iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 2 **Issue:** II **Month of publication:** February 2014

DOI:

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

An Effective Design of Speed Controller for Permanent Magnet Synchronous Motor Using Fuzzy Technique

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Abstract: A permanent magnet synchronous motor (PMSM) features low inertia, high power density, low noise, high efficiency, low maintenance cost, and robustness, a PMSM has been widely used in many industrial applications. However, precise control of a PMSM is not easy due to nonlinearities of PMSM servo systems, parameter and load torque variations. Thus the linear control schemes such as PI control cannot guarantee satisfactory performances. In this paper a Simulink model of PMSM is derived from mathematical model. Then fuzzy model of PMSM is developed based on Takagi–Sugeno fuzzy approach, also a fuzzy speed regulator based on the Takagi–Sugeno fuzzy approach is designed for a PMSM. Simulation results are given to verify that the proposed method can be successfully used to control a PMSM under parameter and load torque variations.

Keywords: Fuzzy system, (PMSM), speed control, Takagi–Sugeno fuzzy model .

I. INTRODUCTION

A Permanent Magnet Synchronous Motor (PMSM) has low inertia, high power density, low noise, high efficiency, low maintenance cost, high torque density, and robustness. The permanent magnet synchronous motor eliminates the use of slip rings for field excitation, resulting in low maintenance and low losses in the rotor. Thus, a PMSM has been widely used in many industrial applications such as chip mount machines, semiconductor production machines, high-resolution computer-numerical-control machines, robots, and hard disk drives. But, precise control of a PMSM is not easy due to the nonlinearities of PMSM servo systems, parameter variations, and load torque variations. The main drawbacks of the linear control approach are the sensitivity in performance to the system parameters variations and inadequate rejection of external perturbations and load changes. Thus, the linear control schemes such as proportional–integral control cannot assure satisfactory performances. To remove this problem, many researchers have proposed various control design methods. e.g., neural network control [2], adaptive control [3][5], and disturbance-observer-based control. Fuzzy-logic, first proposed by L. A. Zadeh, has recently received a great deal of attention. The easy way of defining a fuzzy controller by rules with an obvious physical meaning has helped to expand this control technique. When it is applied to control nonlinear systems, this nonlinear control strategy has shown better results than classical controllers do.

II. PMSM MODEL

By taking the rotor coordinates of the motor as reference coordinates, a surface-mounted PMSM can be represented by the following nonlinear equation

$$V_{qs}^{r} = (r_s + pL_q)i_{qs}^{r} + \omega_r\, L_d i_{ds}^{r} + \omega_r \lambda_m^{\prime r} \qquad (1)$$

$$V_{ds}^{r} = (r_s + pL_d)i_{ds}^{r} - \omega_r\, L_q i_{qs}^{r} \qquad (2)$$

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)(\lambda_m^{\prime r} i_{qs}^{r} + (L_d - L_q) i_{qs}^{r} i_{ds}^{r}) \qquad (3)$$

$$T_e = T_L + B\omega_m + J.\, p\omega_m \qquad (4)$$

Where

$\omega_m = \omega_r \left(\frac{P}{2}\right)$

P denotes no. of poll and p differentiation.

By using equation 1 through 4, a surface-mounted PMSM can be represented by the following nonlinear equation

$$\omega_r^* = k_1 i_{qs}^r - k_2 \omega_r - k_3 T_L \qquad (5)$$

$$i_{qs}^{r*} = -k_4 i_{qs}^r - k_5 \omega_r + k_6 V_{qs} - \omega_r\, i_{ds}^r \qquad (6)$$

$$i_{ds}^{r*} = -k_4 i_{ds}^r + k_6 V_{ds} + \omega_r\, i_{qs}^r \qquad (7)$$

Where * denotes differentiation T_L represents the load torque, ω_r is the electrical rotor angular speed, and $k_i > 0$, i = 1 . . . 6, are the parameter values given by $k_1 = \frac{3}{2}\frac{1}{J}\frac{p^2}{4}\lambda_m$, $k_2 = \frac{B}{J}$, $k_3 = \frac{p}{2J}$, $k_4 = \frac{R_s}{L_s}$

$k_5 = \frac{\lambda_m}{L_s}$, $k_6 = \frac{1}{L_s}$

We want to design a T-S control system so a T-S model of PMSM is required. In T–S fuzzy modeling n operating points for a nonlinear system are first chosen, then a set of n simple local linear subsystem models for each operating point is obtained, and each subsystem model is associated with a fuzzy inference rule. Based on the T–S fuzzy modeling approach, the PMSM model can be approximated by a third order r-rule fuzzy model. The i[th] rule of the T–S fuzzy model is of the following form

Plant Rule i : If i_s is F_i, Then

$$\omega_r^* = k_1 i_{qs}^r - k_2 \omega_r - k_3 T_L$$

$$i_{qs}^{r*} = -k_4 i_{qs}^r - k_5 \omega_r + k_6 V_{qs} - \omega_r\, I_{dsi}^r$$

$$i_{ds}^{r*} = -k_4 i_{ds}^r + k_6 V_{qs} + \omega_r\, I_{qsi}^r$$

where F_i (i = 1, . . . , n) values denote the fuzzy sets, n is the number of fuzzy rule, (I_{qsi}, I_{dsi}) is the i_{th} operating point, and $i_s = [i_{qs}, i_{ds}]^T$. Each fuzzy set F_i is characterized by a membership function $m_i(i_s)$ and the i[th] operating point (i_{qs}, i_{ds}) = (I_{qsi}, I_{dsi}). By using a standard T-S fuzzy inference mechanism, the following global nonlinear model of PMSM can be obtained

$$\omega_r^* = k_1 i_{qs}^r - k_2 \omega_r - k_3 T_L \qquad (8)$$

$$i_{qs}^{r*} = -k_4 i_{qs}^r - k_5 \omega_r + k_6 V_{qs} - \sum_{i=1}^{n} h_i(i_s) I_{dsi}^r\, \omega_r$$

(9)

$$i_{ds}^{r*} = -k_4 i_{ds}^r + k_6 V_{qs} + \sum_{i=1}^{n} h_i(i_s) I_{qsi}^r\, \omega_r$$

(10)

where $h_i(\cdot) = m_i(\cdot)/\sum_{j=1}^{n} m_j(\cdot)$, $m_i : R^2 \rightarrow [0, 1]$, i = 1,. . . , n is the membership function of the system with respect to plant rule i, h_i can be regarded as the normalized weight of each if–then rule and satisfies $m_i(i_s) \geq 0$ and $\sum_{i=1}^{n} m_i(\cdot) = 1$

Assuming two operating point such that $I_{qs1} = I_{qs2} = I_0$, $I_{ds1} = -I_{ds2} = I_0$ and $m_i(i_s)$ are given by

$$m_1 = \frac{e^{-\mu(i_{ds}^r - I_0)^2}}{e^{-\mu(i_{ds}^r - I_0)^2} + e^{-\mu(i_{ds}^r + I_0)^2}}$$

$$m_2 = 1 - m_1$$

Simulink model for fuzzy PMSM model is made of various subsystems these subsystem model are given hare

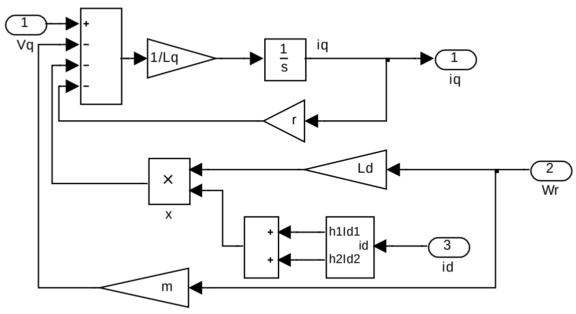

Figure 1: q-axis T-S fuzzy model

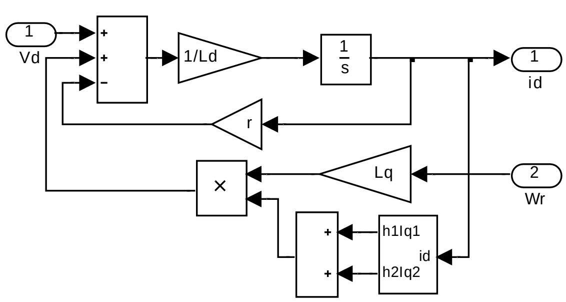

Figure 2: d-axis T-S fuzzy model

These blocks are combined along with abc to d-q conversion block, to get complete fuzzy model of Permanent magnet synchronous motor.

III. FUZZY SPEED REGULATOR DESIGN

Let us define i_{qsd} as $i_{qsd} = (k_2\omega_d + k_3T_L)/k_1$, then by using assumptions that va 'T_L is unknown and T_L^* can be neglected, and it can be set as $T_L^* = 0$', and the desired speed ω_d is constant and $\omega_d^* = 0$', it can be shown that $i^*_{qsd} = 0$. Taking $\tilde{\omega}$ and $\widetilde{i_{qs}}$ as $\tilde{\omega} = \omega_r - \omega_d$ and $\widetilde{i_{qs}} = i_{qs}^r - i_{qsd}$ respectively.

Let the control input variables V_{qs} and V_{ds} be decomposed as

$$V_{qs} = \frac{1}{k_6}(u_q + u_{qf}), \qquad V_{ds} = \frac{1}{k_6}(u_d + u_{df})$$

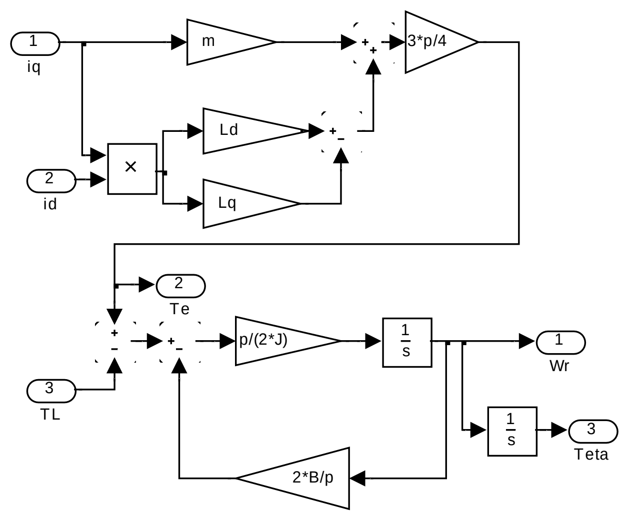

Figure 3: Torque and speed model

Then, fuzzy model can be transformed into

$$\tilde{\omega}^* = k_1\widetilde{i_{qs}} - k_2\tilde{\omega}$$

$$\widetilde{i_{qs}}^* = -k_4 i_{qs}^r - k_5\omega_r + u_q + u_{qf} - \sum_{i=1}^{n} h_i(i_s) I_{dsi}^r\,\omega_r$$

$i_{ds}^{r*} = -k_4 i_{ds}^r + u_q + u_{qf} + \sum_{i=1}^{n} h_i(i_s) I_{qsi}^r\,\omega_r$ Let the local speed regulator be given by the following linear controller

Controller Rule i : If i_s is F_i, then

$$u_q = k_4 i_{qs}^r + (k_5 + I_{di})\omega_r$$

$$u_d = k_4 i_{ds}^r - I_{qi}\omega_r$$

$u_{qdf} = k_i x$

Where $X = [\,\tilde{\omega}, \widetilde{i_{qs}}, i_{ds}\,]^T$ $u_{qdf} = [u_{qf} \;\; u_{df}\,]^T$, and $K_i \in R^{2\times 3}$ are gain matrices. Then, the final fuzzy speed regulator inferred as the weighted average of the each local controller is given by

$$u_q = k_4 i_{qs}^r + k_5 \omega_r + \sum_{i=1}^{n} h_i(i_s) I_{dsi}^r\, \omega_r \quad (11)$$

$$u_d = k_4 i_{ds}^r - \sum_{i=1}^{n} h_i(i_s) I_{qsi}^r\, \omega_r \quad (12)$$

$$u_{qdf} = \sum_{i=1}^{n} h_i(i_s)\, k_i x \quad (13)$$

Simulink model for fuzzy speed regulator is given in figure 4.

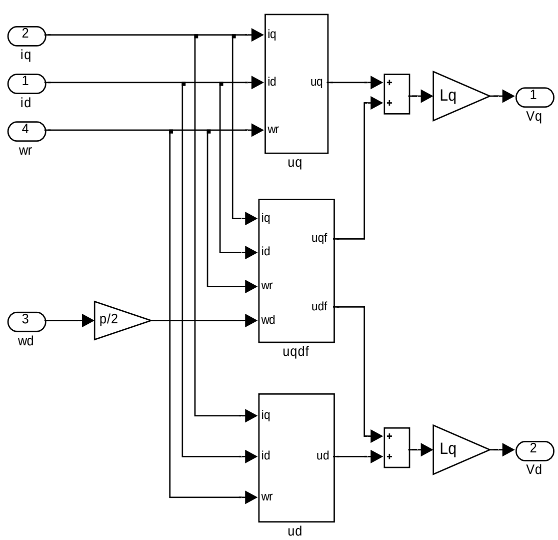

Figure 4: Simulink model of Fuzzy speed regulator

IV. SIMULATION RESULT

Table 1

Parameters	Rating
Rated phase voltage	230 V
Rated phase current	3.94 A
Number of poles (P)	12
Stator resistance(r)	0.99 Ω
Stator inductance($L_d = L_q$)	5.82 mH
Magnetic flux(λ_m)	0.079153 V.sec/rad
Equivalent inertia(J)	0.0012 kg.m^2
Viscous friction coefficients(B)	0.0003 N.m.sec/rad

A PMSM given by equation 8, 9 and 10 is considered with nominal parameters values given in table 1, load torque is 1 N-m Two rule fuzzy model is assumed Two set point are given by $I_{qs1} = I_{qs2} = I_0$, $I_{ds1} = -I_{ds2} = I_0$, $I_0 = 4$ and μ =0.0313. The controller gain matrix is given as

$$K_1 = 10^3 \times \begin{bmatrix} -0.2701 & -0.5271 & 0 \\ -0.0157 & 0 & -1 \end{bmatrix}$$

$$K_2 = 10^3 \times \begin{bmatrix} -0.0131 & -0.04232 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

Matlab/Simulink was used for simulation. Simulation was performed using fixed step of size 0.00001,Runge-Kutta method has been used for the solution of differential equations. For the simulation pulse-width modulation frequency is chosen as 45 kHz and space vector PWM (SVPWM) technique was used .

ISSN: 2321-9653

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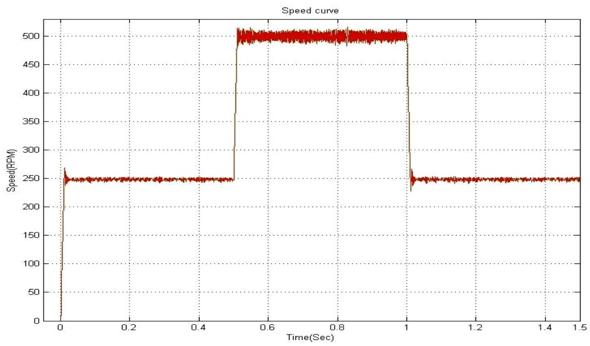

Figure 5: Motor speed with nominal parameters

Firstly simulation with nominal parameters given in table 1 is performed. Figures 5 to 9 show the simulation results for the case when reference speed is increases from 250 rpm to 500 rpm and then decreases from 500 rpm to 250 rpm with nominal parameters.

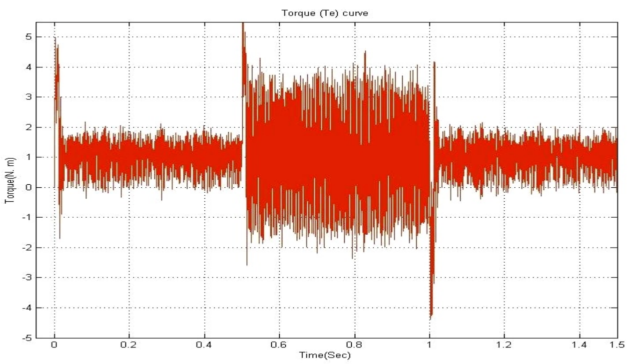

Figure 6: Electromagnetic torque with nominal parameters

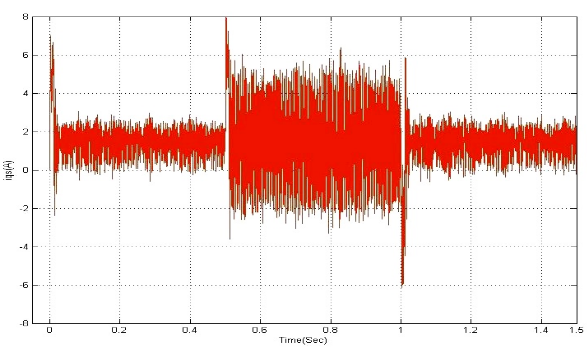

Figure 7: i_{qs} with nominal parameters

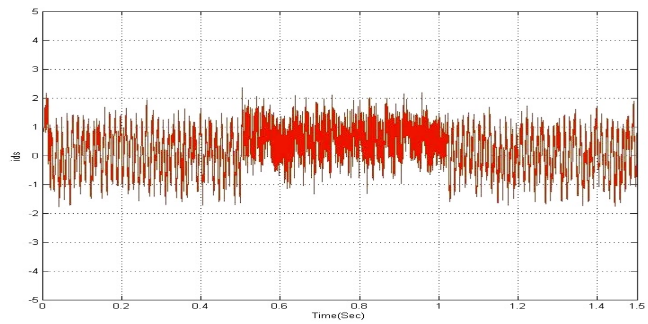

Figure 8: i_{ds} with nominal parameters

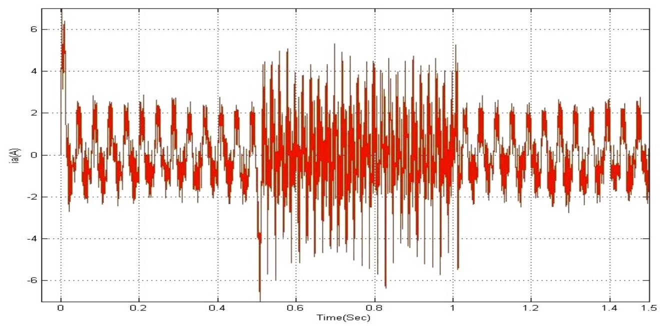

Figure 9: i_a with nominal parameters

In second case simulation is performed with parameter variation of 125% of some parameter of table 1. The values of new parameters are r =1.24 Ω, $L_d = L_q = 7.28$ mH, J= 0.0015 kg.m^2, T_L=1.5 N-m. The PMSM parameters usually vary due to aging, wear, and change of operating point. It can be verified that the proposed fuzzy controller gives very performance such as fast transient response, a small steady state error and a good performance under model parameter and load torque variation.

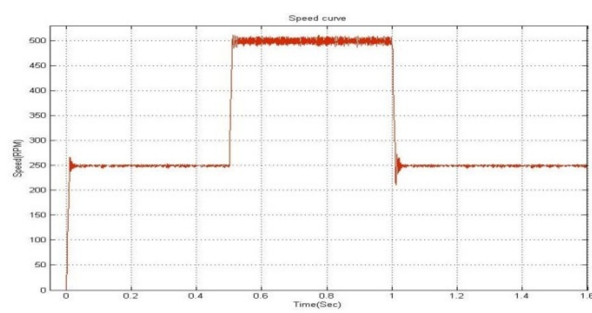

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Figure 10: Motor speed with parameter variation

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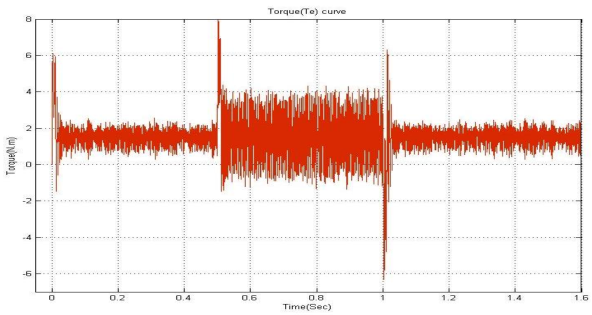

Figure 11: Electromagnetic torque with parameters variation

Figure 10 to 14 show the simulation result of the motor under parameter variation for same variation of speed as in case 1. Under these conditions also motor speed track the reference speed signal quit accurately.

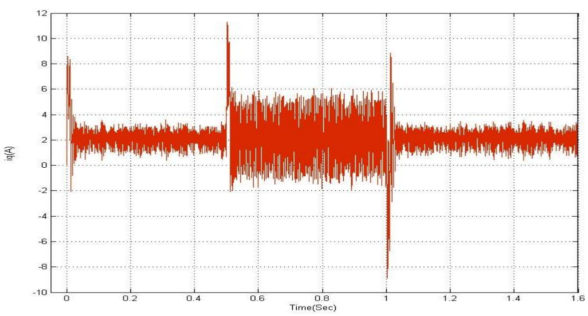

Figure 12 q-axis current with parameters variation

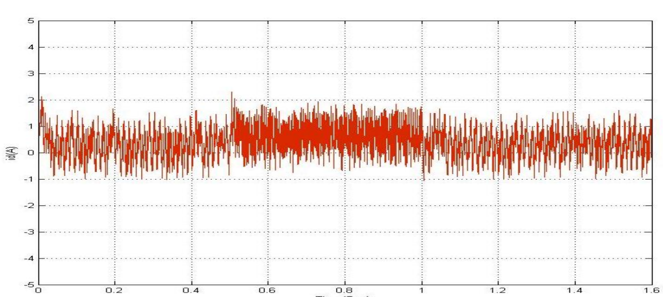

Figure 13: d-axis current with parameters variation

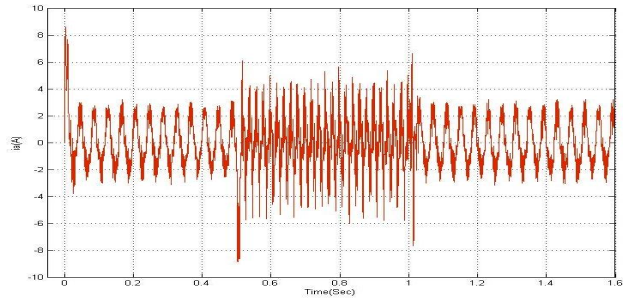

Figure 14: Motor phase current i_a with parameters variation

CONCLUSION

Fuzzy model of PMSM is purposed and based on this fuzzy model T-S fuzzy speed regulator is given. In the last simulation for speed regulation was done using two rule T-S fuzzy model. Simulation is first time performed with nominal motor parameter and second time with 125% variation of some parameter. From the simulation results we conclude that the response of proposed fuzzy speed regulator is fast as compared to conventional speed controller. Effect of parameters variation on the performance of regulator is very low with fuzzy speed regulator. Performance is almost invariant with respect to parameters and load torque variations. Simulation results have been given to show the effectiveness of proposed design method.

REFERENCES

[1] Han Ho Choi , Nga Thi-Tuy Vu, and Jin-Woo Jung "Design and Implementation of a Takagi–Sugeno Fuzzy Speed Regulator for a Permanent Magnet Synchronous Motor" IEEE Transactions On Industrial Electronics, Vol. 59, No. 8, pp 3069-3077,August 2012

[2] A. V. Topalov, G. L. Cascella, V. Giordano, F. Cupertino, and O. Kaynak,"Sliding mode neuro-adaptive control of electric drives," IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 671–679, Feb. 2007.

[3] S. Li and Z. Liu, "Adaptive speed control for permanent-magnet synchronous motor system with variations of load

inertia," IEEE Trans. Ind. Electron., vol. 56, no. 8, pp. 3050–3059, Aug. 2009

[4] H. Z. Jin and J. M. Lee, "An RMRAC current regulator for permanent magnet synchronous motor based on statistical model interpretation," IEEE Trans. Ind. Electron., vol. 56, no. 1, pp. 169–177, Jan. 2009.

[5] MarianTarnık Jan Murga "Model reference adaptive control of permanent magnet synchronous motor" Journal of ELECTRICAL ENGINEERING, VOL. 62, NO. 3, 2011, 117–125

[6] N. J. Patil, R. H. Chile and L. M. Waghmare "Fuzzy adaptive controllers for speed control of PMSM drive" International Journal of Computer Applications vol.1 – No. 11 2010, 0975 – 8887

[7] Jin-Woo Jung*, Han Ho Choi*, and Dong-Myung Lee "Implementation of a robust fuzzy adaptive speed tracking control system for permanent magnet synchronous motors" Journal of Power Electronics, Vol. 12, No. 6, November 2012

[8] Han Ho Choi, Jin-Woo Jung "Takagi–Sugeno fuzzy speed controller design for a permanent magnet synchronous motor" Mechatronics 21 (2011) 1317–1328

[9]T. Takagi and M. Sugeno, "Fuzzy identification of systems and its applications to modeling and control," IEEE Trans. Syst., Man, Cybern., vol. SMC-15, no. 1, pp. 116–132, Jan. 1985.

[10] Mukhtar Ahmad, High Performance AC Drives Modeling Analysis and Control Springer 2010.

[11] B. K. Bose, Modern power electronics and AC drives: Prentice Hall, 2002.

[12]R. Krishnan, Electric Motor Drives Modeling, Analysis, and Control Pearson Education, 2001.

[13]B. K. Bose, Power Electronics and Variable Frequency Drives, 1 ed: Wiley, John & Sons, 1996.

[14] Simulation of direct torque controlled permanent magnet synchronous motor drive , Selin Özçıra, Nur Bekiroğlu Engin, Ayçiçek,Yildiz Technical University, Department of Electrical Engineering, 34349 Besiktas, Istanbul, Turkey

[15]Enrique L. Carrillo Arroyo, "Modeling and Simulation of Permanent Magnet Synchronous Motor Drive System", in ELECTRICAL ENGINEERING University Of Puerto Rico Mayagüez Campus 2006

[16] R.-J. Wai and K.H. Su, "Adaptive enhanced fuzzy sliding-mode controlfor electrical servo drive," IEEE Trans. Ind. Electron., vol. 53, no. 2,pp. 569–580, Apr. 2006.

[17] T. A. Johansen, R. Shorten, and R. Murray-Smith, "On the interpretation and identification of dynamic Takagi–Sugeno fuzzy models," IEEE Trans. Fuzzy Syst., vol. 8, no. 3, pp. 297–313, Jun. 2000.