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Field Oriented Control for Rotor Position Estimation of IPM Drives over a Wide Speed Range

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***Abstract* — Field oriented control strategy of Interior Permanent Magnet IPM Synchronous Motor drives over a wide speed range applications is presented. Rotor position estimation using model reference adaptive system method for IPM Drive without using a mechanical sensor is illustrated considering the effects of cross-saturation between the *d* and *q* axes. The cross saturation between *d* and *q* axes has been calculated by finite-element analysis. The inductance measurement regards the cross saturation which is used to obtain the suitable i_d - characteristics in base and flux weakening regions. The simulation results show that rotor position estimation error accuracy was improved. Various dynamic conditions have been investigated.**

***Keywords* – Magnetic Saturation, Rotor Position Estimation, Model Reference Adaptive System Method.**

I. INTRODUCTION

Interior Permanent Magnet Synchronous Motors (IPMSM) are used in many applications that require rapid torque response and high-performance operation such as robotics, vehicle propulsion, heat pumps, actuators, and machine tools [1]. In these applications, the IPMSM drive systems are required to position or velocity feedback. In most applications, there is an optical shaft position encoder or resolver for position feedback signal. The objectives of sensorless drives control are: reduction of hardware complexity and cost, increased mechanical robustness, operation in hostile environments, higher reliability, and unaffected machine inertia [2].

Therefore, FOC control of a pulse width modulation (PWM) inverter-fed motor drive is proposed with two main objectives: first, achievement of an accurate and fast response of the flux and the torque, and second, reduction in the complexity of the control system.

II. MODELING OF THE PMSM

The space-state equations can be written as:

$$\begin{cases} \dot{x} = Ax + BU \\ y = Cx \end{cases} \tag{1}$$

Where:

$$x = \begin{bmatrix} i_{s\alpha} & i_{s\beta} \end{bmatrix}^T \quad U = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \end{bmatrix}^T, \quad y = \begin{bmatrix} i_{s\alpha} & i_{s\beta} \end{bmatrix}^T \tag{2}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}^T$$

The Matlab/Simulink block diagram for the proposed system is shown in Fig.1.

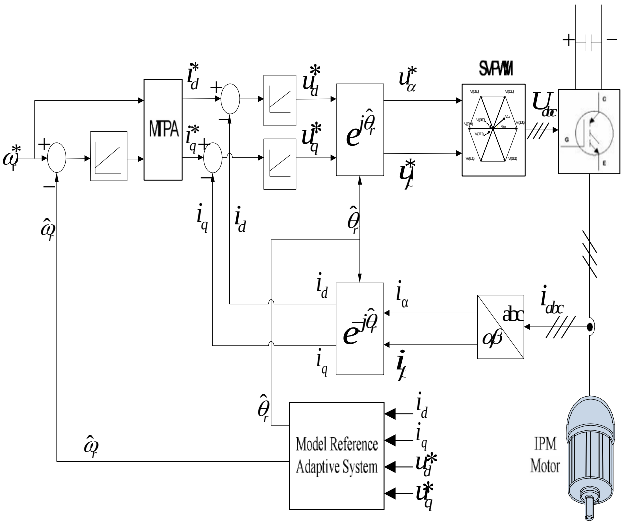


Fig.1. Matlab/Simulink block diagram

III. MODEL REFERENCE ADAPTIVE SYSTEM MODEL

Model reference adaptive system (MRAS) based rotor position estimation method is employed to estimate rotor position and speed [3]. Fig.2 shows the forward voltage compensation model where the rotor position is estimated with MRAS that required in transformation process needs for the compensation algorithm.

The voltage equations for IPM motor are as follows:

$$\begin{cases} L_d \dfrac{di_d}{dt} + R i_d = u_d' \\ L_q \dfrac{di_q}{dt} + R i_q = u_q' \end{cases} \tag{3}$$

Where R and L_d, L_q are stator resistance and d-q inductances, respectively. The d-q axis voltages are:

$$\begin{cases} u_d' = K_p(i_d^* - i_d) + K_i \int (i_d^* - i_d) dt \\ u_q' = K_p(i_q^* - i_q) + K_i \int (i_q^* - i_q) dt \end{cases} \tag{4}$$

To avoid the variation of the controlled currents, a saturation signal has been used.

$$\begin{cases} u_d^* = E_s - \omega L i_q + u_d' \\ u_q^* = \omega L i_d + u_q' \end{cases} \tag{5}$$

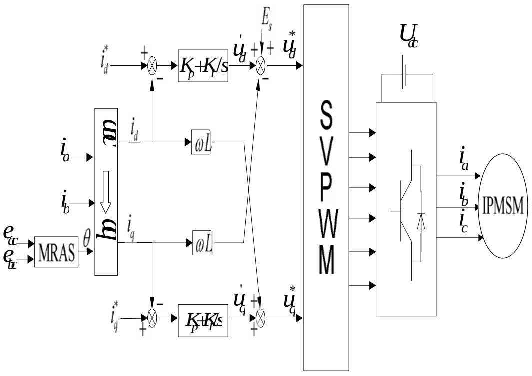
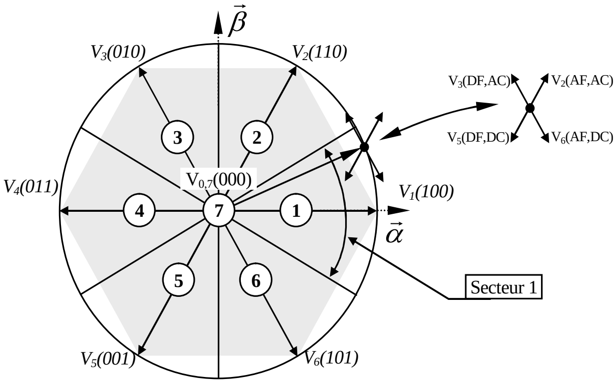


Fig.2. Forward compensation system model

To illustrate the space vector pulse width modulation (SVPWM) strategy [4] Table 1, shows the commutation strategy suggested by Takahashi, to control the stator flux and the electromagnetic torque. Fig.3 gives the partition of the complex plan in six angular sectors SI = 1… 6.



Le code V_6(1 0 1) signifie :
- 1 : interrupteur supérieur du 1er bras fermé;
- 0 : interrupteur supérieur du 2eme bras ouvert;
- 1 : interrupteur supérieur du 3eme bras fermé.

Fig.3 Partition of the complex plan in six angular sectors S I = 1… 6.

Table 1 Selection table for direct torque control

$\Delta\Psi_s$	ΔC_e	S_1	S_2	S_3	S_4	S_5	S_6
1	**1**	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	**1**	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

To explain the system of speed regulation, the saturation of the manipulated variable can involve a phenomenon of racing of the integral action during the great variations (starting of the machine), which is likely to deteriorate the performances of the system or even to destabilize it completely. To overcome this phenomenon, a solution consists in correcting the integral action according to the diagram shown in Fig. 4.

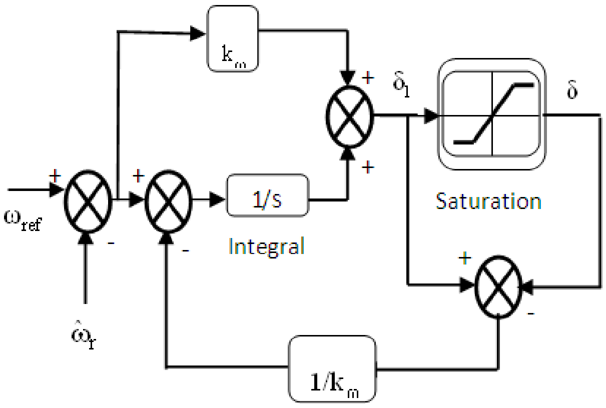


Fig.4. Structure of the anti-windup PI system

IV. CROSS SATURATION EFFECT

In order to consider the saturation effect therefore the *d* and *q* inductances are calculated based on saturation effects. The *d*-*q* inductance calculations are obtained using finite element analysis via Maxwell software. The L_d variation with respect to i_d is shown in Fig.5-a, while the L_q variation with respect to i_q is shown in Fig.5-b.

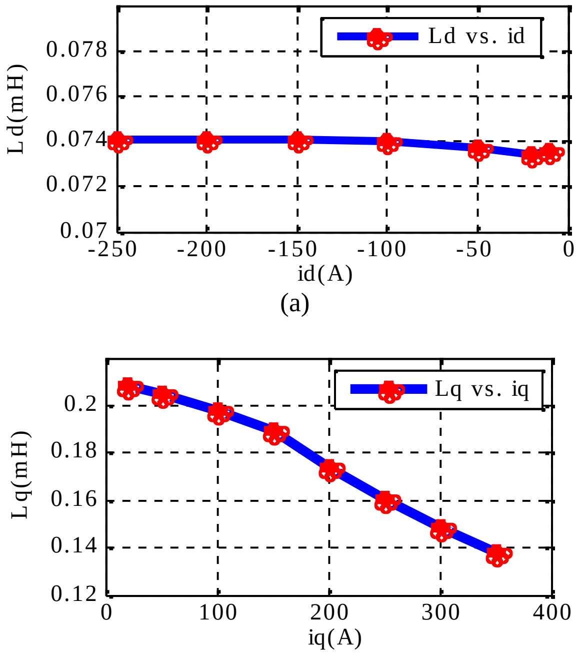


Fig.5. d and q inductances calculations with finite element analysis

V. SIMULATION RESULTS

Fig. 6 presents the simulation results for the extended EMF voltage, estimated rotor position $\hat{\theta}_r$ respectively. The estimated rotor position follows the voltage.

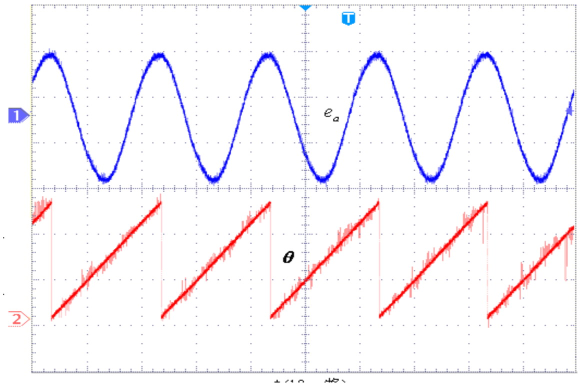
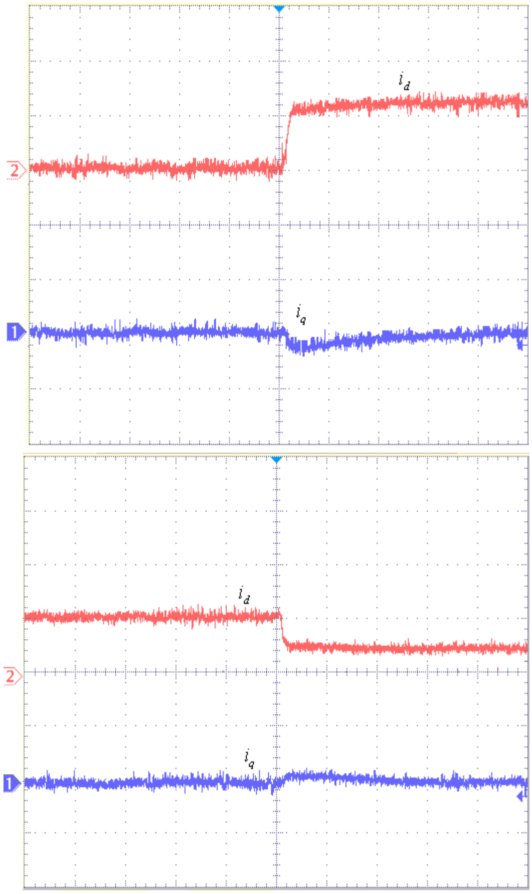


Fig.6. Simulation results: Estimated rotor position and extended EMF

From the simulation results shown in Fig.7, it can be observed that:

(1) Without consider saturation effect as shown in Fig.7-a, when the $i_d^* = 4A$, $i_q^* = 0A$, then changes load to $i_d^* = 8A$ and $i_q^* = 0A$.

(2) Consider saturation effect as shown in Fig.7-b, when the $i_d^* = 6A$ and $i_q^* = 0A$, then changes load to $i_d^* = 6A$, $i_q^* = -5A$.



(a) (b)

Fig.7. i_d^* , i_q^* currents (a) without consider saturation effect, (b) consider saturation effect

VI. CONCLUSIONS

This paper presented a sensorless FOC on of MRAS improves the system performance. The magnetic saturation effect is considered hence the d and q inductances calculations are obtained using the finite element analysis. Simulation results reveal that the flux and speed tracking are good and error convergence is guaranteed. However an anti-windup PI regulator has been used to replace the classical PI controller in the speed control. In conclusion, it seems that the anti-windup PI controller outperforms the classical PI controller in speed control of high performance FOC motor drive. Simulation results demonstrate a good performance and robustness.

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