ISSN 2321 – 2004
ISSN 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 1, Issue 6, September 2013

Simulation of IPMSM Sensorless Drive and Identification of Permanent Magnet Rotor Flux By Extended Kalman Filter

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Abstract: Interior permanent magnet synchronous motor (IPMSM) has buried magnets in the rotor core possesses mechanically robust construction, can also be used in high speed applications. This motor has high performance because of neglected rotor copper losses. In this paper the drive is tested for speeds adjusting during its operation. A rotor flux oriented vector control with model reference adaptive system (MRAS) based rotor position/speed estimation is implemented as the basic control strategy for IPMSM drive. An identification scheme based on Extended Kalman Filter for the permanent magnet flux of IPMSM is proposed. The simulation results of MATLAB/SIMULINK model shows very good dynamic response. Hence this drive can be used in high speed as well as low speed applications.

Keywords: Extended Kalman filter (EKF), Model reference adaptive system (MRAS), interior permanent magnet synchronous motor (IPMSM), Vector Control

I. INTRODUCTION

Till now various applications of Induction Motor drive have been developed. With the development of IPMSM the performance of the drives can be still improved because the rotor copper losses in Induction Motor can be neglected in IPMSM which consists of Permanent Magnet rotor construction. In the past sensors like tacho generators, encoders are used to estimate the speed of the motor which has poor dynamic response. With the development of state observers various senseless technique have been developed to estimate the rotor position / speed .Signal Injection is one of the method valid only for low speed applications. Some of the recent methods are Adaptive schemes and Extended Kalman Filter schemes which can be implemented easily for any speed ranges.

Estimation of rotor position is important in sensorless control of IPMSM motor in order to get high performance. Accurate estimation of rotor position is based on accurate identification of parameter. The motor parameters vary during the motor operation due to demagnetization, temperature etc., such parameter variations are required in high performance IPMSM sensorless control system. Permanent magnet flux variation has great influence on the performance of IPMSM drives which leads to stability problem.

The parameter identification of ac motors can be divided into several categories: 1) the methods based on MRAS 2) the methods based on neural network and 3) the methods based on EKF. The solution of state equations of IPMSM used in MRAS is a second order state equation which can only estimate one parameter (rotor position) accurately while another parameter(permanent magnet flux) is divergent. Hence it is not possible to estimate other parameters of IPMSM sensorless device .

This paper focuses on the application of IPMSM drive for various speeds adjusted during operation. The MRAS observer has been used to estimate the speed. The permanent magnet flux is identified in IPMSM drive by EKF for constant speed with step torque and constant torque with step speed. The whole control scheme of the drive is presented. Simulation results and experiment verifications are presented.

The most important idea of this paper is to complete the permanent magnet flux identification of IPMSM using EKF and MRAS position/speed estimation simultaneously and accurately, which provides a simple way for researchers to conduct parameter identification in sensorless ac motor drives.

II.SENSORLESS CONTROL OF IPMSM BASED ON MRAS

A. *Mathematical Model of IPMSM*

The precise model of IPMSM is very important for high-performance vector-controlled servo drive system. However, the real PM motor is a nonlinear and time-variant system. Usually, the IPMSM is considered to be an ideal model based on the following hypothesis.

1) Three phase stator windings are symmetrical.
2) Slot effect is neglected, and the back EMF is sinusoidal.
3) Saturation, eddy currents, and hysteresis losses are neglected.
4) There is no damping on the rotor.

With these assumptions, the stator voltage and flux equations of the IPMSM in the rotating d−q frame in high speed range are given by

$$\left.\begin{aligned} u_d &= R\, i_d + L\frac{di_d}{dt} - \omega L_q i_q \\ u_q &= R i_q + L\frac{di_q}{dt} + \omega L_d i_d + \omega\psi_r \end{aligned}\right\} \qquad (1)$$

$$\left.\begin{aligned} \psi_d &= L_d i_d + \psi_r \\ \psi_q &= L_q i_q \end{aligned}\right\} \qquad (2)$$

Where

u_d, u_q are the stator voltages
i_d, i_q are the stator currents
R is the stator resistance
L_d , L_q are the d−q axis stator inductances
ψ_d, ψ_q are the d−q-axis stator magnetic flux,
ω is the electrical rotor speed, and ψ_r is the rotor flux.

The electro-mechanical torque is

$$T_e = P[\psi_r i_d + (L_d - L_q) i_d i_q] \qquad (3)$$

The mechanical equations of the IPMSM drive is described as

$$J\frac{d\omega}{dt} = P[T_e - T_L - B\frac{\omega}{P}] \qquad (4)$$

Where J and B are the inertia and friction coefficient of the motor respectively Te and T_L are the electromagnetic torque and load torque respectively P is the number of pole pairs.

The aforementioned d−q model is usually used for a high-performance PMSM drive. However, this d−q model cannot be utilized directly in the position sensorless system because the estimation error of rotor position is not taken into account. The mathematical model of IPMSM in the estimated rotating γ−δ frame, considering the lag theta θ_e from the conventional d−q reference frame as shown in Fig. 1, Since effects due to saliency is ignored in this paper, which means that the IPMSM model in the rotating d−q frame is employed to estimate the rotor position and speed.

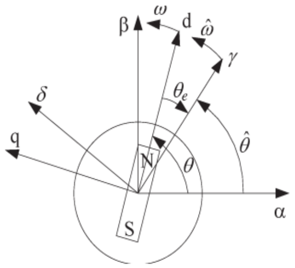

Fig.1 Stator and Rotor Reference Frame Diagram of IPMSM

B. *Principle of the MRAS Control Scheme*

As the rotor speed ω is included in the current equations, the current model of the IPMSM is employed as the adjustable model and the real motor is considered as the reference model. Both of these two models have the outputs i_d and i_q . According to the difference between the outputs of the two models, through a certain adaptive mechanism the estimated value of the rotor speed can be obtained. Then the rotor position can be obtained by integrating the speed. Equation (1) can be rewritten as follows

$$\left.\begin{aligned} L_d\frac{di_d}{dt} &= -Ri_d + \omega L_q i_q + u_d \\ L_q\frac{di_q}{dt} &= -Ri_q - \omega L_d i_d - \omega\psi_r + u_q \end{aligned}\right\} \qquad (5)$$

The d−q-axis currents i_d and i_q are the state variables of the current model of the IPMSM, which is described by (5).

Rewrite (5) into matrix form as follows:

$$\frac{d}{dt}\begin{bmatrix} i_d + \frac{\psi_r}{L_d} \\ i_q \end{bmatrix} = \begin{bmatrix} \frac{-R}{L_d} & \omega\frac{L_q}{L_d} \\ -\omega\frac{L_d}{L_q} & \frac{-R}{L_q} \end{bmatrix}\begin{bmatrix} i_d + \frac{\psi_r}{L_d} \\ i_q \end{bmatrix} + \begin{bmatrix} \frac{u_d}{L_d} + \frac{R\psi_r}{L_d} \\ \frac{u_q}{L_q} \end{bmatrix} \qquad (6)$$

For the convenience of stability analysis, the speed ω has been confined to the system matrix

$$A = \begin{bmatrix} \frac{-R}{L_d} & \omega\frac{L_q}{L_d} \\ -\omega\frac{L_d}{L_q} & \frac{-R}{L_q} \end{bmatrix} \qquad (7)$$

To be simplified, define

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} i_d + \frac{\psi_r}{L_d} \\ i_q \end{bmatrix} \qquad (8)$$

$$u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} \frac{u_d}{L_d} + \frac{R\psi_r}{L_d} \\ \frac{u_q}{L_q} \end{bmatrix} \qquad (9)$$

Then, the reference model can be rewritten as

$$\frac{d}{dt}x = Ax + u \qquad (10)$$

The adaptation mechanism uses the rotor speed as the corrective information to obtain the adjustable parameter current error between two models in order to drive the current error to zero. Then the estimated value can be considered as a correct speed. The process of speed estimation can be described as follows

$$\frac{d}{dt}\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} = \begin{bmatrix} \frac{-R}{L_d} & \hat{\omega}\frac{L_q}{L_d} \\ -\hat{\omega}\frac{L_d}{L_q} & \frac{-R}{L_q} \end{bmatrix}\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} + \begin{bmatrix} \hat{u}_1 \\ \hat{u}_2 \end{bmatrix} \qquad (11)$$

Where $\hat{\omega}$ is to be estimated; (11) can be simplified as follows:

$$\frac{d}{dt}\hat{x} = A\hat{x} + \hat{u} \qquad (12)$$

The error of the state variables is

$$e = x - \hat{x}$$

According to (10) and (11), the estimation equation can be written as

$$\begin{aligned} \frac{d}{dt}e &= Ae - Iw \\ v &= De \end{aligned} \qquad (13)$$

where $w = (\hat{A} - A)\hat{x}$; by choosing D=I, then $v=Ie=e$.

According to the Popov hyper stability theory, if
1) $H(s)=D(sI-A)^{-1}$ is a strictly positive matrix,
2) $\eta(0,t_0)=\int_0^{t0} v^T \omega \, dt \geq -\gamma_0^2, \forall t_0 \geq 0$, where γ_0^2 is a limited positive number, then $\lim_{t\to\infty} e(t)=0$.
The model adaptive reference system will be stable.
Finally, the equation of $\widehat{\omega}$ can be achieved as

$$\widehat{\omega} = \int_0^t k_1 [x_1\hat{x}_2 - x_2\hat{x}_1] d\tau + k_2[x_1\hat{x}_2 - x_2\hat{x}_1] + \widehat{\omega}(0) \quad (14)$$

Where $k_1, k_2 \geq 0$, Replace x with i

$$\widehat{\omega} = \int_0^t k_1 \left[i_d\hat{\imath}_q - i_q\hat{\imath}_d - \frac{\psi_r}{L_d}(i_q - \hat{\imath}_q) \right] d\tau + k_2 \left[i_d\hat{\imath}_q - i_q\hat{\imath}_d - \frac{\psi_r}{L_d}(i_q - \hat{\imath}_q) \right] + \widehat{\omega}(0) \quad (15)$$

In the above equation $\hat{\imath}_d$ and $\hat{\imath}_q$ can be calculated through the adjustable model ,id and iq can be obtained by the transformation of the measured stator currents and ψ_r here is treated as a constant input.
The rotor position can be obtained by integrating the estimated speed

$$\hat{\theta} = \int_0^t \widehat{\omega} \, d\tau \quad (16)$$

The MRAS scheme is illustrated in Fig. 2. The inputs of the speed and position estimation block are the voltages and currents of the real motor, and the outputs are the estimated speed and position

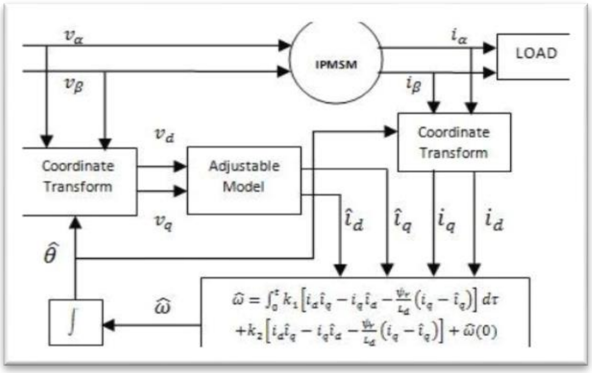

Fig 2. Block diagram of control scheme of MRAS

C. *Multiparameter Identification Using MRAS*

Equation (11) can be written as

$$\frac{d}{dt}\begin{bmatrix}\hat{\imath}_d \\ \hat{\imath}_q\end{bmatrix} = \begin{bmatrix} \frac{-\hat{R}_s}{L_d} & \omega\frac{L_q}{L_d} \\ -\omega\frac{L_d}{L_q} & \frac{-\hat{R}_s}{L_q} \end{bmatrix}\begin{bmatrix}\hat{\imath}_d \\ \hat{\imath}_q\end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_q} \end{bmatrix}\begin{bmatrix}\hat{u}_d \\ \hat{u}_q\end{bmatrix} + \begin{bmatrix} 0 \\ \frac{-\psi_r}{L_q} \end{bmatrix}\omega \quad (17)$$

It can be written as

$$\frac{d}{dt}\hat{\imath} = \hat{A}\hat{x} + Bu + \hat{C}\omega \quad (18)$$

Where

$$\hat{A} = \begin{bmatrix} \frac{-\hat{R}_s}{L_d} & \omega\frac{L_q}{L_d} \\ -\omega\frac{L_d}{L_q} & \frac{-\hat{R}_s}{L_q} \end{bmatrix}; \quad B = \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_q} \end{bmatrix}; \quad \hat{C} = \begin{bmatrix} 0 \\ \frac{-\psi_r}{L_q} \end{bmatrix}$$

$$\hat{\imath} = \begin{bmatrix}\hat{\imath}_d \\ \hat{\imath}_q\end{bmatrix}; u = \begin{bmatrix}u_d \\ u_q\end{bmatrix}$$

With the similar definition of state variable errors and Popov hyper stability theory the magnetic flux would be

$$\hat{\psi}_r = \hat{\psi}_r(0) + \frac{1}{L_q}\left[k_1 \int_0^t [(i_q - \hat{\imath}_q)\omega] \, d\tau + k_2[(i_q - \hat{\imath}_q)\omega]\right] \quad (19)$$

III. MULTIPARAMETER ESTIMATION ISSUES OF MRAS

Multiparameter identification using model reference adaptive technique has been researched and it is cleared that when the identifications of rotor speed and permanent magnet flux are conducted at the same time by using MRAS, the coupling of two parameters exists and cannot be avoided. Simulations about identifications of such two parameters at the same time by MRAS are researched. It is clear from the identification results that both rotor speed and permanent magnet flux are probably not convergent so that the motor cannot operate stably due to inaccurate identified value of the permanent magnet flux. Therefore, it is surely difficult to realize this simultaneous multiparameter identification only by MRAS. A proper way to achieve multiparameter identification is to carry out rotor speed/position estimation by using MRAS and identify permanent magnet flux by using EKF.

IV. ONLINEIDENTIFICATION OF PERMANENT MAGNET FLUX BASED ON EKF

In the PMSM control system, rotor flux linkage generated by rotor permanent magnet is one of the key parameters. In the full order or reduced order observer, rotor flux linkage is treated as a constant parameter or a constant input.
However, in applications the rotor flux linkage varies in a very wide range under different operating conditions such as temperature rise and saturations. Incorrect control method and rough operating condition may cause magnet demagnetization so the permanent magnet flux identification for IPMSM is very significant, particularly in speed sensorless control system.

A. Brief Introduction to EKF

The Kalman filter is a least square estimator, which can be extended to a nonlinear system as named EKF. Its main feature is the recursive processing of the noise measurement risk. The system state-space model and its discrete measurements are described as follows:

$$\begin{aligned} \dot{x}(t) &= f[x(t)] + Bu(t) + \sigma(t) \\ y(t_k) &= h[x(t_k)] + \mu(t_k) \end{aligned} \quad (20)$$

Where σ(t) and μ(t $_k$)are zero-mean white Gaussian noises with Covariance Q(t) and R(t$_k$) respectively and independent from the system state x and t$_k$. u(t) is the deterministic input vector.

B. *IPMSM Model Based on EKF*

In this paper, the sensorless control system of IPMSM is considered. The amplitude and phase angle of permanent magnet flux vector may change with different operation conditions as shown in Fig. 3 so that (5) can be rewritten as follows:

$$\left.\begin{aligned} \frac{di_d}{dt} &= -\frac{Ri_d}{L_d} + \frac{\omega L_q i_q}{L_d} + \widehat{\omega}\frac{\psi_{rq}}{L_d} + \frac{u_d}{L_d} \\ \frac{di_q}{dt} &= -\frac{Ri_q}{L_q} + \frac{\widehat{\omega} L_d i_d}{L_q} + \omega\frac{\psi_{rd}}{L_q} + \frac{u_q}{L_q} \end{aligned}\right\} \quad (21)$$

In order to observe the rotor flux linkage, the rotor flux linkage is chosen as one state variable. Because the rotor flux linkage cannot change sharply, its deviation is set to zero

$$\left.\begin{aligned} \frac{d\psi_{rd}}{dt} &= 0 \\ \frac{d\psi_{rq}}{dt} &= 0 \end{aligned}\right\} \quad (22)$$

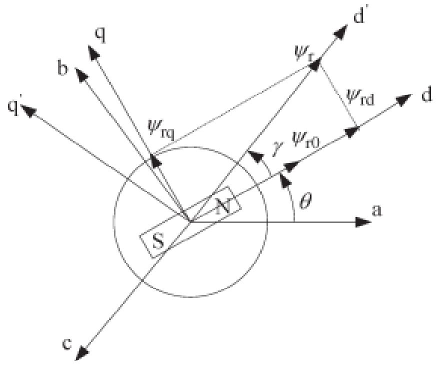

Fig.3Variation of PM flux linkage in IPMSM

By choosing the new set of variables and the rotor flux linkage as the state variables, a fourth order Kalman filter is constructed. The state, input vector and output vector are

$$\left.\begin{aligned} x &= [i_d \quad i_q \quad \psi_{rd} \quad \psi_{rq}]^T \\ u &= [u_d/L_d \quad u_q/L_q]^T \\ y &= [i_d \quad i_q]^T \end{aligned}\right\} \quad (23)$$

The system and output measurements are

$$\dot{x} = \begin{bmatrix} \frac{-R}{L_d} & \widehat{\omega}\frac{L_q}{L_d} & 0 & \frac{\widehat{\omega}}{L_d} \\ -\widehat{\omega}\frac{L_d}{L_q} & \frac{-R}{L_q} & -\frac{\widehat{\omega}}{L_q} & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} x + \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} u \quad (24)$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} x \quad (25)$$

The estimated rotor electrical speed $\widehat{\omega}$ and position $\widehat{\theta}$ are obtained from (14) and (15) by MRAS method. It is shown that the rotor flux linkage observer is a fourth-order linear system. After choosing $[i_d \; i_q \; \psi_{rd} \; \psi_{rq}]^T$ as the state variable and $[i_d \; i_q]^T$ as the output, the proposed system is linear to the input and the output

V. SYSTEM CONTROL STRATEGY

The control diagram of the sensorless IPMSM drive system by using the proposed EKF-based permanent magnet flux identification is shown in Fig. 5. Conventional vector control is employed as the basic control strategy for IPMSM drives. The reference voltage vector is obtained by current proportional integral regulators. As shown in Fig. 5, “space vector pulse width modulation (SVPWM)” module realizes SVPWM or over modulation algorithms according to the amplitude of the reference voltage vector. “Sampling” module detects motor currents. “EKF” module calculates permanent magnet flux by iterative computations of EKF method, “MRAS” module for rotor position/speed estimation. In this system, rotor position/speed estimation by MRAS and permanent magnet flux identification by EKF are interrelated and interact on each other. The d−q-axis reference voltages, the d−q-axis currents, and the estimated speed by MRAS are used in flux identification.

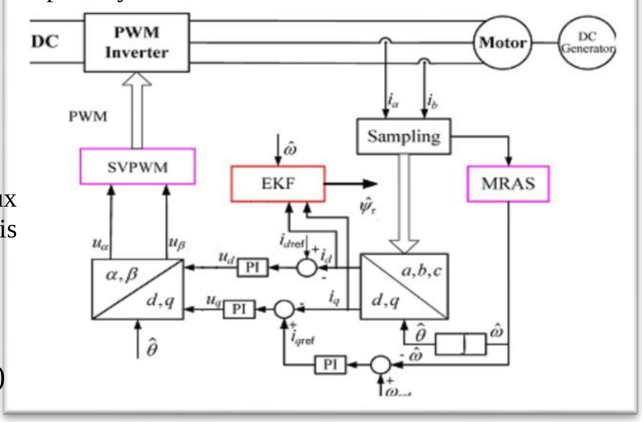

Fig.4 Control diagram of sensorless IPMSM drive by using the proposed EKF based permanent magnet flux identification

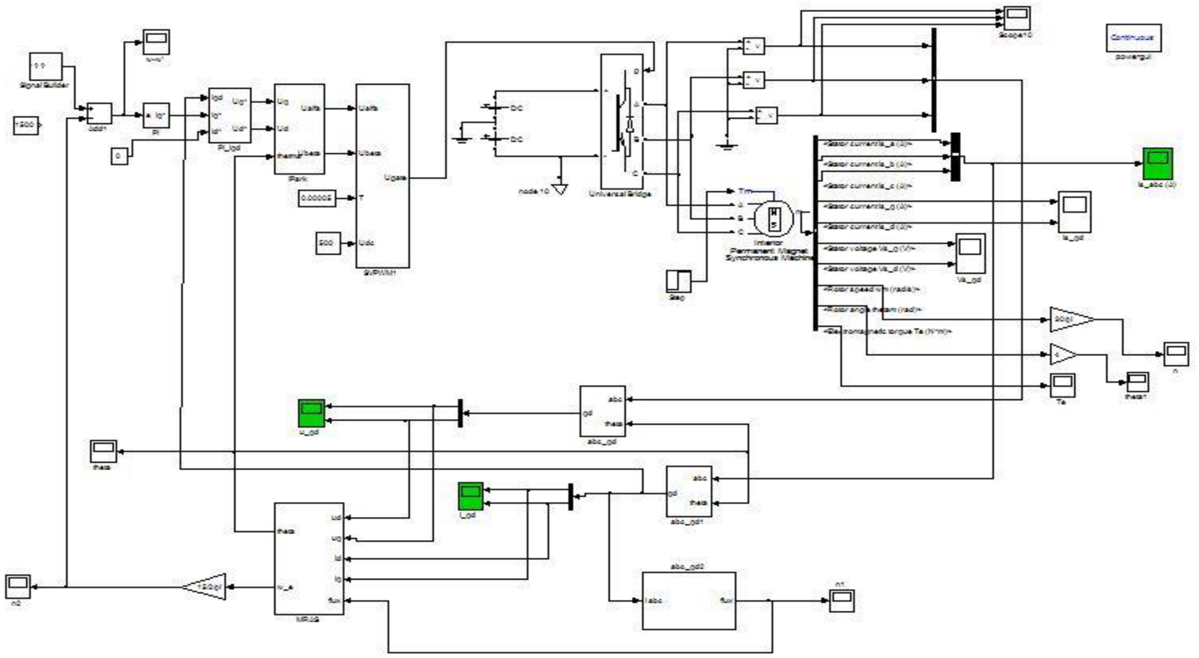

Fig.5 Simulink model of control strategy for IPMSM drive

TABLE I
PARAMETERS FOR THE MOTOR AND INVERTER SYSTEMS INSIMULATIONS

Parameter	**value**
d-axis inductance L_d	7.418mH
q-axis inductance L_q	12.285mH
Stator resistance R	0.618 ohm
Back EMF coefficient KE	0.2256V/(rad/sec)
Pole Pairs	2
DC link voltage	100 V
Maximum allowable current of motor and inverter	8 A
Load Torque	2 N-m

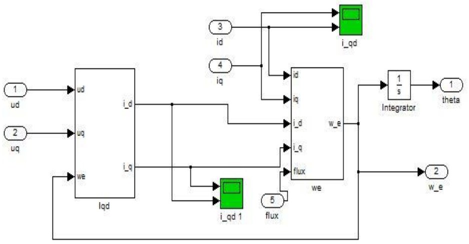

Fig.6 The MATLAB/SIMULINK model of MRAS control scheme

VI. SIMULATION STUDY

In order to verify the proposed control strategy, a model of pulse width modulation (PWM) inverter-fed IPMSM drive system is built in MATLAB/SIMULINK platform. Simulation studies are carried out with a 10-kHz control frequency

The parameters of IPMSM used in the simulation are listed in Table I . The influence of the dead time is not taken into account in simulations.

Fig. 5 shows the Simulated Model of IPMSM Sensorless drive for constant torque or constant speed application with MRAS and EKF observers.

Fig.6 shows the MATLAB/SIMULINK model of MRAS control scheme which is the main heart of IPMSM sensorless drive scheme used to identify the speed

Fig 7 shows the simulation results of IPMSM sensor drive control scheme which consists of three phase sinusoidal currents, Electro Magnetic Torque, Electrical Speed, Mechanical Speed and Position of Rotor.

Fig.8 shows the coincidence of Speed of drive with the reference speed.

Fig 9 shows the identified flux by MRAS observer and Extended Kalman Filter.

Based on these results, the IPMSM drive system with EKF based permanent magnet flux identification exhibits very good steady state performance. Simulations are conducted to examine the dynamic performance of the proposed identification scheme in terms of motor speed changes and load torque changes.

Fig.10 shows the identified flux when the motor speed changes from 1300 to 1500 r/min at 0.6 s

Fig.11 shows the identified flux when the load torque increases from 1.5 to 2 N-m at 0.6 s

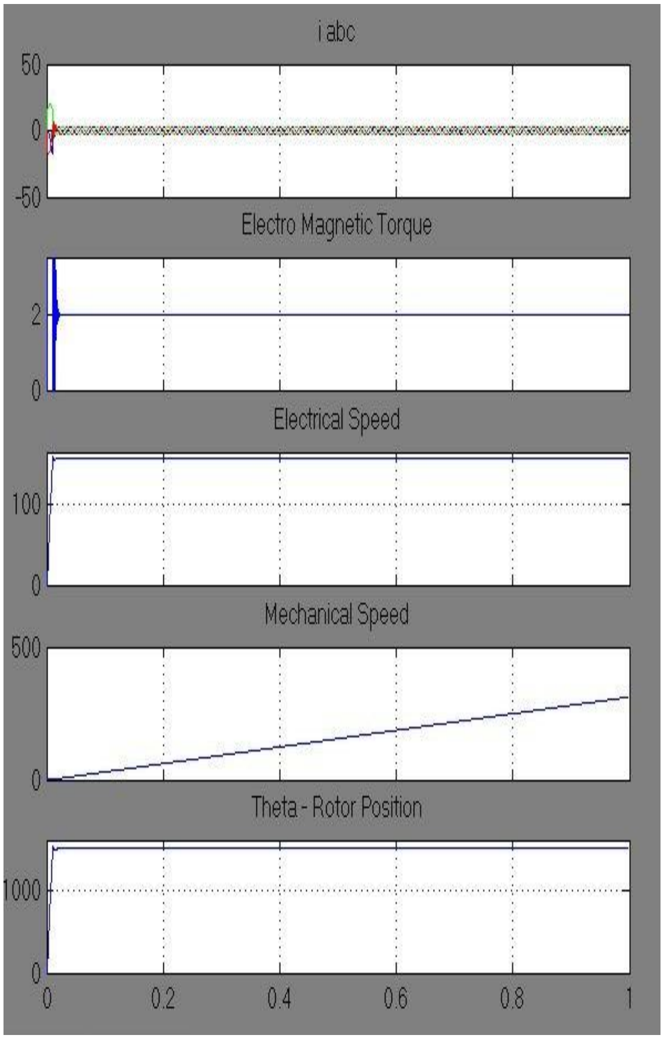

Fig.7 Simulation Results of IPMSM Sensor Drive

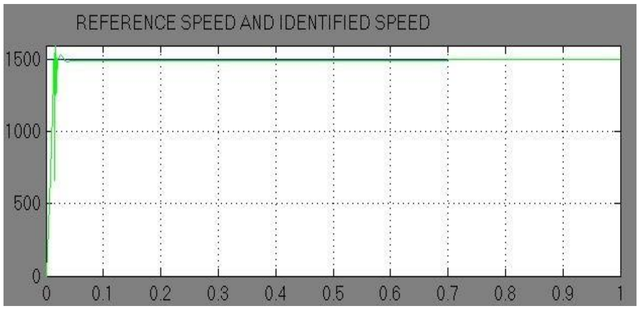

Fig 8. Identified speed by MRAS

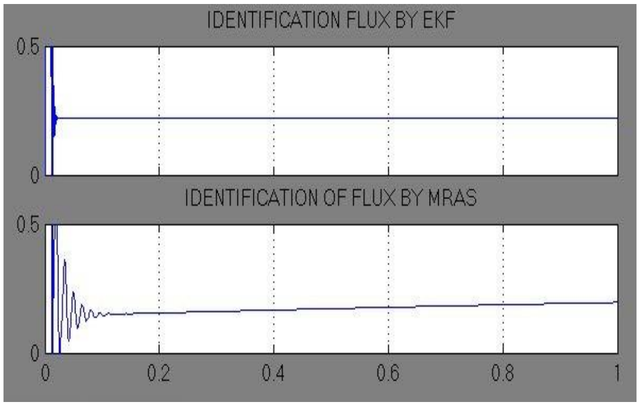

Fig.9 Flux identification by EKF and MRAS observer

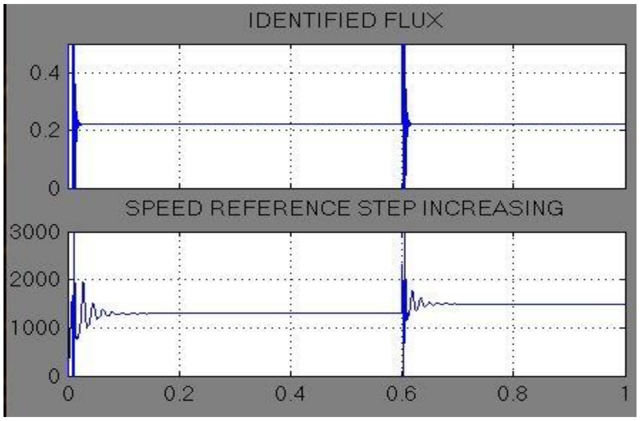

Fig.10 Flux identification with motor speed from 1300 to 1500 rpm

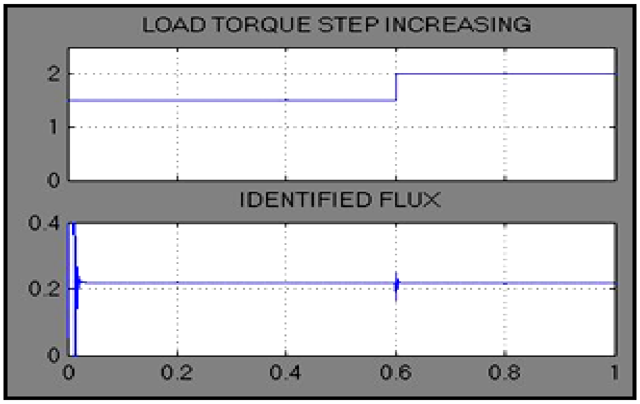

Fig.11 Flux identification with motor load torque increases from 1.5 to 2 N-m at 0.6 s

Simulation results show that the identified flux is convergent to its real value even under dynamic conditions. It is proved that the estimation and control of rotor speed by MRAS and the flux identification by EKF are decoupled effectively.

VII. CONCLUSION

In this paper, Adjustable Speed Control of IPMSM Sensorless Drive and identification scheme of the permanent magnet flux based on EKF has been proposed. This is used to provide the precise information of rotor flux for the MRAS rotor position/speed estimation in the sensorless vector controlled IPMSM drive system.

Simulations and experiments demonstrate the following.

1) By using the proposed scheme, the online accurate identification of permanent magnet flux is realized with very small error.

2)The steady state identified permanent magnet flux and rotor speed(1500-1499.2) are limited within a very low level.

REFERENCES

[1] A. Accetta, M. Cirrincione, M. Pucci, and G. Vitale, "PMSM drives sensorless position control with signal injection and neural filtering," in Proc. IEEE Int. Elect. Mach. Drives Conf., 2009, pp. 279–285.

[2] S. Morimoto, M. Sanada, and Y. Yakeda, "Mechanical sensorless drives of IPMSM with online parameter identification," IEEE Trans. Ind. Appl., vol. 42, no. 5, pp. 1241–1248, Sep./Oct. 2006.

[3] A.Piippo, M. Hinkkanen, and J. Luomi, "Analysis of an adaptive observer for sensorless control of interior permanent magnet synchronous motors," IEEE Trans. Ind. Electron.,vol. 55, no. 2, pp. 570–576, Feb. 2008.

[4] X. Xiao and Y. Li, "A sensorless control based on MRAS method in interior permanent magnet machine drive," in Proc. Int. Conf. Power Electron. Drive Syst., 2005, vol. 1, pp. 734–736.

[5] Y. Liang and Y. Li, "Sensorless control of PM synchronous motors based on MRAS method and initial position estimation," inProc. Int. Conf. Elect. Mach. Syst., 2003, vol. 1, pp. 96–99.

[6] Q. An and L. Sun, "On-line parameter identification for vector controlled PMSM drives using adaptive algorithm," inProc. IEEE Vehicle Power Propulsion Conf., Sep. 2008, vol. 1, pp. 1–6.

[7] S. J. Underwood and I. Husain, "Online parameter estimation and adaptive control of permanent-magnet synchronous machines "IEEE Trans. Ind. Electron., vol. 57, no. 7, pp. 2435–2443, Jul. 2010.

[8] T. Boileau, B. Nahid Mobarakeh, and F. Meibody Tabar, "Online identification of PMSM parameters: Model reference vs EKF," in Conf Rec IEEE IAS Annu. Meeting, 2008, vol. 1

[9] Z. Peroutka, "Development of sensorless PMSM drives: Application of extended Kalman filter," inProc. IEEE Int. Symp. Ind. Electron., 2005, vol. 4, pp. 1647–1652.

[10] M. C. Huang, A. J. Moses, F. Anayi, and X. G. Yao, "The comparison of sensorless estimation techniques for PMSM between extended Kalman filter and flux-linkage observer," inProc. IEEE APEC, 2006, pp. 654–659.

[11] A. Ahmad, H. Mickaël, and D. Demba, "A sensorless PMSM drive using a two stage extended Kalman estimator," inProc. 34th IEEE IECON, 2008, pp. 2776–2781.

[12] X. Xiao, M. Zhang, Y. Li, and M. Li, "On-line estimation of permanent magnet flux linkage ripple for PMSM based on a Kalman filter," inProc. IECON, 2006, vol. 1, pp. 1171–1175.

[13] S. Morimoto, K. Kawamoto, M. Sanada, and Y. Takeda, "Sensorless control strategy for salient-pole PMSM based on extended EMF in rotating reference frame,"IEEE Trans. Ind. Appl., vol. 38, no. 4, pp. 1054–1061, Jul./Aug. 2002.

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