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MODEL REFERENCE ADAPTIVE CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR
KONTROLLI ADAPTIV ME MODEL REFERIMI I MOTORIT SINKRON ME MAGNET PERMANENT

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PËRMBLEDHJE
Përmirësimi i sjelljes së transmisioneve elektrike me motor sinkron me magnet permanent, veçanërisht në shpejtësi të vogla, ka çuar drejt zhvillimit të skemave me sistem adaptiv me model reference. Teknika e paraqitur në këtë punim rezulton më pak e ndjeshme ndaj ndryshimit të parametrave të makinës meqë algoritmi i vlerësimit varet vetëm nga komponentja sipas aksit-q të induktivitetit të statorit. Metoda nuk kërkon volum të madh llogaritjesh, pasi në sistemin adaptiv me model reference janë përdorur shprehje të thjeshtuara të modelit matematik. Përdorimi i teknikës pa sensorë, ka për qëllim mospërdorimin e sensorëve mekanikë që janë të kushtueshëm dhe të komplikuar. Pozicioni i rotorit dhe shpejtësia këndore merren nga matja e madhësive elektrike duke mos harruar që saktësia e pozicionit të rotorit varet nga parametrat e makinës. Për kontrollin e shpejtësisë dhe pozicionit të rotorit është përdorur teknika e kontrollit vektorial. Rezultatet e simulimeve në MATLAB/Simulink tregojnë efektivitetin e metodës.
Fjalët çelës: kontroll adaptiv me model reference, motor sinkron me magnet permanent

SUMMARY
To improve the performance of permanent magnet synchronous motor drives, especially at low speeds, when the performance is not satisfactory, model reference adaptive system schemes are developed. The proposed technique in the paper is less parameter sensitive, as the estimation-algorithm is only dependent on q-axis stator inductance. Also, the method requires less computational efforts as the simplified expressions are used in the Model Reference Adaptive System. Usage of sensor less technique has the aim to eliminate mechanical sensor, which are rather expensive and delicate. The rotor position and angular velocity are obtained from the measurement of electrical quantities, keeping in mind that the precision of rotor position depends by motor's parameters. The vector control technique is used for the control of the speed and rotor position. Simulations made on MATLAB/ Simulink are discussed.
Key words: model reference adaptive control, Permanent Magnet Synchronous Motor

INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM) is widely used for its robustness of mechanical construction, easy and low cost maintenance, high efficiency, better dynamic performances for different work conditions etc.

In general, an optical encoder is necessary for the PMSM control system in order to obtain the rotor position and speed, but sensors increase the complexity, weight and cost of the system.

In order to reduce the complexity of the control algorithm and enhance the robustness of the system, it is proposed a sensorless reduced-order model reference adaptive system (MRAS) control strategy with the variable structure controller as adaptive mechanism. The PMSM drive requires two current sensors and a rotor position sensor for implementation of any control strategy. The position sensors cost as much as a low-power motor, thus making the total system cost very noncompetitive compared to other types of motor drives. Between the two sensors, the current sensor is easier to accommodate in the electronic part of the system whereas the position sensor requires a considerable labor and spatial volume in the motor for its mounting. That makes very important to control the PMSM drive system without position sensor. As for the current sensors, they are not as expensive as the rotor position sensor and note that other types of drives also require their use in feedback control. Hence, the control and operation of PMSM drive without a rotor position sensor would enhance its applicability to many other cost-sensitive applications and to provide a backup control in sensor-based drives during sensor failures.

One of the most discussed schemes for sensor less control of PMSM drives is the scheme based on model reference adaptive method.

Many researchers have used MRAS approach to estimate speed and rotor position. It makes use of the redundancy of two machine models of different structures that estimate the same state variable (rotor speed) of different set of input variables. The estimator, that does not involve the quantity to be estimated, is chosen as the reference model, and the other estimator may be regarded as the adjustable model. The error between the estimated quantities obtained by the two models is proportional to the angular displacement between the two estimated flux vectors. A PI adaptive mechanism is used to give the estimated speed. As the error signal gets minimized by the PI, the tuning signal ω approaches the actual speed ω of the motor.

Based on MRAS principle, different researchers propose different solutions. For example, Andreescu G. D, at [1] has used voltage and current model to calculate stator flux, and the error between the two results is used to estimate rotors speed. Though it is simple for application, the estimated result depends greatly on motor parameter accuracy.

In order to overcome this problem, Piippo A, at al in [4] and [5] have used a combined method. The idea comes from injection method. In the proposed method a calibration signal ε, containing estimated angle error, is used for the calculation of stator flux using the voltage model. The author claims that the proposed combination of the two methods results in an observer having good steady-state accuracy and excellent dynamic properties over a wide speed range.

Other researchers are based on model reference adaptive system that computes instantaneous reactive power (Q_{ref}) and the adjustable model computes steady-state reactive power (Q_{est}), Kumar P. Sai at [2]. Both the reactive powers are then compared to get the error signal. The error signal is then passed through an adaptation mechanism to estimate rotor speed.

Lipeng Wang at [3], have used the sliding mode variable structure strategy instead of the conventional constant gain PI controller as the adaptive mechanism to fit with the speed estimation problem. A new speed-estimation adaptation law for the sliding mode scheme is based on Lyapunov theory to ensure stability and fast error dynamics.

The aim of this paper is to propose new MRAS scheme for speed control of PMSM drive system. The speed estimation equation is given by (1):

$$\hat{\omega} = \int_0^t k_i \left[i_d \hat{i}_q - i_q \hat{i}_d - \frac{\Psi_r}{L_d}(i_q - \hat{i}_q) \right] d\tau + k_p \left[i_d \hat{i}_q - i_q \hat{i}_d - \frac{\Psi_r}{L_d}(i_q - \hat{i}_q) \right] \tag{1}$$

Where: $\boldsymbol{k_p}$ and $\boldsymbol{k_i}$, are the proportional and integral constants respectively.

The tracking performance of the speed estimation and the sensitivity to noise are depending on proportional and integral coefficient gains. This method is easy for industrial application. Based on vector control theory of PMSM and equation (1) for estimation of speed, it is built up a scheme in MATLAB/Simulink software, based on model reference adaptive system. The stability of the system is guaranteed by the Popov super stability theory. It is somewhat robust to parameter inaccuracy.

PROBLEM STATEMENT AND PRELIMINARIES.

The algorithms for estimating the rotor speed based on rotor flux observers are complicated and parameters dependent. The designing procedure of speed controllers will be very difficult if a complex mathematical model of PMSM is used. The model reference adaptive systems, as robust controllers, have good dynamic and static performance even structured and unstructured uncertainties appear. Therefore, the model reference adaptive system can be designed by using simplified models of PMSM. This paper present a MRAS method, based on the information taken from measurement of stator currents. An adaptive mechanism is established using PMSM motor itself as a reference model, as shown in (Fig.1). The methodology used in this paper, is based on a simplified model of PMSM and the estimation of rotor speed is based on currents of stator, that are measurable state variables.

For simplicity, several assumptions are made in the PMSM mathematical model. The assumptions are: 1) magnetic saturation is neglected, 2) motor is assumed to have a smooth rotor, no slots, 3) no saliency effect is considered, 4) the induced EMF is sinusoidal, 5) eddy current and hysteresis losses are assumed to be negligible.

The model of PMSM in d-q axis is:

$$\frac{d}{dt}\begin{bmatrix} i_d + \Psi_r / L_d \\ i_q \end{bmatrix} = A\begin{bmatrix} i_d + \Psi_r / L_d \\ i_q \end{bmatrix} + B\begin{bmatrix} u_d + R_s\Psi_r / L_d \\ u_q \end{bmatrix} \quad (2)$$

Where: u_d, u_q, i_d, i_q are stator voltage and current in d-q axes; L_d, L_q are inductances in d-q axis, here $Ld = Lq = L$ for the SPMSM; R_s is stator resistance; Ψr is rotor flux; B, J are friction coefficient and moment of inertia; p is the number of the poles of the motor.

Or: $$\frac{d}{dt}i' = Ai' + Bu'$$

where:

$$A = \begin{bmatrix} -R_s / L_d & \omega_r \\ -\omega_r & -R_s / L_q \end{bmatrix}, \quad B = \begin{bmatrix} 1/L_d & 0 \\ 0 & 1/L_q \end{bmatrix}$$

The equation of adaptive model is:

$$\frac{d}{dt}\hat{i}' = \hat{A}i' + B\hat{u}' \quad (3)$$

where :

$$\hat{i}' = \begin{bmatrix} \hat{i}_d + \Psi_r / L_d \\ \hat{i}_q \end{bmatrix},$$

$$\hat{u}' = \begin{bmatrix} u_d + R_s\Psi_r / L_d \\ u_q \end{bmatrix}, \quad \hat{A} = \begin{bmatrix} -R_s / L_d & \hat{\omega}_r \\ -\hat{\omega}_r & -R_s / L_q \end{bmatrix}$$

And the generalized error equation is:

$$e = i' - \hat{i}' \quad (4)$$

Table 1: Parameters of motor

Parameters		Values	
Nominal Power	P_n	*1100*	*W*
Nominal speed	ω_n	*1500*	*rpm*
Armature Resistance	R_s	*2.875*	*Ω*
d-axis Inductance	L_d	*8*	*mH*
q-axis Inductance	L_q	*8*	*mH*
Magnet Flux linkage	Y_r	*0.175*	*Wb*
Number of poles	p	*4*	
Motor Inertia	J	*0.001*	*kgm²*
Friction Coefficient	B	*0.00038*	*Nms*

SPEED ESTIMATION SCHEME BASED ON MRAS

Figure 1 shows the speed estimation scheme based on model reference adaptive system from stator currents. It uses the outputs of both models: reference model that have independent inputs from rotor's speed and the adaptive model that have dependent inputs from rotor's speed in order to generate an error signal. The adaptation mechanism uses a PI controller to guarantee the convergence of the system.

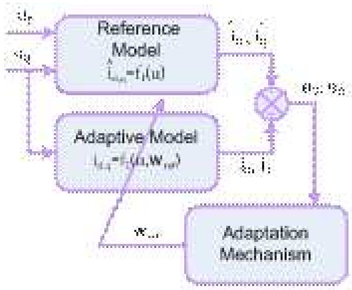

Figure 1. Speed Estimation Scheme for MRAS

SIMULATION RESULTS AND DISCUSSIONS

The control block diagram of the whole system is shown in Fig.2. and the parameters of PMSM are shown in Table 1. It is assumed the reference d-axis current i^*_d= 0 based on the traditional vector control theory. Space Vector Pulse Width Modulation method is used in the control of the two-level three-phase inverter. The reduced-order variable structure MRAS scheme acts as the feedback sensor like the speed/position shaft sensor. It can work out the rotor's angular speed and produce the rotor's angular position.

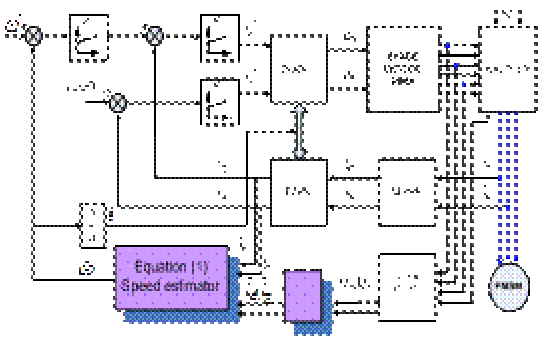

Figure 2. Block diagram for the MRAS based sensor less control system.

Based on block diagram for the MRAS sensor less control system, a scheme for rotor speed and position estimation with model reference adaptive system in MATLAB/Simulink is built up, as shown in Figure 3. This block estimates the rotor speed based on equation (1) and acts like the speed and position shaft sensor. It can work out the rotor's angular speed and produce the rotor's angular position.

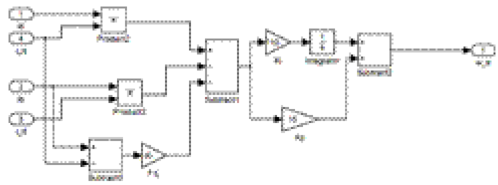

Figure 3. Scheme for speed estimation of PMSM with MRAS in MATLAB/Simulink (equation (1).

The System is started with and without load. Than the proposed scheme is verified by tests for two different work conditions as follows:

1) Reference speed (command law for speed) is changed from 400 rpm to 1500 rpm at time instant t=0.2 s, load torque is changed at t=0.2s from $M_{t=0-0.2}$=0.3Nm to $M_{t=0.2-0.4}$=0.9Nm

2) Reference speed is changed from +1000rpm to -1000rpm at t=0.2s for constant load torque M=0.7Nm.

For each working condition are done the simulations in MATLAB /Simulink and the results are shown at figures 4 and 5, that represent the system responses (rotor speed and position) for specific command laws of speed and load torque. It seems clearly from results of simulation, shown in figure 4 and 5, that sensorless control of PMSM with Model Reference Adaptive System Observer guarantee a good dynamic and static performance for motor drive in different conditions of operations. This sensorless control strategy will be successfully applied for mechanism that have strong requirements, for example very often sign changes of speed. The stationary regime is reached in 0.025 seconds for Forward Motoring mode of operation. The absolute speed error for stationary regime is ±2rpm, or ±0.13% for Forward Motoring and Forward Regenerating mode operation (I and II quadrants).

Simulation results of Regime I

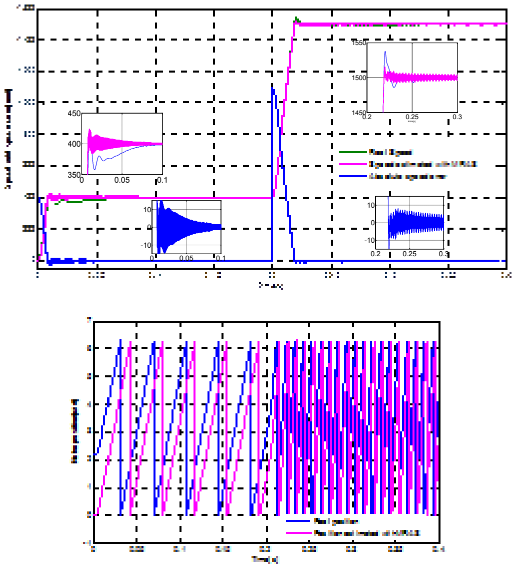

Figure 4. Rotor speed [rpm] and absolute error of speed [rpm], rotor position [rad] for Regime I.

For the second regime, the simulation results are as follows:

Simulation results of Regime II

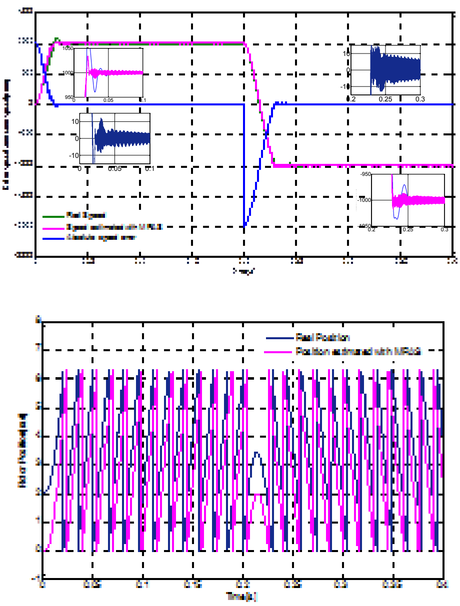

Figure 5. Rotor speed [rpm] and absolute error of speed [rpm], rotor position [rad] for Regime II.

CONCLUSIONS:

In this paper, is verified by simulation in MATLAB/Simulink that the proposed MRAS scheme for speed control of PMSM drive system, under the conditions of the variation of speed command and load torque, has satisfactory performance for the rotor speed and position identification. The MRAS for estimating rotor position angle and speed is based on a stator current estimator, due to the fact that only stator currents are directly measurable in a PMSM drive. The proposed method is simple, needs a low computation efforts and has a high speed adaptation even at low speeds, is more stable and robust because the produced error in the speed adaptation, by PI action, is eliminated. The work in future will be continue with build of more complex system, which will take in consideration magnetic saturation and saliency effect.

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