International Journal of Engineering Inventions
e-ISSN: 2278-7461, **p**-ISBN: 2319-6491
Volume 2, Issue 3 (February 2013) PP: 77-86

Speed Sensor less Control and Estimation Based on Mars for Pmsm under Sudden Load Change

K prasada rao[1], Dr Sukhdeo sao[2]
[1]Associate professor, EEE Dept, Christu jyothi institute of technology and science, JANGAON, AP INDIA.506167
[2]Professor, EEE dept, Bharat Institute of Engineering& technology Ibrahimpatnam, RR district Hyderabad AP INDIA

Abstract:- Permanent magnet synchronous motors (PMSM) are appropriate for applications with load-independent speeds or synchronous operation with high accuracy under defined speed. In this paper analysis the structure and equations of the PMSM, direct torque control (DTC) and voltage space vector process then study model reference adaptive system (MRAS) estimators. The PI controller uses from estimate speed feedback and do the speed sensor less control of PMSM based on DTC method with MRAS. The simulation results show that the speed of rotor estimates with high precision and torque response is considerably fast. Principle of rotor speed and and position for PMSM by MARS is given, simulation models are made. Dynamic estimation performances are different under sudden load change, which depends mainly on system structure and PI controller performance

Keywords:- permanent magnet synchronous motor, speed control, direct torque control, model reference adaptive system. Load modeling, estimation, analytical models.

I. INTRODUCTION

In the last years permanent magnet synchronous motor, because of properties such as high efficiency, high torque, high power, small volume and accurate speed control have become more attention and uses in chemical industry, texturing plants, glass industry, transport systems, electrical household appliances, ship engines, robotic automation, and escalators. The control methods used for the permanent magnet synchronous motors are: V/f control, field oriented control and direct torque control [1].

The basic principle of DTC is to directly select stator voltage vectors according to the differences between the reference and actual torque and stator flux linkage. The DTC possesses advantages such as lesser parameter dependence and fast torque response when compared with the torque control via PWM current control [2].

Position sensor with higher quality is a necessary component part of the drive system employed in industrial and automotive applications. But the high cost and strict requirement extremely limit the application in the drive system. So that it is highly desired to develop the position sensor less technology of PMSM. For the mechanical position sensor could be bulky and easy to failure in harsh environments, sensor less technology can increase the reliability of the drive system. Research on sensor less technology has increased in academic and industrial communities over.

During recent years, sensor less drives of PMSM have attracted much attention. Many techniques have been proposed in order to estimate the rotor speed and position, such as open-loop estimators using stator voltages and currents, back EMF-based position estimators, MRAS estimators, observe-based position speed and position estimators, high-frequency signal injection and artificial intelligence.
This paper adopts the MRAS scheme which uses the PMSM itself as the reference model to estimate the speed of the motor [3].

II. PERMANENT MAGNET SYNCHRONOUS MOTORTECHNOLOGY

Permanent magnet synchronous motors can be designed in different structures according to their application. In this mot-or permanent magnet can replacing the DC induction coils of the rotor, that is supplied the magnetic flux on the rotor.

Stator coils placed on the stator are three phase and the amount of current drawn from the supply is minimal that leads to low losses of the rotor and excitation, increase of efficiency comparable with other motors and savings on energy costs.

The magnets on the rotor have two following structure:

A. Placing the magnets on the rotor surface

Magnets are installed on the rotor in forms of strips or arcs. These motors have large air gap and faint armature reaction and are utilized in low-speed applications because the low endurance of the magnets to the centrifugal forces. These motors are usually known as surface permanent magnet motors (SPMSM). This motor is shown in Fig. 1.

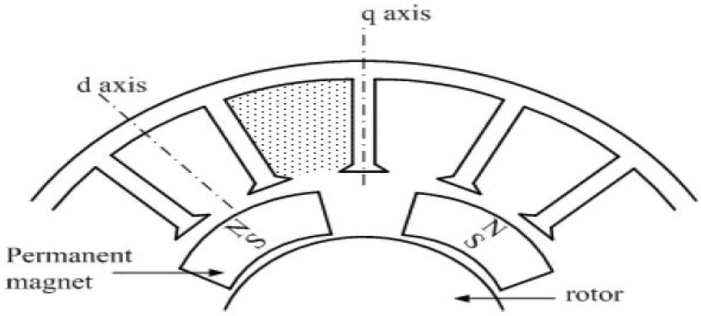


Figure 1. Magnets on the rotor surface

B. Placing the magnets inside the rotor (radially or circular)

At the previous state the magnets being exposed to high centrifugal forced under high speeds and air gap induction is limited. For solution of this problem the magnets are placed in the rotor to two figures of radially and circular.

In this state the magnets have a better resistance to centrifu-gal forces appropriate for high speed applications. Also the efficiency of these motors is also higher than other magnet motors. But these motors have high costs because needs to high technology. These motors are usually known as interior permanent magnet synchronous motor (IPMSM). Figs. 2 and 3 are shown the radially and circular structure respectively.

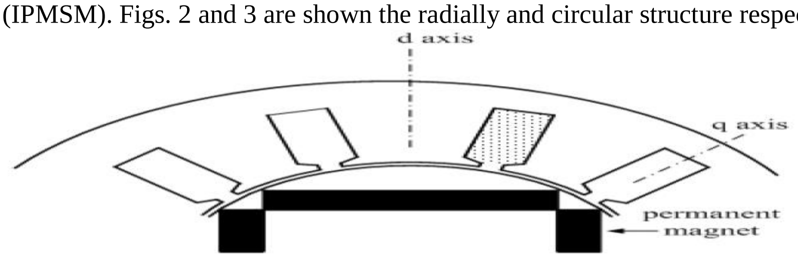


Figure 2. Radially structure

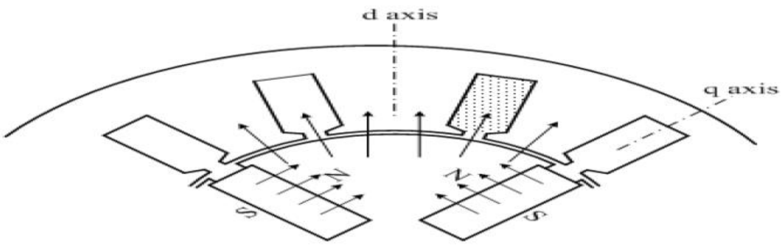


Figure 3. Circular structure

The differences between Radially and Circular structure are shown in table 1 [4].

TABLE I. DIFFERENCES RADIALLY AND CIRCULAR STRUCTURE

	Radially structure	Circular structure
Place of magnets	around the rotor axis	pointing the main axis
gap	low	high
Resistance to the centrifugal forces	high	high

III. DIRECT TORQUE CONTROL

DTC is a sensorless technique which operates the motor without requiring a shaft mounted mechanical sensor. It is suitable for control of the torque and flux without changing the motor parameters and load. In this method torque and stator flux are directly controlled by two hysteresis controllers [5-7]. The block diagram of direct torque control for permanent magnet synchronous motor is shown in Fig. 4.

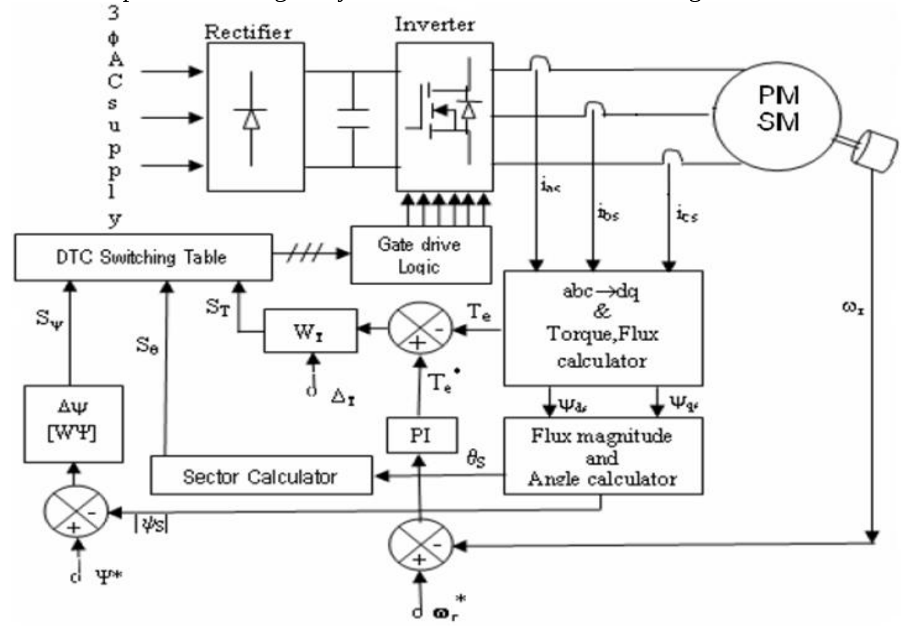


Figure 4. Block diagram of DTC for PMSM

Permanent magnet synchronous motor Equations

Stator current vector on rotor flux (dq) reference system as i_d, i_q and the electromagnetic torque is related with these vectors. Equations (1-3) and equation (4) are electrical and mechanical model equations respectively [8].

$$\frac{d}{dt}i_d = \frac{1}{L_d}u_d - \frac{R_s}{L_d}i_d + \frac{L_q}{L_d}\omega_r i_q \qquad (1)$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}u_q - \frac{R_s}{L_q}i_q - \frac{L_d}{L_q}\omega_r i_d - \frac{\psi_f \omega_r}{L_q} \qquad (2)$$

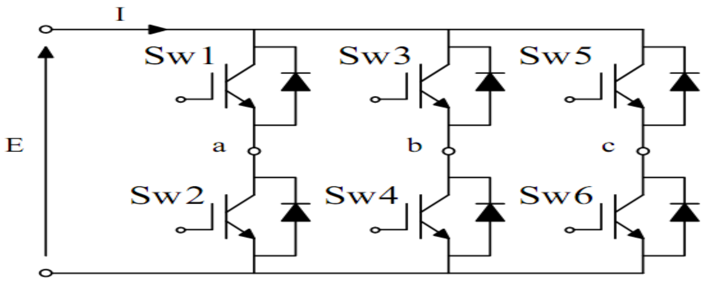
$$T_e = 1.5P[\psi_f i_q - (L_q - L_d)i_d i_q] \qquad (3)$$

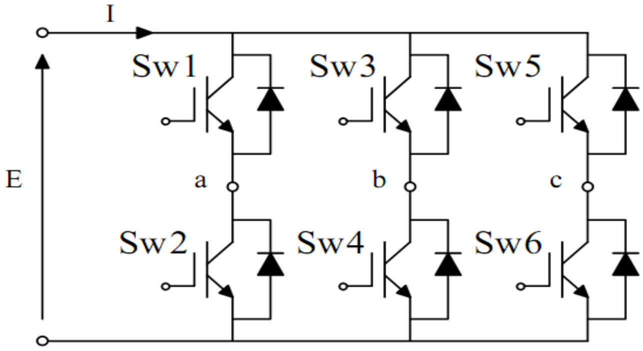
$$\frac{d}{dt}\omega_m = \frac{1}{J}(T_e - B\omega_m - T_L) \qquad (4)$$

$$\omega_r = p\omega_m \qquad (5)$$

where Ψ_f is :rotor magnetic flux, L_d is d axis stator inductance, L_q is q axis stator inductance, R_s is stator resistance, T_e is electromagnetic torque, T_L is load torque, ω_m is mechanical speed, ω_r is angular speed, J is moment of inertia, β is friction coefficient, p is number of pole couples.

Structure of voltage-source inverter (VSI) is shown in Fig. 5 at the same time only one switch on the each of column can be on [5].





$$V_{ab} = E.(S_a - S_b) \tag{6}$$

$$V_{bc} = E.(S_b - S_c) \tag{7}$$

$$V_{ca} = E.(S_c - S_a) \tag{8}$$

Line-to-neutral voltages are:

$$V_a = \frac{2V_{ab} + V_{bc}}{3} \tag{9}$$

$$V_b = \frac{V_{bc} - V_{ab}}{3} \tag{10}$$

$$V_c = \frac{-V_{ab} - 2V_{bc}}{3} \tag{11}$$

The stator voltage-vectors (V1-V8) can be expressed in terms of the dc-link voltage (E) which obtained from transformation motor terminal voltages to stator D and Q axes. These voltages are show in Table 2 [5].

TABLE II. VOLTAGES V_D , V_Q

	v_d	v_q
V_1	E	0
V_2	0.5E	0.866E
V_3	-0.5E	0.866E
V_4	-E	0
V_5	-0.5E	-0.866E
V_6	0.5E	-0.866E
V_7	0	0
V_0	0	0

Stator magnetic flux can be calculated with following equation:

$$\Psi_s = \int (u_s - R_s i_s)dt \tag{12}$$

Value of R is low, equation (12) implies that the flux vector equal voltages integrate and the stator flux vector will move in the same direction voltage vector as shown in Fig. 6.

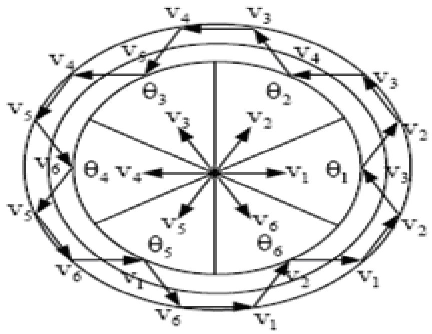


Figure 6. Voltage space vectors

Voltage vectors controlling the amplitude of the stator flux, so the voltage vector plane is divided into six regions as shown in Fig. 6. In each region, there are two adjacent voltage vectors that increase or decrease the amplitude of ψs. For example, when ψs is in region 1, vectors of V1, V2, V6 and V3, V4, V5 are increase and decrease the amplitude of ψs, respectively. In this way, ψs can be controlled at the required value by selecting the proper voltage vectors [9-12]. Switching table, for controlling both the flux and torque are indicated in Table 3. If ψ=1, and ψ=0 then the actual flux is smaller and bigger than the reference value, respectively. The same is true for the torque.

TABLE III. SWITCHING TABLE OF PMSM

		θ					
ψ	T	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6
$\psi=1$	T=1	V_2	V_3	V_4	V_5	V_6	V_1
	T=0	V_6	V_1	V_2	V_3	V_4	V_5
$\psi=0$	T=1	V_3	V_4	V_5	V_6	V_1	V_2
	T=0	V_5	V_6	V_1	V_2	V_3	V_4

IV. MODEL REFERENCE ADAPTIVE SYSTEM

When the motor is running, its parameters will change and its performance will become bad. Adaptive control can remove this problem. The model reference adaptive system (MRAS) is an important adaptive controller [13]. The rotor speed is included in the (1) and (2) equations that present current model are relevant to rotor speed. So the stator current model is chosen as the state variable:

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_d} & \omega_e \frac{L_q}{L_d} \\ -\omega_e \frac{L_d}{L_q} & -\frac{R_s}{L_q} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} \frac{u_d}{L_d} \\ \frac{u_q}{L_q} - \omega_e \frac{\psi_f}{L_q} \end{bmatrix} \tag{13}$$

Define $i_d^*, i_q^*, u_d^*, u_q^*$ as follow:

$$i_d^* = i_d + \frac{\psi_f}{L_d}, \; i_q^* = i_q \tag{14}$$

$$u_d^* = u_d + \frac{R_s}{L_d}\psi_f, \; u_q^* = u_q \tag{15}$$

So equation (14) can be converted to the equation state of the adjustable model of PMSM with speed angle as the adjustable parameter as follow:

$$\frac{d}{dt}\begin{bmatrix}\hat{i}_d^*\\ \hat{i}_q^*\end{bmatrix}=\begin{bmatrix}-\frac{R_s}{L_d} & \hat{\omega}\frac{L_q}{L_d}\\ -\hat{\omega}\frac{L_d}{L_q} & -\frac{R_s}{L_q}\end{bmatrix}\begin{bmatrix}\hat{i}_d^*\\ \hat{i}_q^*\end{bmatrix}+\begin{bmatrix}\frac{1}{L_d}u_d^*\\ \frac{1}{L_q}u_q^*\end{bmatrix} \qquad (16)$$

where:

$$\hat{i}_d^*=\hat{i}_d+\frac{\psi_f}{L_q}\ ,\ \ \hat{i}_q^*=\hat{i}_q \qquad (17)$$

Presume the adaptive mechanism as follow:

$$\hat{\omega}=\int_0^t F_1(v,t,\tau)\,d\tau+F_2(v,t)+\hat{\omega}(0) \qquad (18)$$

F_1 and F_2 are show as follow:

$$\begin{cases}F_1(v,t)=k_1e^TJ\hat{i}^*\\ F_2(v,t)=k_2e^TJ\hat{i}^*\end{cases} \qquad (19)$$

where:

$$J=\begin{bmatrix}0 & \frac{L_q}{L_d}\\ -\frac{L_d}{L_q} & 0\end{bmatrix} \qquad (20)$$

$$e=\begin{bmatrix}i_d^*-\hat{i}_d^*\\ i_q^*-\hat{i}_q^*\end{bmatrix} \qquad (21)$$

$$\hat{i}^*=\begin{bmatrix}\hat{i}_d^*\\ \hat{i}_q^*\end{bmatrix} \qquad (22)$$

So with replace equation (17) into equation (16), the speed adaptive mechanism finally appear[14]:

$$\hat{\omega}=(K_p+\frac{K_i}{p})\left[\frac{L_q}{L_d}i_d\hat{i}_q-\frac{L_d}{L_q}i_q\hat{i}_d\right.$$
$$\left.-\frac{\psi_f}{L_q}(i_q-\hat{i}_q)+\hat{i}_d\hat{i}_q(\frac{L_d}{L_q}-\frac{L_q}{L_d})\right]+\hat{\omega}(0) \qquad (23)$$

But the above equation for SPMSM can be simplified as follow (because $L_d=L_q=L_s$):

$$\hat{\omega} = (K_p + \frac{K_i}{p})\left[i_d \hat{i}_q - i_q \hat{i}_d - \frac{\psi_f}{L_s}(i_q - \hat{i}_q) \right] + \hat{\omega}(0) \qquad (24)$$

By these equations, block diagram control of the PMSM based on MRAS can be gotten, and it is shown as Fig. 7.

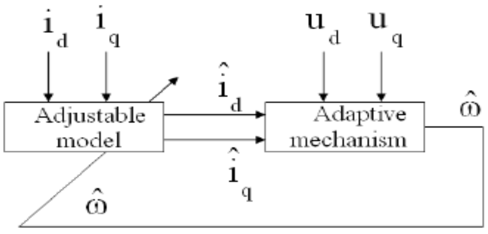


Figure 7. The block diagram control of based on MRAS

V. SIMULATION OF SPEED SENSORLESS CONTROL OF PMSM BASED ON DTC METHOD WITH MRAS REFERENCE ADAPTIVE SYSTEM

With combine Fig. 4 and Fig. 7, can be estimated the rotor speed and simulate with MATLAB software. Fig. 8 shows the block diagram of speed sensor less control of PMSM based on DTC method with MRAS. In Fig. 8, the estimate output speed of MRAS compare with the reference speed of input and uses from this speed as the real speed of machine.

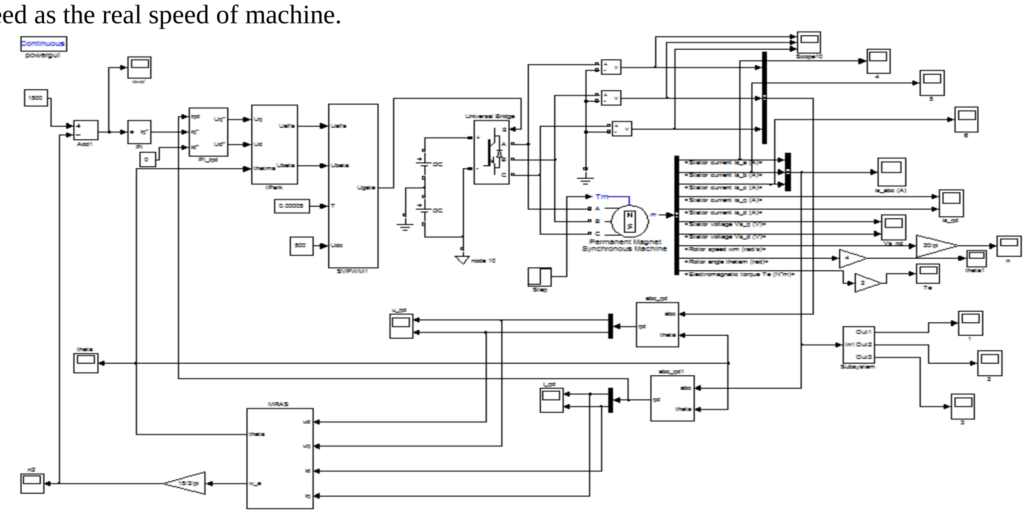


Figure 8. The block diagram DTC method with MRAS

Reference speed is 25 rad/s at 0s and then leaps to 10 rad/s at 1s. In the Fig. 9 speed of the motor is 25 rad/s at 0.8 s and 10 rad/s at 1.6s. Fig. 10 shows the torque of the motor. Load torque is 10 N.m as shown in Fig. 10, torque response is fast. Fig. 11 and Fig. 12 show flux of alfa axis and beta axis.

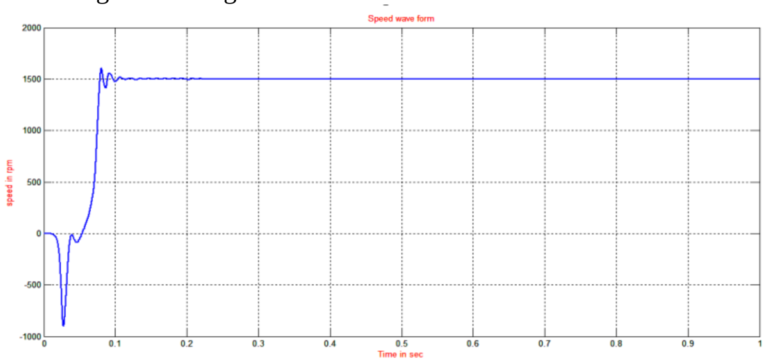


Figure 9. Estimated speed of PMSM

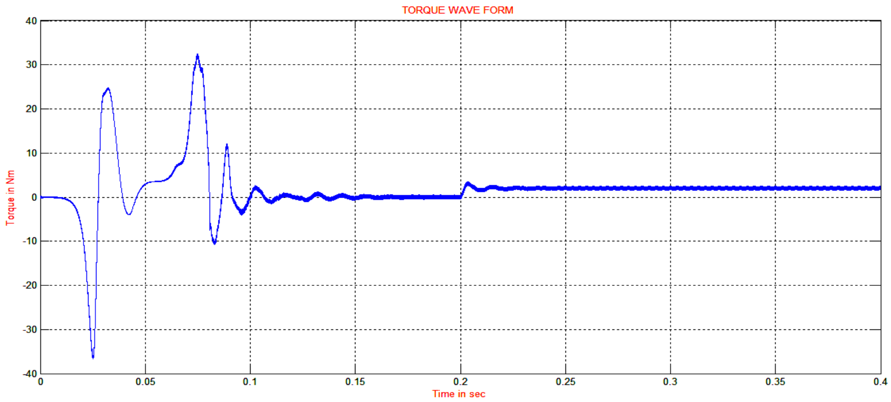


Figure 10. Torque of PMSM

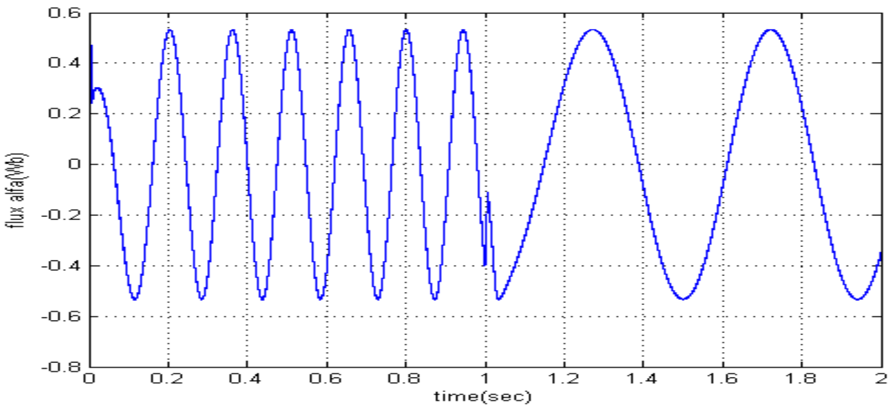


Figure 11. Flux of alfa axis

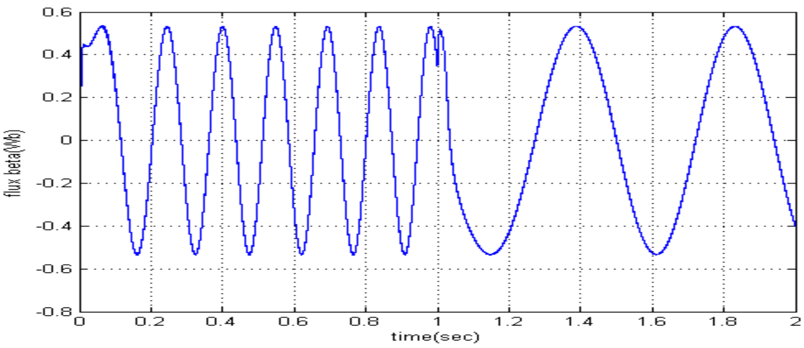


Figure 12. Flux of beta axis

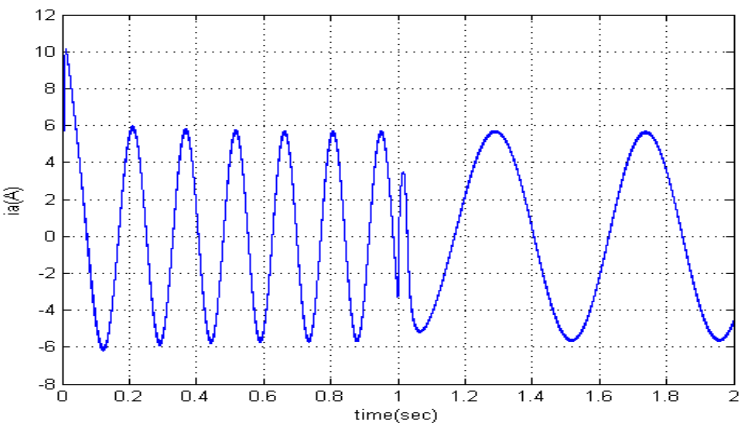


Figure 13. The current of phase a (ia)

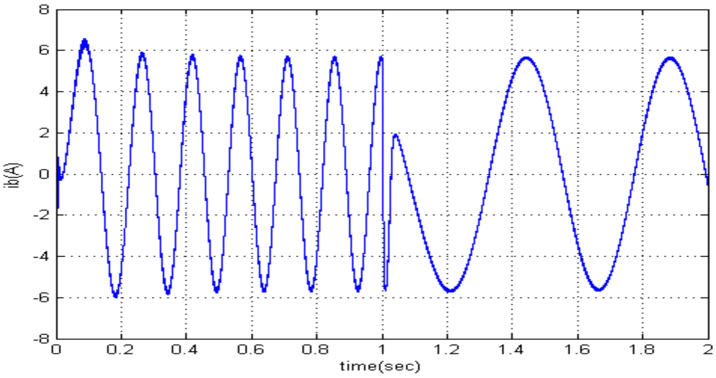


Figure 14. The current of phase b (ib)

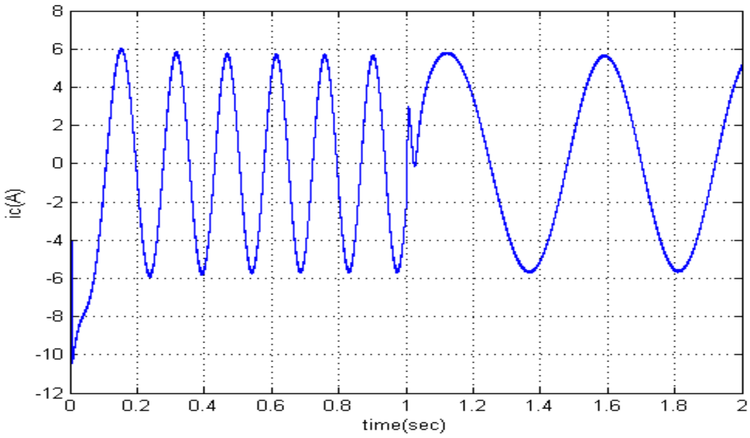


Figure 15. The current of phase c (ic)

In Fig. 16 flux is constant and about 0.532 wb. Table 4 shows the parameters of the PMSM used to simulate

TABLE IV. PARAMETERS OF PMSM

Parameter	Value
Ψ_M	0.533 wb
R_s	5.8 Ω
L_d	44.8 mH
L_q	102.7 mH
J	0.0329 kgm^2
V_d	165 V
B_m	0.0003882
P	2

VI. CONCLUSION

In this paper analysis DTC method and a control system of MRAS is introduced. DTC method is designed for an efficient control of the torque and flux without changing the motor parameters and load, with in this method the flux and torque can be directly controlled with the inverter voltage vectors. The DTC is use in a wide speed range. MRAS method using the adjustable model and the reference model so that estimates the position and speed of the rotor, which in this method uses the motor itself as the reference model.

The simulation results with MATLAB software indicate that speed sensor less control of PMSM based on DTC method with MRAS has preferable good dynamic performance, speed estimation precise and fast torque response. This control technology is available both for SPMSM and IPMSM.

REFERENCES

1) M. Jafarboland, E. Babaei, "Sensorless speed/position estimation for permanet magnet synchronous machine via extended Kalman filter", Jour. of Trans. on Elec. Tech. (JTET), Vol.1, No.1, pp.31-36, Winter 2009.
2) L. Zhong, M..F. Rahman, W.Y. Hu, K.W. Lim, "Analysis of direct torque control in permanet magnet synchronous motor drives", IEEE Trans. on Pow. Elec., ol.12, No.3, pp. 528-536, 1997.
3) Z. Tan , Y. Li, Z. Ji, "Speed sensorless DTC and parameter estimation of induction motor based on a full-order MRAS method", IEEE Trans.on Pow. Elec. ,pp.1202– 1206, 2000.
4) S. Özçıra, N. Bekiroğlu, E. Ayçiçek "Speed control of permanent magnet synchronous motor based on direct torque control method", IEEE/ISPE, pp. 268-272, 2008.
5) M. F. Rahman, L. Zhong, E. Haque, "Selection of voltage switching tables for DTC controlled interior permanent magnet motor", Sch. Of Elec. Eng. and Tele., The Uni. of New Sou. Wal., Sydney, NSW 2052 Australia, 1999.
6) D. Sun, F. Weizhong, H. Yikang, "Study on the Direct Torque Control of Permanent Magnet Synchronous Motor Drives", IEEE/ ICEMS, pp. 571-574, 2001
7) Y. A. Chapuis, D. Roye, J. Davoine, "Principles and implementation of direct torque control by stator flux orientation of an induction motor", PESC, pp. 185–191, 1995.
8) C. French, P. Acarnley, "Direct torque control of permanent magnet drive", in IEEE Ind, Applicat, Society Annu, Meet , pp. 199–206, 1995.
9) F. M. Abdel-kader, A. El-Saadawi, A. E. Kalas, O. M Elbaksawi, "Study in direct torque control of induction motor by using space vector modulation". Power System Conference, MEPCON 2008.12th International Middle-East, pp.224 – 229, 2008.
10) Luukko, "Direct Torque Control of Permanent Magnet Synchronous Machines-Analysis and Implementation", Diss. Lappeenranta University of Technology, Stockholm, Sweden, 2000.
11) S. Dan, F. Weizhong, H. Yikang, "Study on the direct torque control of permanent magnet synchronous motor drives". IEEE/ICEMS, Vol.1, pp.571 – 574, 2001.