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Comparative Study of the Success of PI and PI-Fuzzy Controller for Induction Motor Drive using SVPWM Method

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Abstract: *Asynchronous motors have a wide range of applications in the industry.Therefore, speed control of asynchronous motors is of great importance.Speed control of asynchronous motors based on vector control techniques to achieve high performance.The vector control technique, motor flux and moment variables can be controlled independently of each other.Because of the nonlinear and complex model of asynchronous motors, the speed control applications of these motors are not provided with great efficiency by classical control methods.Fuzzy logic controllers (FLC), which were successful in many areas, present great performance in speed control of an asynchronous motor.In this study, a simulation study regarding speed control of a three-phase squirrel cage asynchronous motor was carried out with a PI-Fuzzy type FLC and a conventional PI type controller.The data obtained by simulation are evaluated and the performances of the control methods are compared.*

Keywords: *Fuzzy Logic Control, PI type Control, Space Vector Pulse Width Modulation (SVPWM), Three-phase squirrel cage asynchronous motor,*

I. Introduction

Asynchronous motors are the most widely used machine in the industry due to their simple construction, low cost, reliable operation in extreme operation, low maintenance requirement and high efficiency. Scalar control method derived from steady state model and vector control methods obtained from dynamic model of motor are used in speed control of these motors [1].In the scalar speed control method, the steady state model of the motor is used and speed control is performed by keeping the voltage / frequency ratio (V / f) as constant [2-3].Fundamentals of achieving high performance in the speed control of asynchronous motors are based on vector control techniques. The vector control made possible to obtain a considerable dynamic performance in asynchronous motor control just as provided in free excited direct current machines.By the vector control method, the motor flux and moment variables can be controlled independent from each other. The torque, speed and acceleration of electric motors can be improved and the efficiency can be increased when these parameters are controlled with the power electronics [4-5].The asynchronous motors require complicated control and transformation algorithms because of their nonlinear structure [6].Classical controllers exhibits low performances in the control of nonlinear systems that of their mathematical models are not well defined.Fuzzy logic, artificial neural networks or neural fuzzy controllers are more successful in controlling such systems. It is not possible to model a nonlinear system exactly [7].The structure of the fuzzy logic controller has adaptive properties.Therefore, when FLC is used in the systems with uncertainties, variable parameters and loads, it guarantees desired responses for the system [8].The fuzzy logic approach gives machines the ability to process special data of humanity and ability to operate by taking advantage of their experiences and expertises.By performing this ability, it uses symbolic expressions instead of numeric expressions.The basis of fuzzy logic is the controller's verbal expressions and the logical connections between them.While FLC is applied to system, mathematical modeling of the system is not required [9].In order to make decisions, the FLC algorithm uses rules that contain information about the system.This rule based decision making mechanism, which reminds of the method used by human brain, is determined by taking the advantage of user experience. Classical logic uses a sharp concept while decision making whether an individual is a member or not a member of a set, and there is a precise boundary to determine for belonging of an individual to the set. An element belongs to a set or it does not. On the contrary, fuzzy logic considers the intermediate values [10].

In this paper, a simulation study was performed using PI-Fuzzy type fuzzy logic controller and PI type controller for speed control of an asynchronous motor with a three-phase star connected squirrel cage. Indirect field oriented control (IFOC) method was used for the drive method of asynchronous motor.This paper presents the performance of PI and PI-Fuzzy type speed control method for simulation study.

II. Mathematical Model of Three-Phase Squirrel Cageasynchronous Motor

Basically while performing the simulation study, it requires the mathematical model to determine physical behavior of a system.The most appropriate control rules for the control of system are determined with the studies on this model. The three phase variables of the motor are transferred to the dq plane in order to obtain the mathematical model of the asynchronous motor. As a result, the asynchronous motor is simulated as a direct current motor by applying the controlled field-oriented control in the d-q axis set rotating at synchronous speed.This model is arranged as a suitable format to computer analysis and simulation studies which will be used to determine control rules [4,7,11,15,17,22].

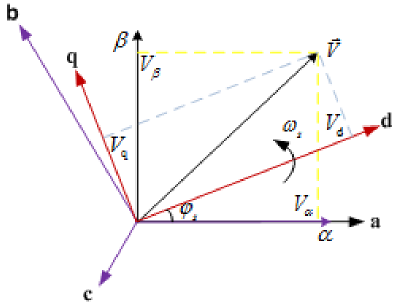

Fig. 1:a-b-c, α-β ve d-q axis set plane

For the asynchronous motor, the differential equations in the d-q axis set can be derived as the following formulas;

Equivalent resistance;

$$R_E = R_s + \frac{R'_r L_m^2}{L_r'^2} \tag{1}$$

Leakagefactor;

$$\sigma = 1 - \frac{L_m^2}{L_s L_r'^2} \tag{2}$$

$$\frac{di_{sd}}{dt} = \frac{1}{\sigma L_s}\left[-R_E i_{sd} + \sigma L_s \omega_s i_{sq} + \frac{L_m R'_r}{L_r'^2}\psi_{rd} + \omega_r \frac{L_m}{L'_r}\psi_{rq} + V_{sd} \right] \tag{3}$$

$$\frac{di_{sq}}{dt} = \frac{1}{\sigma L_s}\left[-R_E i_{sq} - \sigma L_s \omega_s i_{sd} - \omega_r \frac{L_m}{L'_r}\psi_{rd} + \frac{L_m R'_r}{L_r'^2}\psi_{rq} + V_{sq} \right] \tag{4}$$

$$\frac{d\psi_{rd}}{dt} = \frac{R'_r L_m}{L'_r} i_{sd} - \frac{R'_r}{L'_r}\psi_{rd} + \omega_{sl}\psi_{rq} \tag{5}$$

$$\frac{d\psi_{rq}}{dt} = \frac{R'_r L_m}{L'_r} i_{sq} - \frac{R'_r}{L'_r}\psi_{rq} - \omega_{sl}\psi_{rd} \tag{6}$$

$$\frac{d\omega_m}{dt} = \frac{pL_m}{JL'_r}(i_{sq}\psi_{rd} - \psi_{rq} i_{sd}) - \frac{B}{J}\omega_m \tag{7}$$

Sliding speed;

$$\omega_{sl} = \omega_s - \omega_r = \frac{R'_r i_{qs}}{L'_r i_{ds}} \tag{8}$$

Synchronous position;

$$\theta_s = \int \omega_s dt \tag{9}$$

III. Space Vector Pulse Width Modulation (SVPWM)

TheThree phase voltage with desired amplitude and phase is obtained from a simple DC voltage at inverter's three output terminals by SVPWM. Three-phase voltages previously mentioned are represented by a reference voltage space vector.

$$\vec{V}_{ref} = \vec{V}_{\alpha} + j\vec{V}_{\beta} = \frac{2}{3}\left(V_{ao}.\vec{a}^{\,0} + V_{bo}.\vec{a}^{\,1} + V_{co}.\vec{a}^{\,2}\right) \tag{10}$$

where $\vec{a} = e^{j\frac{2\pi}{3}}$.

The three-phase voltage source is obtained from eight possible switching positions of the three terminal inverter shown in Fig. 2 and given in Table 1.

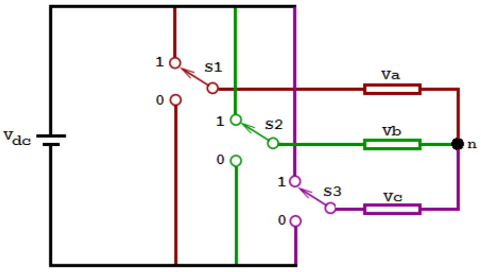

Fig. 2: Circuit diagram of three terminal inverter and star connected motor

Table 1: Eight switching positions and voltage vectors

S1	S2	S3	Vk	Va	Vb	Vc
0	0	0	V_0	0	0	0
0	0	1	V_5	$-V_{dc}/3$	$-V_{dc}/3$	$2V_{dc}/3$
0	1	0	V_3	$-V_{dc}/3$	$2V_{dc}/3$	$-V_{dc}/3$
0	1	1	V_4	$-2V_{dc}/3$	$V_{dc}/3$	$V_{dc}/3$
1	0	0	V_1	$2V_{dc}/3$	$-V_{dc}/3$	$-V_{dc}/3$
1	0	1	V_6	$V_{dc}/3$	$-2V_{dc}/3$	$V_{dc}/3$
1	1	0	V_2	$V_{dc}/3$	$V_{dc}/3$	$-2V_{dc}/3$
1	1	1	V_7	0	0	0

The six nonzero active state space vectors can be stated as in Equation 11.

$$\vec{V}_k = \frac{2}{3}V_{dc}\,e^{j(k-1)\frac{\pi}{3}} \qquad k=1,2,3,4,5,6 \tag{11}$$

Here, the two adjacent active vectors can be expressed as the following with equation 12 and 13.

$$\vec{V}_k = \frac{2}{3}V_{dc}\left[\cos(k-1)\frac{\pi}{3} + j\sin(k-1)\frac{\pi}{3}\right] \tag{12}$$

$$\vec{V}_{k+1} = \frac{2}{3}V_{dc}\left[\cos\frac{k\pi}{3} + j\sin\frac{k\pi}{3}\right] \tag{13}$$

When the voltage vector $V_{ref}$is examined on the α-β axis, six space vectors will form when the output voltages are checked for period T.These vectors are placed at 60^0 degree intervals on the axis set.This case is shown in Fig. 3.

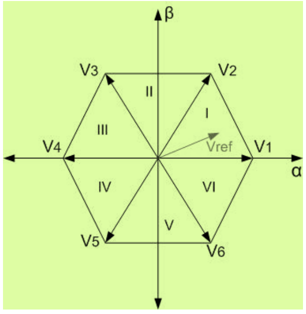

Fig. 3: Demonstration of space vectors on the α-β axis

$V_{ref}$is defined as the average space vector in each switching period Ts.The V_{ref}voltage vector can be expressed as a combination of vectors 0 and 7 in each of the six regions and a weighted average of the two adjacent active space vectors. When V_{ref} is assumed in region k, in this case adjacent vectors will be V_k and V_{k+1}. While switching from a position to another, switching position of only a terminal in inverter will be changed. This operation also provides the best harmonic performance. The V_{ref} voltage vector is stated as in equation 14. Where *Ts* is sampling time.]. In case *Ts* is assumed to be as small as possible, then $V_{ref}$is assumed to be approximately constant [18-20, 23].

$$\vec{V}_{ref}\frac{T_s}{2} = \vec{V}_k T_k + \vec{V}_{k+1} T_{k+1} \tag{14}$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \frac{T_s}{2} = \frac{2}{3} V_{dc} \begin{bmatrix} \cos(k-1)\frac{\pi}{3} & \cos\frac{k\pi}{3} \\ \sin(k-1)\frac{\pi}{3} & \sin\frac{k\pi}{3} \end{bmatrix} \begin{bmatrix} T_k \\ T_{k+1} \end{bmatrix} \tag{15}$$

$$\begin{bmatrix} T_k \\ T_{k+1} \end{bmatrix} = \frac{\sqrt{3}}{2}\frac{T_s}{V_{dc}} \begin{bmatrix} \sin\frac{k\pi}{3} & -\cos\frac{k\pi}{3} \\ -\sin(k-1)\frac{\pi}{3} & \cos(k-1)\frac{\pi}{3} \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{16}$$

Where $T_k$and $T_{k+1}$are the times for applying the voltages $V_k$veV_{k+1}.T_0 is the time for applying the zero voltage vector (V_0or V_7) [10].

$$T_k = \frac{\sqrt{3}}{2}\frac{T_s}{V_{dc}}\left(V_\alpha \sin\frac{k\pi}{3} - V_\beta \cos\frac{k\pi}{3}\right) \tag{17}$$

$$T_{k+1} = \frac{\sqrt{3}}{2}\frac{T_s}{V_{dc}}\left(-V_\alpha \sin(k-1)\frac{\pi}{3} + V_\beta \cos(k-1)\frac{\pi}{3}\right) \tag{18}$$

$$\frac{T_s}{2} = T_0 + T_k + T_{k+1} \Rightarrow T_0 = \frac{T_s}{2} - T_k + T_{k+1} \tag{19}$$

The switching system will be different for each region. The switching design for region I is shown in figure 4.

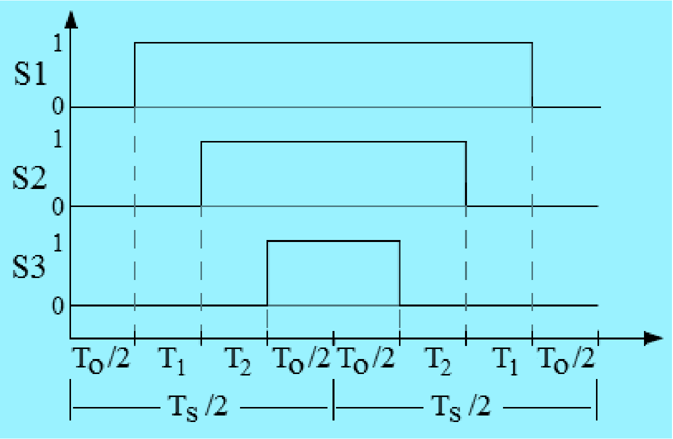

Fig. 4:SVPWM switching for Region I

IV. Fuzzy logic control

A FLC block diagram is shown in figure 5.FLC consists of four basic components which are fuzzification, fuzzy inference, defuzzification and knowledge base.

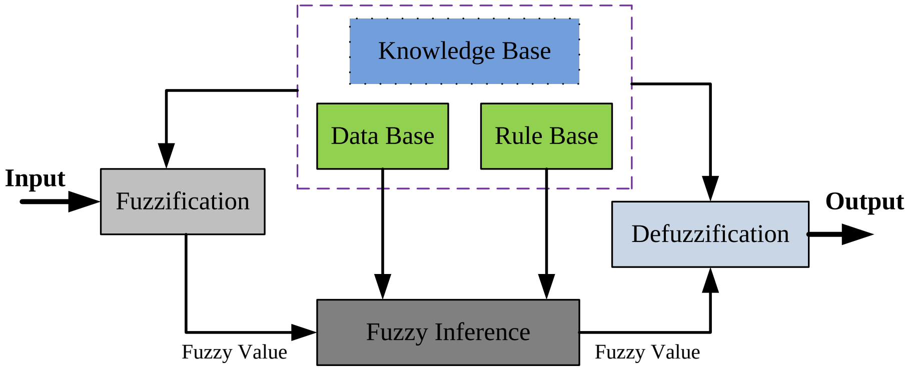

Fig. 5: Block diagram of fuzzy logic controller

Fuzzification is the process that firstly a crisp set of input data taken from a system are converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. Fuzzy inference is made based on a set of rules. This unit provides fuzzy output set by applying the fuzzy input set to the rules of rule base. The most widely used method in fuzzy inference methods and the method used in this study is the Mamdani method.Defuzzification, the resulting fuzzy output is converted to a crisp output using the membership functions. Consequently, this process provides the real values which will be used in application. Knowledge base consists of a data table that hosts information about the system. Connections between inputs and outputs are provided using rule-based rules. While a rule base is developed for a system, input values that can affect the output of system are supposed to be well determined. Fuzzy control rules are usually constituted by expert knowledge [11-14, 16, 21].

IV.I. PI-Fuzzy Type Control

In classical PI type controller, K_p is the proportional gain constant, and K_i is the integral gain constant.

$$u(t) = Kp.e(t) + Ki.\int e(t)dt \tag{20}$$

The PI-Fuzzy type control system is a two-input single-output fuzzy system referenced to the classical PI control system.Where $K_i$is the gain factor used with error, and K_p is the gain factor used with error variance.The block diagram of PI-Fuzzy type controller is shown in fig. 6 [24].

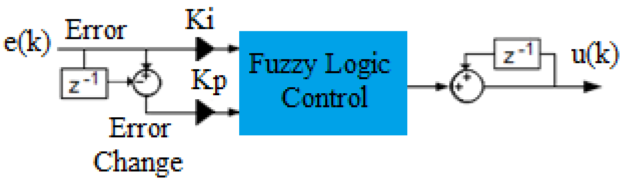

Fig. 6: PI-Fuzzy type Controller

V. Simulation Results

MATLAB is used in simulation studies of speed control of asynchronous motor.Parameters of the asynchronous motor are listed as the following:

P=3 kW	n=1430 rpm	p=2	L_m=0,1878 H
U=380 V	R_s=1,45Ω	L_s = 0,2 H	J=0,03 kg.m^2
I=6,7 A	R_r =1,93 Ω	M=10 Nm	B=0,03Nm.san/rad

Resulting values from motor output are compared to reference values and flux information, and error values are obtained. By using these values, required transformations and calculations have been performed for modulation.The optimal switching vector detection of the inverter is performed considering the sector in which the reference voltage vector is located. The motor is drived by applying The SVPWM signals obtained by calculating the durations of these vector to the inverter. In study, sampling time *Ts*= 0.2ms. The block diagram of the study is seen in fig. 7.In this study, two inputs are selected for each PI-Fuzzy type controller.Where error (*e*) and error change (*de*).k is the iteration number, and the error and error change are expressed as the following:

$$e_q(k)=i_{sqref}(k)-i_{sq}(k) \tag{22}$$

$$de_q(k)= e_q(k)-e_q(k-1) \tag{23}$$

$$e_d(k)=i_{sdref}(k)-i_{sd}(k) \tag{24}$$

$$de_d(k)=e_d(k)-e_d(k-1) \tag{25}$$

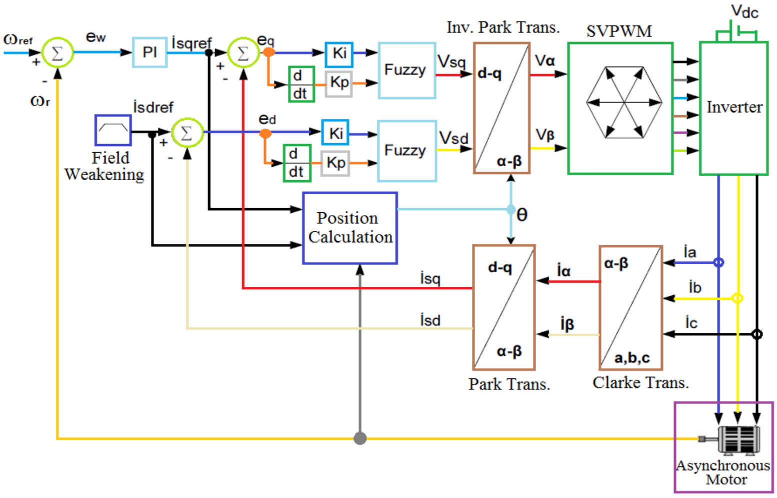

Fig. 7: Design of IFOC based FLC architecture

In the fuzzification step, input and output information received from the system are converted to symbolic expressions which are linguistic variables.Inputs and outputs in the specified range are represented with seven different symbolic expressions.These are NL (Negative Large), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), PL (Positive Large), respectively.Selection of the membership functions for each input and output is optional among triangular, trapezoidal, sinusoidal, cauchy, bell, sigmoid, gaussian.Five triangular and two trapezoidal membership functions are used for input and output in the system. These membership functions are shown in fig. 8 [14, 17, 25].

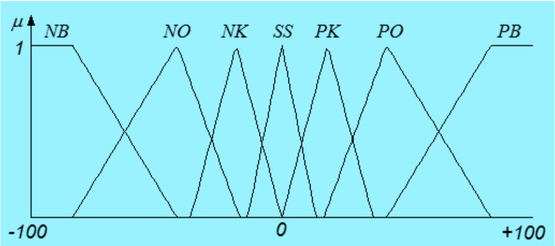

Fig. 8: Fuzzy output membership functions

In the fuzzy inference unit, the relation of the inputs with output is provided by the rules constituting the rule base. There are 49 rules in the study of Rule Editor of Matlab / Fuzzy Logic Toolbox / FIS. The rule table is shown in Table 2.

Table 2: Fuzzy rule table

e Δe	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

In defuzzification unit, the membership weights of error and change of error are obtained for each rule, afterwards, minimum terms of membership weight are determined for each region and output membership values are determined accordingly. The values obtained in the output of the fuzzification unit are VsdveVsq voltages.The supply voltage of the inverter is 550V DC and the switching frequency is 5 kHz. For simulation study of asynchronous motor, the reference speed is given as 110 and 120 rad / s one by one. The motor is loaded with 10 Nm at the 1st second. The resulting simulation of PI-Fuzzy type FLC is shown in fig. 9, 10, 11, and 12.

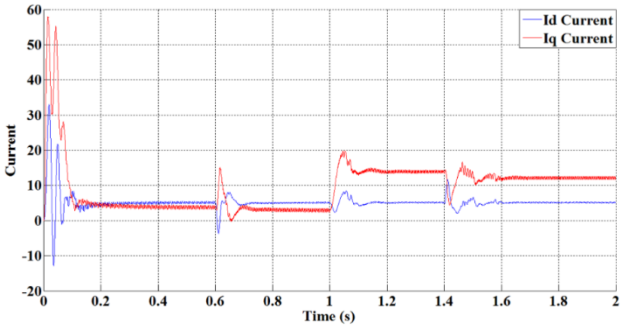

Fig. 9: PI-Fuzzy (Id-Iq) Current versus time graph

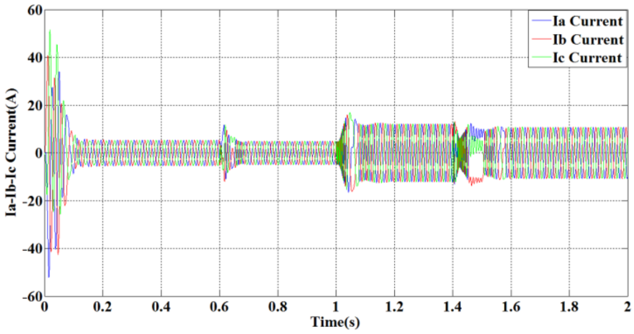

Fig. 11: PI-Fuzzy (Ia-Ib-Ic) Current versus time graph

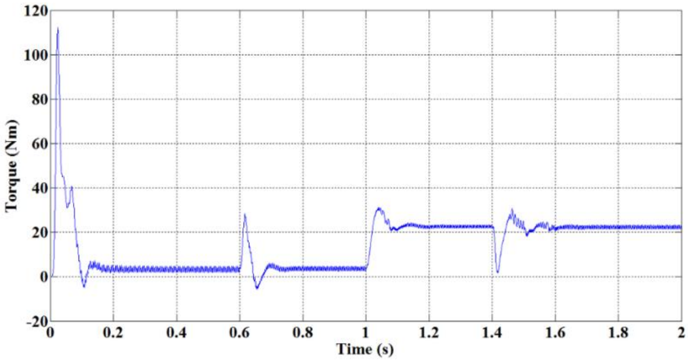

Fig. 11: PI-Fuzzy Torgue versus time graph

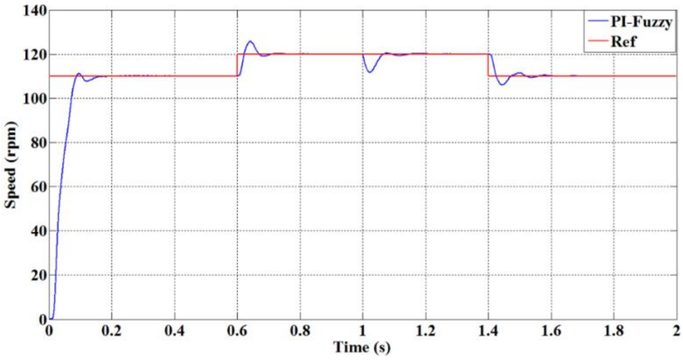

Fig. 12: PI-Fuzzy Speed versus time graph

Simulation study of asynchronous motor, the reference speed is given as 110 and 120 rad / s one by one. The motor is loaded with 10 Nm at the 1st second. The resulting simulation ofconventional PI type control is shown in fig. 13, 14, 15, and 16.

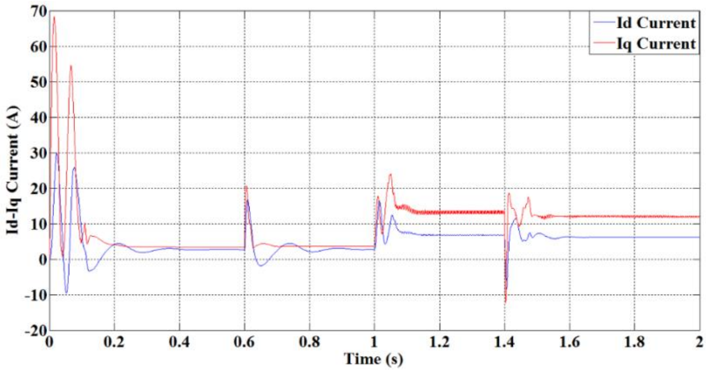

Fig. 13: PI (Id-Iq) Current versus time graph

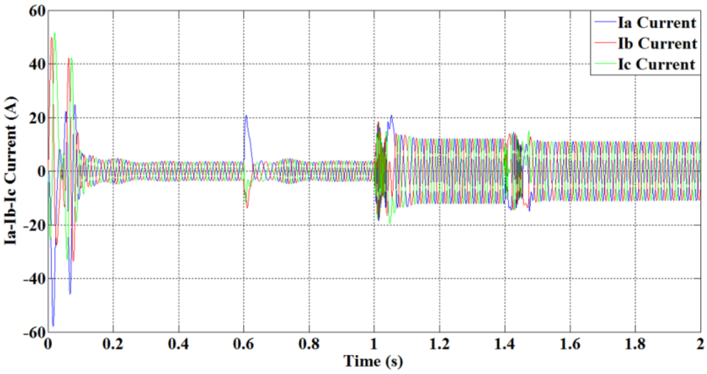

Fig. 14: PI (Ia-Ib-Ic) Current versus time graph

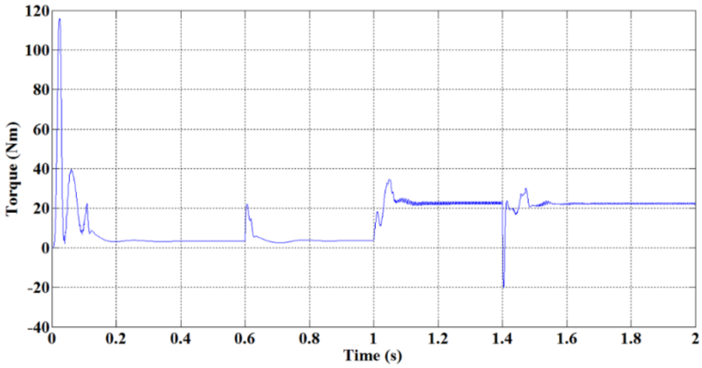

Fig. 15: PI Torgue versus time graph

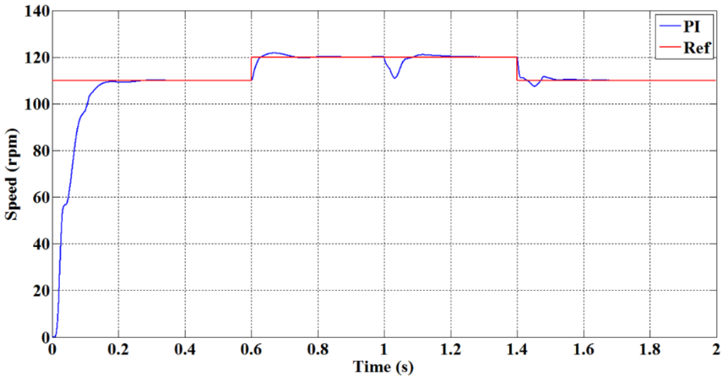

Fig. 16: PI Speed versus time graph

When the speed versus time graph in fig. 12 and fig. 16 are reviewed, it is reveal that nominal speed has reached the reference speed faster in PI-Fuzzy control technique than PI control. Also,this situation is understood from the table 3.The performance parameters of the controllers are the rise time t_r, settling time $t_y$and overshoot %M, respectively. The parameter values are given in Table 3.

Table 3: Initial performance values of control

Control	t_r (s)	t_y(s)	%M
PI-Fuzzy	0.08	0.18	1
PI	0.15	0.21	0

VI. Conclusion

Because of the fact that asynchronous motors have a wide range of applications in the industry, it requires to control these motors efficiently.In this study, speed control of a star connected three-phase squirrel cage asynchronous motor is performed with PI-Fuzzy type controller and PI type controller using IFOC method.Basic control signals of the control, there has been created control blocks in the form of stator voltages in the d-c coordinate system.When we examine the obtained graphs, overshoot in PI-Fuzzy type control at the regions that reference speed change is higher than the overshoot occurred in PI control. Overshoot in PI-Fuzzy control at the load change regions given to the system is smaller than the overshoot in PI control. PI-Fuzzy type control has smaller rise time and settling time when compared to PI type control. As a result, the performance of control processes for both controllers is clearly seen with the simulation results. By investigating the points of motor loading and rapid changing in the given reference speed orbit, the deviations occurred in that process has been removed in a short time. In conclusion, by considering all operating conditions, the PI-Fuzzy logic technique had clearly revealed better performance than PI controller in order for faster minimization of the error.

References

[1] E., Kilic, H.R., Ozcalik, S., Yilmaz, S., Sit, A Comparative Analysis of FLC and ANFIS Controller for Vector Controlled Induction Motor Drive, *2015 IEEE International Aegean Conference on Electrical Machines & Power Electronics (ACEMP2015)*, 2-4 September 2015, Side-Antalya, Turkey.

[2] B.K., Bose .Power Electronics and AC Drives", *Prentice Hall*, 1986.

[3] B.K., Bose, Microcomputer Control of Power Electronics and Drives", *IEEE Press*. 1987

[4] S., Sit, E., Kilic, H.R., Ozcalik, M.,Altun, A., Gani, Model Reference Adaptive Control based on RBFNN for Speed Control of Induction Motors. *International Conference on Natural Science and Engineering (ICNASE'16)*, 3355-3364 pp. 2016

[5] S., Sit,H.R., Ozcalik, E., Kilic, S., Yilmaz.Investigation of Speed Control Method in Three-Phase Induction Motor Drives. *International Refereed Journal of Engineering And Sciences*, Vol:2 No:5, 125-151 pp. 2015.

[6] Z., Koca, *Speed Control with Artificial Neural Networks with Vector Control of Three Phase Asynchronous Motors*. Kahramanmaraş Sutcu Imam University Institute of Science, MS Thesis, Turkey, 2006.

[7] S., Paçacı, "*A simulator design for speed control of induction motors using artificialneural networks, fuzzy logic and neuro fuzzy controller*", SüleymanDemirelÜniversity, Institute of Science, MS Thesis, Isparta, Turkey, 2011.

[8] U., Güvenç, Y., Sönmez, S., Biroğul "A Computer Based Educational Tool for Fuzzy LogicControlled DC-DC Converters.Journal of Polytechnic. Vol: 10 No: 4 pp.339-346, 2007.

[9] Ç., Elmas, "Artificial Intelligence Applications", Seckinpublishing, Ankara, 2011.

[10] O., Ekren, "*Fuzzy logic control of the compressor speed and electronic expansion valve in a chiller*", DokuzEylülUniversity,Institute of Science, Doctoral Thesis, İzmir, Turkey, 2009.

[11] P.M. Menghal, A.J. Laxmi, "Artificial Intelligence Based Dynamic Simulation of Induction Motor Drives", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), ISSN: 2278-1676 Volume 3, Issue 5 (Nov. - Dec. 2012), PP 37-45.

[12] M. Sekkeli, C. Yıldız, H.R. Ozcalik, "Fuzzy Logic Based Intelligent Speed Control of Induction Motor Using Experimental Approach" International Symposium on Innovaitons in Intelligent Systems and Applications, Trabzon/Turkey, 2009 INISTA, pp.151-154.

[13] M. Sekkeli, C. Yıldız, H.R. Ozcalik, "Fuzzy Logic Based Intelligent Speed Control of Induction Motor Using Experimental Approach" *International Symposium on Innovaitons in Intelligent Systems and Applications, Trabzon/Turkey, 2009 INISTA*, pp.151-154.

[14] P. Tripura, Y.S.K. Babu, "Fuzzy Logic Speed Control of Three Phase Induction Motor Drive" World Academy of Science, Engineering and Technology 60 2011.

[15] M.,Zelechowski, "Space Vector Modulated-Direct Torque Controlled (DTC-SVM) Inverter-Fed Induction Motor Drive", Ph.D. Thesis, Warsaw University of Technology, Faculty of Electrical Engineering, Warsaw-Poland, 2005.

[16] H.R. Ozcalik, C. Yıldız, Z. Koca, S. Doganay, "An Adaptive Neural Controller for Induction Motor Based on Volt-Hertz Driving Method", *Inista'07*, p:96-100, June 2007, Istanbul, Turkey.

[17] H., Açıkgöz, M., Şekkeli, .Examine of Speed Control Performance of Direct Torque Controlled Induction Motor using Fuzzy Logic Controller, *APJES*. Cilt.1, Vol.2, pp.50-57. (Original in Turkish). 2013.

[18] M.T., Lazim, Al-khishali, M.J.M., Al-shawi, A.I., Space Vector Modulation Direct Torque Speed Control of Induction Motor. Procedia Computer Science 5 (2011) pp.505–512.Anonim, "Implementing Space Vector Modulation with the ADMC300", Analog Devices Inc. Catalog, 2000. 2011.

[19] M.E., Asker, M., Özdemir, M.I., Bayındır. "Investigation of V/f and Vector Control Methods in a Speed Control System of Permanent Magnet Synchronous Motor with SVPWM Driven Inverter. *International Advanced Technologies Symposium (IATS'09)*, Karabük, Turkey, 13-15 May 2009.

[20] R., Arulmozhiyal, K., Baskaran, "Space Vector Pulse Width Modulation Based Speed Control of Induction Motor using Fuzzy PI Controller", *International Journal Computer and Electrical Engineering*, Vol.1, No.1, April 2009.

[21] S.R., Maturu, A., Vujji, “SVPWM Based Speed Control of Induction Motor Drive With Using V/F Control Based 3-Level Inverter”, *VSRD International Journal of Electrical, Electronic & Communication Engineering*, Vol. 2 (7), 2012.
[22] E., Hendawi, F., Khater, A., Shaltout, “Analysis, Simulation and Implementation of Space Vector Pulse Width Modulation Inverter”, *Proceedings of the 9th WSEAS International Conference of Applications of Electrical Engineering*, 2010.
[23] L., Reznik, “Fuzzy Controllers”, Newnes, 1997.
[24] P., Tripura, Y., Srinivasa Kishore Babu, “Fuzzy logic Control of Three Phase Induction Motor Drive”, World Academy of Sience, Engineering and Technology, 2011.
[25] H. Acikgoz, O.F. Keçecioğlu, A.Gani, M.Şekkeli, “Speed Control of Direct Torque Controlled Induction Motor By using PI, Anti-Windup PI And Fuzzy Logic Controller” *Intelligent Systems and Applications in Engineering (IJISAE)* Vol.2 No.3, 2014, pp.58-63.