Sigma J Eng & Nat Sci 8 (2), 2017, 117-127

Publications Prepared for the Innovations on Intelligents Systems and Applications Symposium ASYU 2016
Akıllı Sistemler ve Uygulamalardaki Yenilikler Sempozyumu ASYU 2016 için Hazırlanan Yayınlar

Research Article / Araştırma Makalesi

NEW MODEL ADAPTIVE SYSTEM DESIGN FOR SENSORLESS SPEED CONTROL OF PMSM

Mustafa DURSUN*

Duzce University, Department of Electrical and Electronics Engineering, DUZCE

Received/Geliş: 02.12.2016 Accepted/Kabul: 11.12.2016

ABSTRACT

In this study, simulation studies of permanent magnet synchronous motor (PMSM) based on model reference adaptive control method were performed using Matlab / Simulink package program. Instead of the PI controller traditionally used in the Model Reference Adaptive System (MRAS), system performance is examined using fuzzy logic and hierarchical fuzzy logic controllers (HFC). It is clearly seen in the simulation studies that the hierarchical controller is superior to the fuzzy logic controller by giving better dynamic response and less steady state error.
Keywords: PMSM, MRAS, HFC, matlab/simulink.

1. INTRODUCTION

In order to provide high performance vector control in PMSM, precise measurement of rotor position and speed is necessary. In conventional PMSM drive systems, speed and position information are usually obtained using rotary encoders or resolvers. The use of these sensors; Increases cost, size and cable complexity, and reduces the mechanical durability and reliability of PMSM drive systems. The conclusion of research aimed at solving these problems of the last ten years; it has shown itself to be the development of sensorless rotor position / speed drives with dynamic performance comparable to position sensor based drives [1],[2]. Sensorless operation for MRAS based speed control of permanent magnet synchronous motor has also been observed to exhibit excellent dynamic speed response under speed reference change and load torque change situations. Particularly at the same time, it has been found that the stator resistance change is highly resistant to the motor inertia and viscous coefficient [3]. Sensorless vector control of asynchronous motor was performed with MRAS with a new fuzzy logic adaptation mechanism. Using a rotor flux-based MRAS velocity observer, velocity estimation is performed at very low speeds. In addition, a new fuzzy logic adaptation mechanism has been proposed instead of the classical constant gain PI controller. Detailed comparison between the two designs was made using indirect vector controlled asynchronous motor drive. Fuzzy logic implementation showed that better performance in both open loop and closed loop sensorless operating conditions, against

* Corresponding Author/Sorumlu Yazar: e-mail/e-ileti: mustafadursun@duzce.edu.tr, tel: (380) 542 11 33 / 2036

disturbance effects of load torque as well as better transient performance [4]. The sensorless PMSM driver is designed with an MRAS-based adaptive speed estimator. Compared to previous improved methods in the literature (such as extended kalman filter, artificial neural network and sliding mode control), this method consumes less computation time and is also easy to implement with microcontrollers and DSPs. Popov's criterion is used for the adaptive speed estimator with the proposed method. The validity of the proposed adaptive strategy has been confirmed by simulations and experiments [5].

In the study made by Raju and Zhou, the idea of hierarchical fuzzy control, the hierarchical fuzzy system is made adaptable by adjusting the controller parameters according to the system parameter change. The controller is applied to the water flow control problem of the steam generator and its performance is tested by simulation [6].

To create the fuzzy rules of hierarchical fuzzy systems, a new type mapping rule base scheme is proposed. The algorithm of this design has been developed so that the fuzzy rules that form the middle layer of the hierarchical structure can be easily designed. Unlike conventional single layer fuzzy controllers, this method has about performance using the same scaling factor. Examples are given and the simulation results show that the algorithm is effective and feasible [7].

In this article, a sensorless speed control design based on the MRAS method is proposed. In the adaptation mechanism, instead of the traditional PI controller, the fuzzy logic controller, which is widely used in nonlinear systems, and the hierarchical fuzzy logic controller, which was not used in such a structure before, is used. The aim is to make a positive contribution to the dynamic response of the system, to create a good adaptation mechanism for different operating conditions and to improve the performance of speed tracking with minimum error. According to the simulation results, the hierarchical controller proved to be superior to the fuzzy logic controller by giving better dynamic response and less steady state error.

2. TRADITIONAL MRAS BASED SENSORLESS CONTROL

The purpose of the MRAS method is to estimate the stator dq currents and rotor speed as accurately as possible. The MRAS consists of a reference model and an adjustable model. The reference model uses the actual motor currents and voltages, and the adjustable model is used for estimating the id and iq currents using the estimated speed data from the real voltages data [8]. The output of the reference model is compared to the output of the adjustable model, the difference between the adjustable model and the error obtained from the reference model is sent to the adaptation mechanism which adjusts the adaptive model, ensuring that the rotor speed is estimated. The block diagram of the estimation technique based on the traditional MRAS method is shown in Figure 1 [11].

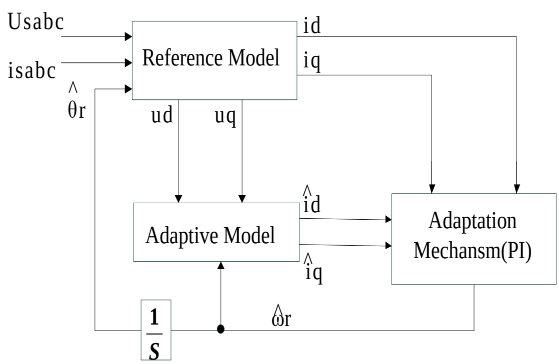


Figure 1. Block diagram of the estimation technique with MRAS.

d-q axis stator currents of PMSM designed as reference model:

$$\frac{di_d}{dt} = -\frac{R_s}{L_s} i_d + \omega_r i_q + \frac{v_d}{L_s} \tag{1}$$

$$\frac{di_q}{dt} = -\frac{R_s}{L_s} i_q - \omega_r i_d - \frac{\psi_r}{L_s}\omega_r + \frac{v_q}{L_s} \tag{2}$$

Where v_d and v_q are the d-q axis stator voltages, L_s and R_s are the stator inductance and resistance, respectively, ω_r rotor speed and ψ_r rotor flux.

The current equations above can be written as:

$$p\begin{bmatrix} i_d' \\ i_q' \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega_r \\ -\omega_r & -\frac{R_s}{L_s} \end{bmatrix} \cdot \begin{bmatrix} i_d' \\ i_q' \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} v_d' \\ v_q' \end{bmatrix} \tag{3}$$

Where,

$$i_d' = i_d + \frac{\psi_r}{L_s}, i_q' = i_q, v_d' = v_d + \frac{R_s\psi_r}{L_s}, v_q' = v_q \tag{4}$$

Equation (3) has variable speed information, which will be used for the adjustable model. The PMSM is used as a reference model and generates the id and iq currents.

$$p\begin{bmatrix} i_d' \\ i_q' \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \omega_r \\ -\omega_r & -\frac{R_s}{L_s} \end{bmatrix} \cdot \begin{bmatrix} i_d' \\ i_q' \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} v_d' \\ v_q' \end{bmatrix} \tag{5}$$

If the equation (5) is abbreviated;

$$\frac{d}{dt} i' = Ai' + Bu' \tag{6}$$

The equation of the adjustable model is as follows;

$$p\begin{bmatrix} \hat{i}_d' \\ \hat{i}_q' \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & \widehat{\omega}_r \\ -\widehat{\omega}_r & -\frac{R_s}{L_s} \end{bmatrix} \cdot \begin{bmatrix} \hat{i}_d' \\ \hat{i}_q' \end{bmatrix} + \frac{1}{L_s}\begin{bmatrix} v_d' \\ v_q' \end{bmatrix} \tag{7}$$

If the equation (7) is abbreviated;

$$\frac{d}{dt} \hat{i}' = \widehat{A}\hat{i}' + Bu' \tag{8}$$

In this model, the estimation of ω_r is necessary and the other parameters must not change. The current fault is:

$$e = i' - \hat{i}' \tag{9}$$

$$\left.\begin{aligned} \frac{d}{dt} e &= Ae - Iw \\ v &= De \end{aligned}\right\} \tag{10}$$

Where;

$$w = (\widehat{A} - A)\hat{i}' \tag{11}$$

D = I and, v=Ie=e.

$$\hat{\omega}_r = \left(K_p + \frac{K_i}{s}\right)\left[-\frac{L_d}{L_q}\left(i_q' - \hat{i}_q'\right)\hat{i}_d' + \frac{L_q}{L_d}\left(i_d' - \hat{i}_d'\right)\hat{i}_q'\right] + \hat{\omega}_r(0) \tag{12}$$

$$i_d' = i_d + \frac{\psi_r}{L_d}, i_q' = i_q, v_d' = v_d + \frac{R_s\psi_r}{L_d}, v_q' = v_q \tag{13}$$

$$\hat{\omega}_r = \left(K_p + \frac{K_i}{s}\right)\left(i_d \hat{i}_q - i_q \hat{i}_d - \frac{\psi_r}{L_s}.\left(i_q - \hat{i}_q\right)\right) + \hat{\omega}_r(0) \tag{14}$$

$\hat{i}_d, \hat{i}_q$ is obtained from the adjustable model and i_d, i_q is obtained from the reference model [9].

2.1. Proposed adaptation design

Figure 2 shows the traditional MRAS adaptation structure. The structure in Fig. 3 is proposed with a slight change in the model. In this structure, instead of the traditionally PI controller, the effects on the system performance are examined by using the firstly fuzzy logic controller and then the hierarchical fuzzy logic controller. The system response is faster and further reduced the steady state error with the design created with especially the hierarchical fuzzy logic controller.

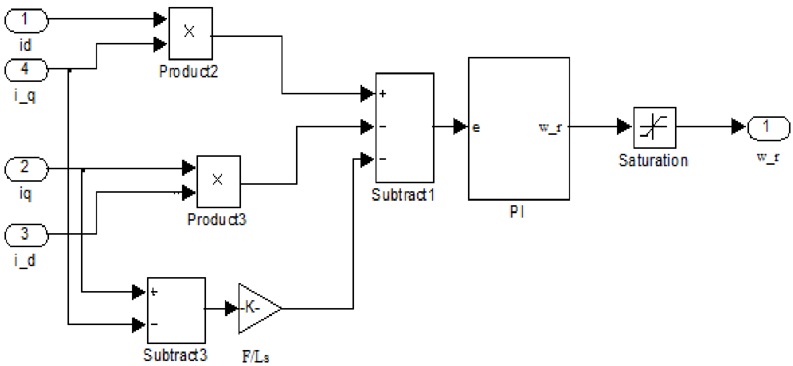


Figure 2. Traditional MRAS adaptation mechanism

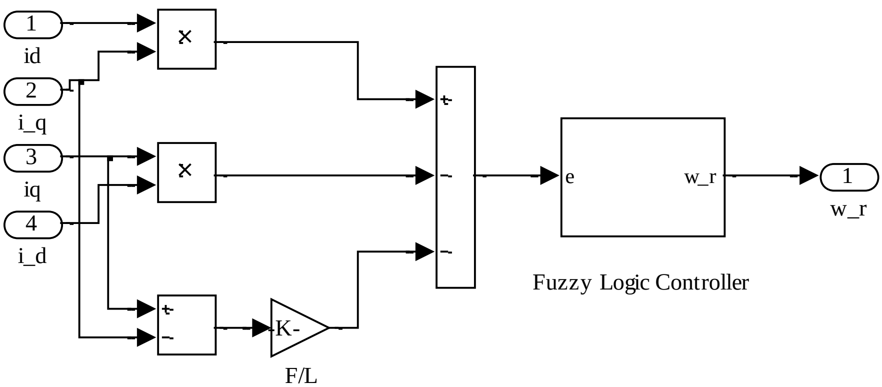


Figure 3. MRAS based on fuzzy logic design [11].

2.1.1. Fuzzy Logic Controller

The fuzzy logic controller has two input variables, the true id-iq, the estimated i_d-i_q, and the error consisting of the current and the inductance values and the change of this error. Figure 4 shows that adaptation structure with the fuzzy logic controller used in Simulink environment.

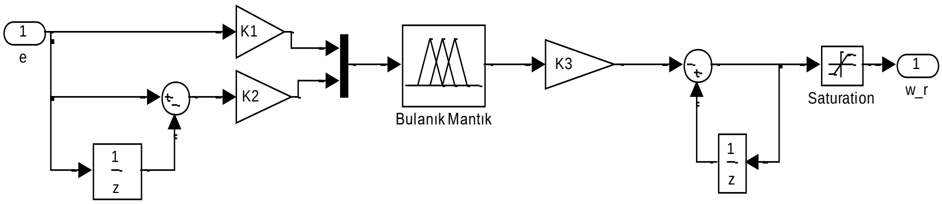


Figure 4. Adaptation mechanism with fuzzy logic controller

The K1, K2, and K3 values are the scaling factors and are chosen as 0.01. The membership functions of the fuzzy logic controller are shown below. The membership function graph corresponding to the error in Fig. 5, the membership function corresponding to the change in the error in Fig. 6 and the output membership function in Fig. 7.

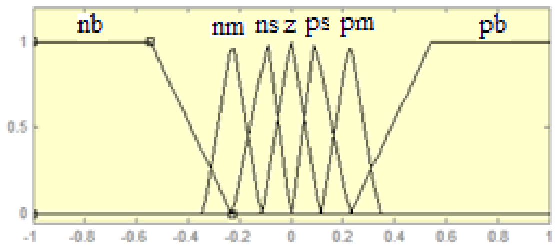


Figure 5. Error (e) membership function graph

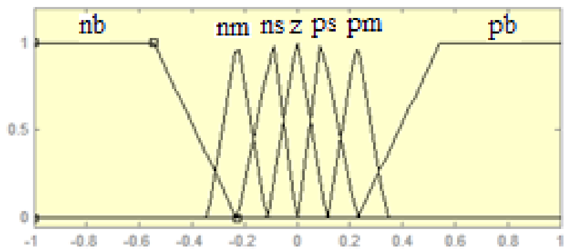


Figure 6. Change of error (de) membership function graph

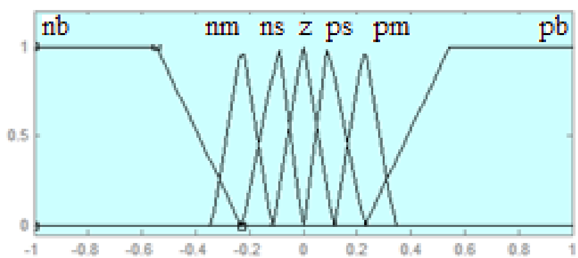


Figure 7. Output (du) membership function graph

The rule table consisting of 49 rules for error and error change is shown in following Table 1 [10].

Table 1. Fuzzy logic rule table

de \ e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NM	NM	NM	NS	Z	PS	PS
Z	NM	NM	NS	Z	PS	PM	PM
PS	NS	NS	Z	PS	PM	PM	PM
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PS	PM	PM	PB	PB

2.1.2. Hierarchical fuzzy logic controller

Simulink block diagram of the proposed hierarchical fuzzy control adaptation mechanism is shown in Figures 8 and 9 [11].

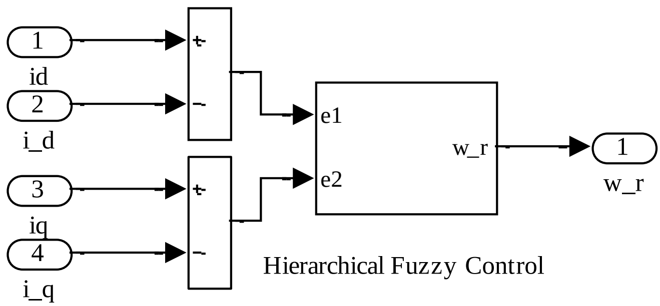


Figure 8. MRAS based on hierarchical fuzzy logic design

The HFC input variables selected in this way are the actual and estimated d and q axis currents produced by the reference model and the adaptive model and their variations.

The hierarchical structure designed in this way will prevent exponent increase in the rule table of an added the third input variable. Also it is aimed to benefit from the performance-enhancing effect of these variables.

The structure of the HFC consists of two fuzzy subsystems, including each two inputs and one output variable. The input variables of the first fuzzy subsystem are $i_d - \hat{i}_d$ and $\Delta(i_d - \hat{i}_q)$, extra $\Delta(i_q - \hat{i}_d)$ with output of this subsystem Δu variables are input variables of the second fuzzy subsystem [11].

All membership functions used in the fuzzy structure in the first subsystem, their boundary values, and the positions of the fuzzy clusters are set to achieve optimum performance. The fuzzy structure to be used in the case of the second sub-system is designed utilizing input and output variables. Input and output membership functions of the first fuzzy subsystem are shown in Fig. 10. Input and output membership functions of the second fuzzy subsystem are shown in Fig. 11. The rule tables are given in Table 2. In these fuzzy structures obtained using Anfis, there are 3 fuzzy sets and 9 rules in total for each membership function [11].

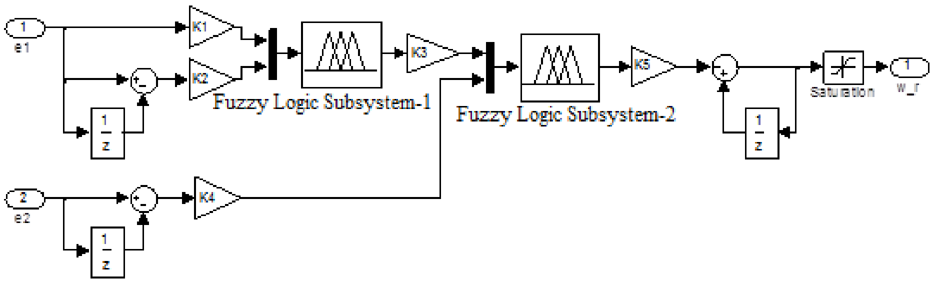


Figure 9. Hierarchical fuzzy logic controller adaptation mechanism

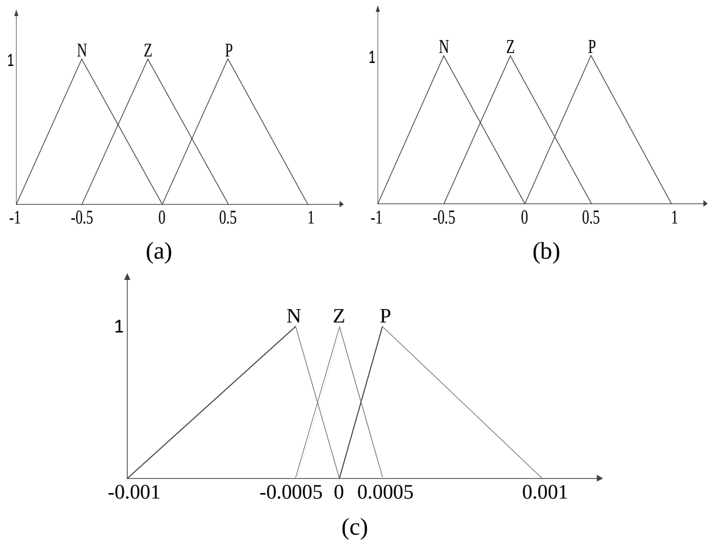


Figure 10. Membership functions of the first subsystem, a) e1, b) Δe_1, c) Δu

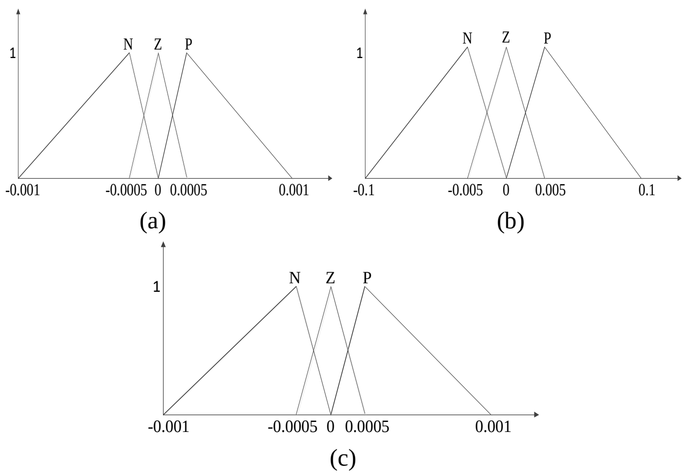


Figure 11. Membership functions of the second subsystem, a) Δu, b) Δe2 , c) Δω

Table 2. Rules table for fuzzy subsystems

e_1 \ Δe_1	N	Z	P	Δu \ Δe_2	N	Z	P
N	N	N	Z	N	N	N	Z
Z	N	Z	P	Z	N	Z	P
P	Z	P	P	P	Z	P	P

So the rule number of all HFC is $k_1^2 + k_2^2$=9+9=18. Instead of this, if the classic fuzzy control system had been used for the three-entry control system, if we consider the increase in membership functions to achieve the same performance, the total number of rules would have to be m_1*m_2*m_3 =7*7*7=343. In addition, setting these rules would make the design of the control system very difficult.

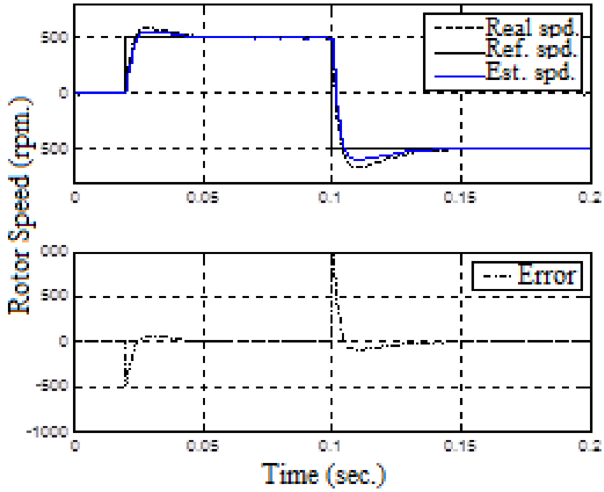
In addition to this design, optimum scaling factors for performance enhancement were determined using the trial and error method as shown in Table 3.

Table 3. Scaling factors used in HFC structure

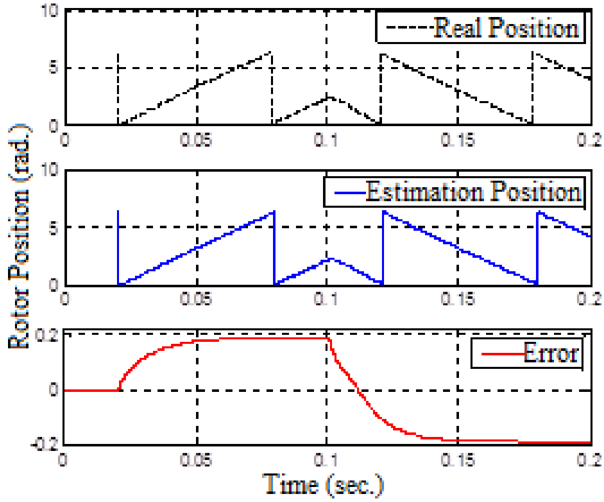
Selected Scaling Factors				
K1	K2	K3	K4	K5
1	1	1	1	0.1

3. CONCLUSIONS FROM SIMULATION STUDIES

Fig. 12 (a) shows the speed error due to speed change and speed change between 500 rpm and -500 rpm in the simulation results obtained for the different operating values with the fuzzy logic controller in the sensorless field effective control of the PMSM. Fig. 12 (b) shows the actual angle value, the estimated angle and the difference graph between that.



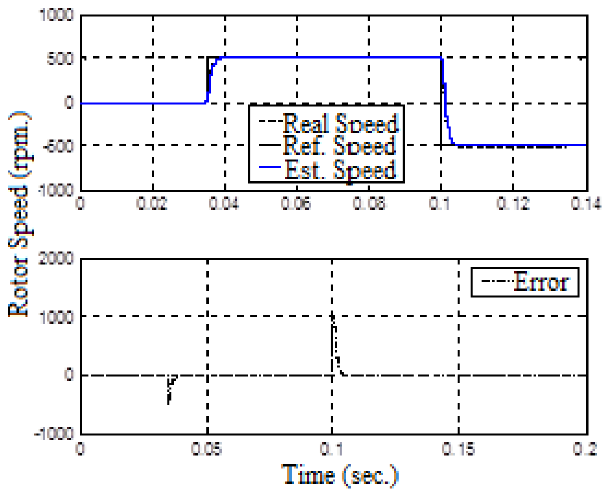
(a)



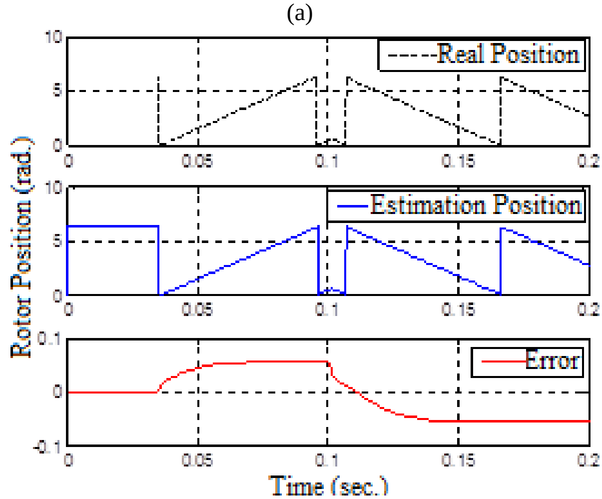
(b)

Figure 12. According to the fuzzy logic adaptation mechanism a) speed changes and error b) position changes and error

Fig. 13 (a) shows the speed error due to speed change and speed change between 500 rpm and -500 rpm in the simulation results obtained for the different operating values with the hierarchical fuzzy logic controller. Fig. 13 (b) shows the actual angle value, the estimated angle and the difference graph between that.



(a)



(b)

Figure 13. According to the hierarchical Fuzzy logic adaptation mechanism a) speed changes and error b) position changes and error

4. RESULTS

In this paper, a novel sensorless speed estimation method for PMSM is investigated. Instead of the traditional PI adaptation mechanism, structures such as fuzzy logic and hierarchical fuzzy logic have been investigated for their superiority to each other. It is clear from the simulation studies that the system with hierarchical structure gives better performance and less steady state error than fuzzy logic system in terms of speed and position estimation. The system is more stable and has less oscillation with the proposed adaptation method. In addition, errors in speed and position estimates are much lower than fuzzy logic.

Acknowledgments / Teşekkür

This study has already been published at the ASYU 2016 conference.

REFERENCES / KAYNAKLAR

[1] M. PACAS,Sensorless drives in industrial applications,IEEE Industrial Electronics Magazine, vol. 5, no.2, pp. 16-23, Jun. 2011.

[2] Y. Li and H. Zhu, Sensorless control of permanent magnet synchronous motor−A survey, in Proc. 2008 Vehicle Power and Propulsion Conference, Sept. 2008, pp. 1-8.

[3] Yan W., vd., A MRAS based Speed Identification Scheme for a PM Synchronous Motor Drive Using the Sliding Mode Teahnique, IEEE, International Conference on Mechatronics and Automation, pp. 3656-3661, 2009.

[4] Gadoue S.M., Giaouris D., and Finch J.W.,A New Fuzzy Logic Based Adaptation Mechanism for MRAS Sensorless Vector Control Induction Motor Drives, 4th IET Conference on Power Electronics, Machines and Drives, pp. 179 – 183, 2008.

[5] Kojabadi M.H., and Chang L.,Sensorless PMSM drive with MRAS-based adaptive speed estimator, Power Electronics Specialists Conference, pp. 1-5, 2006.

[6] Raju, G.V.S., and Zhou, J., Adaptive Hierarchical Fuzzy Controller, IEEE Transactions On Systems, Man, and Cybernetics, Vol. 23, No. 4, July/August, 1993.

[7] Lee M.L., Chung H.Y., ve Yu F.M., Modeling of hierarchical fuzzy systems,Fuzzy Sets and Systems. Volume 138, Issue 2, pp. 343–361, 2003.

[8] Y. Luo, Y. Chen, Y. Pi, Cogging effect minimization in PMSM position servo system using dual high-order periodic adaptive learning compensation. *ISA Transactions,* 2010; 49: 479–488.

[9] Gao, Wei, and Zhirong Guo. Speed Sensorless Control of PMSM using Model Reference Adaptive System and RBFN. Journal of Networks, 2013; 8.1: 213-220.

[10] Dogan, Metin, and Mustafa Dursun. "Application of speed control of permanent magnet synchronous machine with PID and Fuzzy Logic Controller." Energy Educ Sci Technol Part A Energy Sci Res 28.2 (2012): 925-930.

[11] Dursun, M., Boz, A. F., Kale, M., & Karabacak, M. (2016). Sensorless control application of PMSM with a novel adaptation mechanism. Neural Computing and Applications, 1-17.