless vector control.

V. Conclusions

This paper proposed one of the simple and the robust sensorless algorithm for WRIM. Since the estimation algorithm is very simple in comparison with other sensorless algorithm, the computational time for on line estimation is greatly reduced. And also, none of the motor parameters is included in the speed estimation equation but the rotor current, so, the parameter variation which significantly depends on the temperature never degrades the speed estimation accuracy.

The feasibility of the sensorless algorithm is verified through the digital simulation.

The research to improve reliability and the experiment will be carried out continuously in the future.

V. References

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