DIRECT TORQUE CONTROLLED INDUCTION MACHINE WITH MRAS BASED STATOR RESISTANCE ESTIMATION

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ABSTRACT

In direct torque controlled drive system, the stator resistance of induction motor varies with operating conditions such as winding temperature. This stator resistance variation affects the stability and accurate operation at near zero speeds of the induction motor drive system. In this paper a Model Reference Adaptive System (MRAS) is proposed to estimate the stator resistance for direct torque controlled induction motor. In this estimation scheme, the error between the reference model and the adjustable model is used to drive an adaptation mechanism that estimates the stator resistance. The simulation results show the effectiveness of the stator resistance estimation.

I. INTRODUCTION

In many variable speed AC motor drive applications, it is usually desirable that the motor can provide good dynamic torque response [1]. Direct torque control (DTC) produces fast torque control with simple computation on machine parameters [2].

The stator resistance is affected by stator winding temperature and stator frequency changing in system operation. It must be known in system operation to control straight. There are many stator resistance estimation applications to realize stability conditions [3]-[6]. In [3] a technique has been proposed to determine the stator resistance and stator leakage inductance of a four-phase induction machine drive system. These parameters are obtained by solving a least squares minimization method. The performances of the sensorless control of a non-salient-pole permanent-magnet synchronous machine are improved in [4]. In [5] shown how the stator resistance can be estimated online by injecting a small amplitude pseudorandom binary sequence (PRBS) into the normal operating input of the motor. In [6], a neural network and Sugeno fuzzy model used to estimate the stator resistance gives a better estimation of the stator flux and torque in the DTC induction motor.

Direct torque controlled ac machine can be unstable because of the variation of the stator resistance during operation [7]. The appropriate control mechanism must be adapted to the main system to solve the problem. There are several estimation methods can be used.

The stator resistance plays a very important role in the voltage model flux estimation for the direct torque control of induction motor drives. The stator flux in a DTC drive is normally estimated by taking the integral of the difference between the phase voltage and the voltage drop across the stator resistance. The stator voltage drop dominant since the back emf induced in stator windings is small at low speed [8]. The stator voltage drop is also dependent on the stator resistance this situation is critical since even small variations in stator resistance, resulting from changes in the motor temperature or supply frequency, cause an incorrect calculation of the stator flux components and result in inaccurate estimation of the amplitude and the position of the stator flux vector, as well as of the electromagnetic torque.

In this paper, a control system is formed for induction motor. This control type is a DTC. After that DTC is reviewed and MRAS is added to system structure to estimate stator resistance. In MRAS, selecting of reference and adjustable model block parameters is made. Finally, the system with MRAS based method and the system without MRAS based method is simulated and compared.

II. DIRECT TORQUE CONTROL

The basic principle of DTC is to select stator voltage vectors according to the differences between the reference and actual torque and flux linkage [9]. A basic DTC block diagram is given in Figure 1.

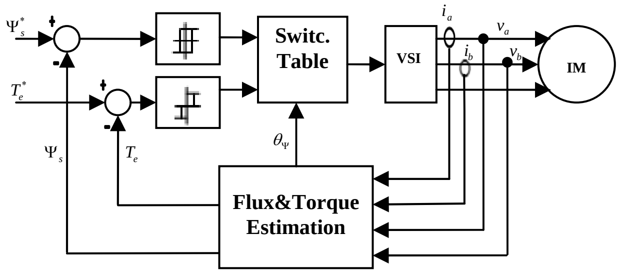

Figure 1. Basic DTC block diagram.

DTC is the first technology using torque and flux as real machine control variable. DTC is largely enough to help industry demands, requires less components, is only used in AC and DC applications and work with other elements harmoniously [10]-[16].

One of the most important issues in implementing DTC strategies for induction motors, is to obtain real-time instantaneous flux level and position with sufficient accuracy for the entire speed range (from almost standstill to high speed level) [17].

The basic properties of the classic direct torque control method are

1. The flux orbit can be shaped by allowable hysteresis band on the flux error.
2. There are lower current harmonics as compared to direct self- control.
3. There is a higher switching frequency than direct self- control.
4. It has variable switching frequency.
5. Six step operation is not integral to controller, the flux orbit must be properly commanded to allow it.
6. There is direct feedback control of torque and stator flux magnitude.
7. No PWM modulator is necessary.
8. There are no reference frame transformations.

The DTC consists of four main sections;

1- Voltage source inverter (VSI).
2- Stator flux and torque estimator.
3- Switching table.
4- Hysteresis flux and torque comparator.

Two level and three level hysteresis band control block diagrams are given in Figure 2 and 3.

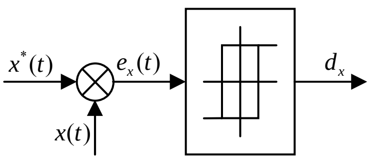

Figure 2. Two level hysteresis band control block diagram.

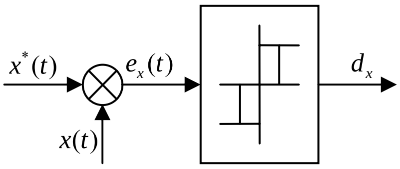

Figure 3. Three level hysteresis band control block diagram.

The hysteresis band controllers chose proper switching vector is given in Table 1 to reduce stator flux and torque errors to zero [18].

Table 1. Switching table.

Flux error position	Torque error position	Sector I	Sector II	Sector III	Sector IV	Sector V	Sector VI
1	1	V2(110)	V3(010)	V4(011)	V5(001)	V6(101)	V1(100)
	0	V7(111)	V0(000)	V7(111)	V0(000)	V7(111)	V0(000)
	-1	V6(101)	V1(100)	V2(110)	V3(010)	V4(011)	V5(001)
0	1	V3(010)	V4(011)	V5(001)	V6(101)	V1(100)	V2(110)
	0	V0(000)	V7(111)	V0(000)	V7(111)	V0(000)	V7(111)
	-1	V5(001)	V6(101)	V1(100)	V2(110)	V3(010)	V4(011)

In DTC optimum switching vector selection is essential. An optimum voltage switching vector look-up table gives the optimum selection of the switching vectors for all the possible stator flux-linkage space-vector positions (six positions, corresponding to the six sectors). Table 1 indicates that any possible combination of torque and stator flux demands in any sector can be fulfilled simultaneously by selecting one of the 8 possible voltage vectors given in Figure 4 [18].

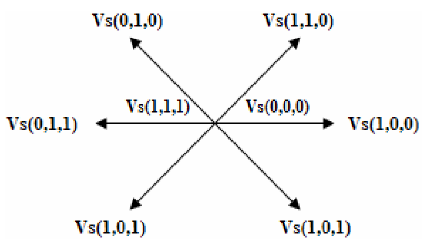

Figure 4. Voltage vectors.

III. PROPOSED STATOR RESISTANCE ESTIMATION

MRAS based method is a representative to construct the sensorless system. The MRAS-based stator resistance estimator scheme consists of the reference model, adjustable model, comparator, adaptation mechanism, limiter and low pass filter as illustrated in Figure 5.

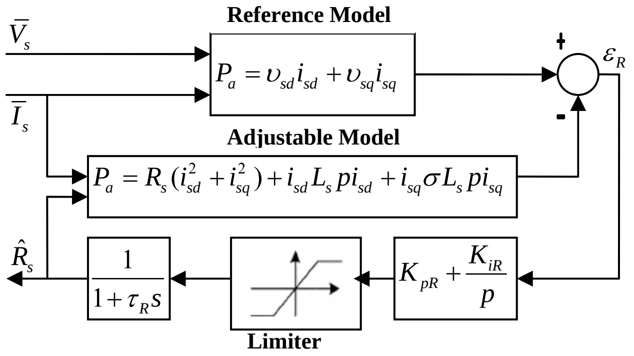

Figure 5. MRAS-based stator resistance estimation scheme.

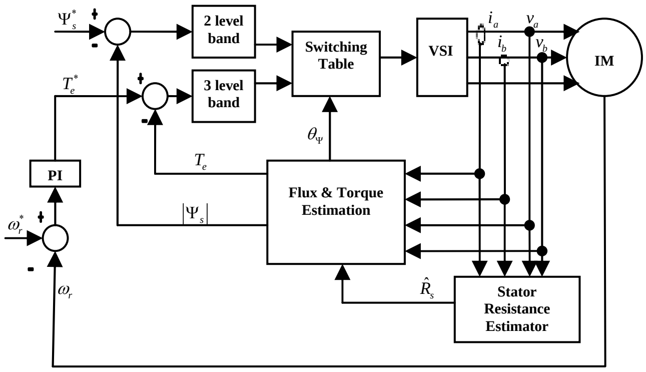

Figure 6. Direct torque controlled machine with stator resistance estimator block diagram.

The error between the reference model and the adjustable model is used to drive an adaptation mechanism that estimates the stator resistance. A proportional-Integral (PI) regulator is used with the stator resistance tuning signal (ε_R) as a input of the PI controller for the adaptation mechanism.

Stator voltage equations are:

$$\overline{V_s} = R_s \overline{I}_s + p\overline{\Psi}_s \tag{1}$$

$$v_{sq} = R_s i_{sq} + p\psi_{sq} \tag{2}$$

$$v_{sd} = R_s i_{sd} + p\psi_{sd} \tag{3}$$

Active power of the machine:

$$P_a = v_{sd} i_{sd} + v_{sq} i_{sq} \tag{4}$$

After arranging (2) and (3) in (4):

$$P_a = R_s (i_{sd}^2 + i_{sq}^2) + i_{sd} p\psi_{sd} + i_{sq} \psi_{sq} \tag{5}$$

$$\overline{\Psi}_s = \psi_{sd} + j\psi_{sq} = L_s i_{sd} + j\sigma L_s i_{sq} \tag{6}$$

$$\sigma = 1 - (M^2 / L_s L_r)$$

After arranging (6) in (5):

$$P_a = R_s (i_{sd}^2 + i_{sq}^2) + i_{sd} L_s p i_{sd} + i_{sq} \sigma L_s p i_{sq} \tag{7}$$

Equation (4) is used in reference model; equation (7) is used in adjustable reference model for stator resistance estimation.

Direct torque controlled machine with stator resistance estimator block diagram is given in Figure 6.

Variations of stator resistance affect motor current, thus the control of flux and torque changing occur.

The stator resistance voltage drop is so small at high speeds that it can be neglected. However, at low speed voltage drop is large and can not be neglected. Due to this state, the variation of stator resistance occurs to estimate incorrectly the flux, torque of stator and stator flux vector location.

IV. SIMULATION RESULTS

A computer program has been developed to simulate the system with and without MRAS based method. The specification and parameters of the simulated induction machine are listed in Table 2.

Table 2. Parameters of the induction machine used

Stator resistance	R_s	28.13
Rotor resistance	R_r	20.76
Rotor Inductance	L_r	0.070
Mutual inductance	M	0.847
Stator Inductance	L_s	0.070
Phase voltage	V	300
Phase current	I	0
Base speed	w_b	314 rad/s, 20 rad/s
Inertia	J	0.001 kgm^2
Frequency	f	50 Hz

Figure 7 and 8 show the d-q stator current with and without MRAS-based stator resistance estimator alternately. The current waveform in Figure 8 is more sinusoidal than the waveform in Figure 7. Stator d-q flux waveforms are shown in Figure 9 and 10. As shown in Figure 9 MRAS based flux waveform is more circular than the classical method waveform shown in Figure 10. Figure 11 and 12 show d-q rotor flux (flux trajectory) with MRAS based and classical method. Figure 13 shows the stator resistance estimation at $\omega_r = 314 rad/s$ speed reference.

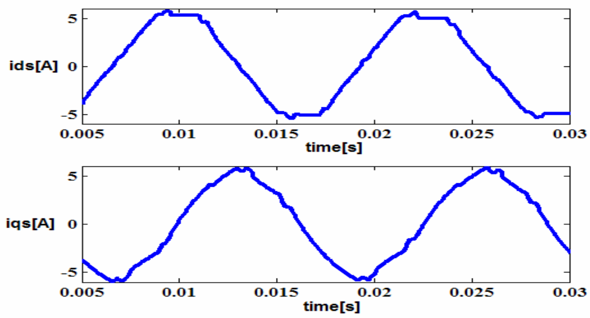

Figure 7. d-q stator current without MRAS based method.

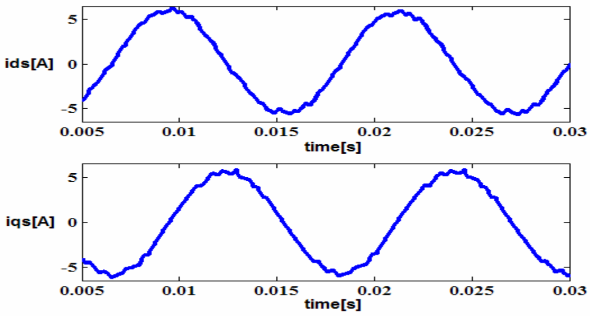

Figure 8. d-q stator current with MRAS based method.

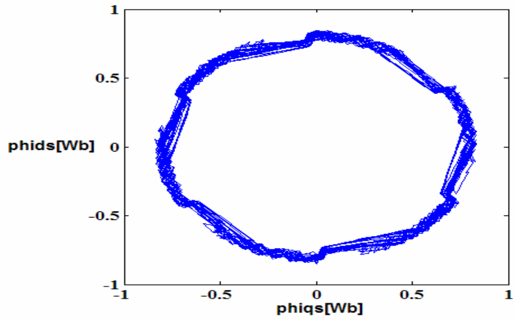

Figure 9. d-q stator flux without MRAS based method.

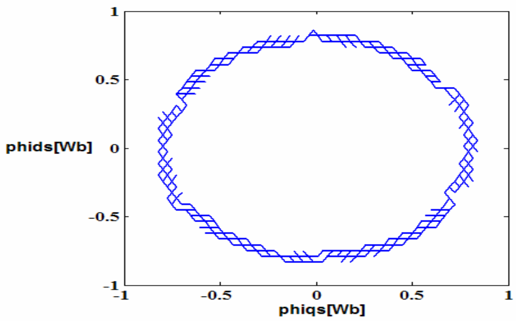

Figure 10. d-q stator flux with MRAS based method.

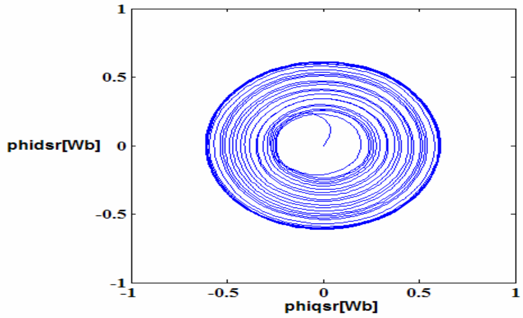

Figure 11. d-q rotor flux without MRAS based method.

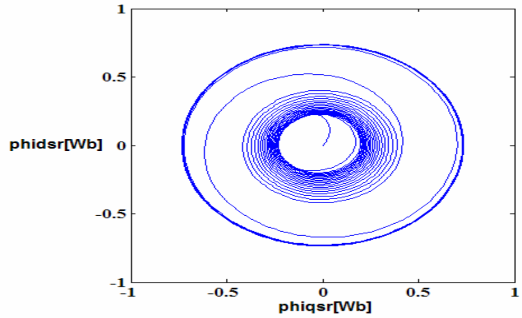

Figure 12. d-q rotor flux with MRAS based method.

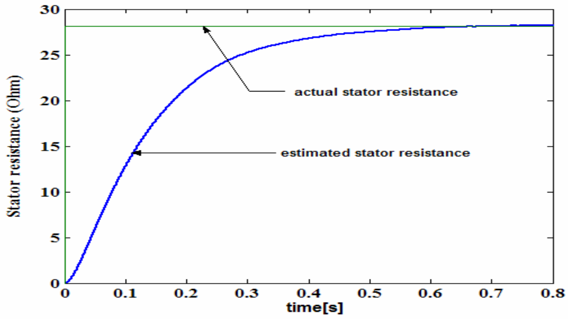

Figure 13. Stator resistance estimation at $\omega_r = 314 rad/s$

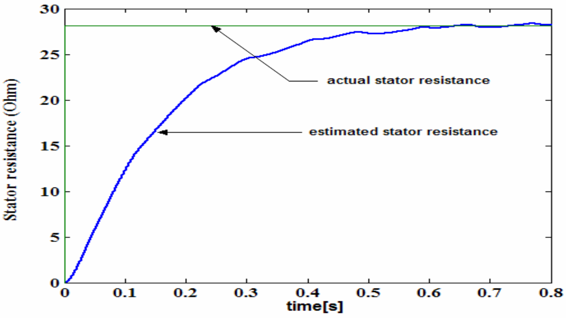

Figure 14. Stator resistance estimation at $\omega_r = 20 rad/s$

V. CONCLUSION

This paper has presented a MRAS-based stator resistance estimation technique. The effect of variation of stator resistance on the performance of a direct torque controlled induction machine has been observed. The variation in stator resistance reduced the performance of DTC drive by introducing errors in the computation of torque and flux. Simulation results demonstrated that the technique can be applied to the DTC induction machine drive applications.

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