IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Intelligent Speed Controller Technique Based on Optimized Fuzzy Gains

Bindra Dawar[1], Prashant Kumar[2]

[1] Ujjain Engineering College & Ujjain
[2]SVNIT & SURAT
[1]Assistant Professor, Dept. of Electrical Engineering, Ujjain Engineering College, M.P, India
[2]Ph.D Scholar, SURAT, India

Abstract: This article proposes the solution for high-performance applications, the Permanent Magnet Synchronous Motors (PMSMs) gained the attraction as compared to other types of ac motors due to some of their advantageous characteristics including high torque, high power, high efficiency, and low noise. Insensitivity to parameter variation and, reaching the speed to a reference value at the shortest time due to any disturbances, are some of the important criteria of the high-performance drive systems used for drive PMSM. The classical proportional-integral (PI) and proportional integral derivative (PID) controllers have been widely employed as speed controllers in PMSM controller's drives. In this work, a Fuzzy logic Controller for controlling the high speed of the Permanent Magnet Synchronous Motor is proposed to achieve a stable state. The fuzzy logic controller is more efficient and gives fast response than the other conventional controller. The simulation results show that out of three controllers, the fuzzy logic controller outperforms the other for the speed control of permanent magnet synchronous drives.

***Index Terms* - Fuzzy Logic Controller, PI Controller, PID**

I. INTRODUCTION

A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. These motors have significant advantages, attracting the interest of researchers and industry for use in many applications. In recent years, permanent magnet synchronous motor drives have been widely used in many industrial applications such as robots, rolling mills, and machine tools. The inherent advantages of these machines Include high power density, low inertia, and high-speed capabilities [1-5]. These aspects make PMSM performance surpasses that of the conventional dc and other ac motors in drives, especially where the overall efficiency is critical. As a result, PMSM drives become competitive to other drives in modern industrial applications requiring precision, efficient and sophisticated products, and services. Traditionally commutator motors, also known as direct current (dc) motors were preferred for variable However, the ac motor control including control of PMS motors is a challenging task due to very fast motor dynamics and highly non-linear models of the machines. Therefore, a major part of motor control development consists of deriving mathematical models in suitable forms. The dynamic models of the motors can be presented in different reference frames to lay down a basis for the motor control design. The mathematical formulations and the equivalent circuit models can be provided to help in better controller design for PMSM drives. There are two competing control strategies for ac motors i.e. vector control (VC) and direct torque control (DTC) for PMSM [8], [9],[10].

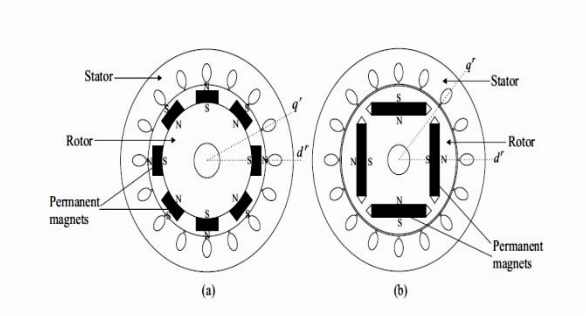


Fig. 1 Motor cross-sections showing different rotor configuration for PMSMs. (a) Surface magnets type (b) Interior magnets type.

The interior magnets type rotor configuration brings saliency characteristics to the machine which is not present in a machine with surface magnets type rotor. As shown in fig.1 (a) and fig.1 (b), the magnetic flux induced by the magnets define the rotor director dr -axis radial through the centerline of the magnets. The rotor quadrature or qr -axis is orthogonally (90 electrical degrees) placed with the rotor dr -axis. Since the permeability of permanent-magnets is almost the same as the air, in\ interior magnets type configuration the effective airgap of dr -axis is increased compared to the q r -axis. Therefore, the dr -axis reluctance is higher than the q r -axis reluctance. This results in the q r -axis inductance is higher than the dr -axis inductance, i.e. Lq>Ld, in IPMSMs [18],[19].

II. DRIVE SYSTEM OF PMSM

A conceptual drive system is pictured in fig 2. There, a speed, position, or torque command is input to the drive system. The motion controller implements feedback control based on mechanical sensors (or estimators). The controller outputs a command for the electrical variables to obey. The electrical control block converts its input commands into commands for the power converter/modulator block and sometimes utilizes feedback of voltage or current. The power converter block imposes the desired electrical signals onto the PMSM machine with the connected load [33], [36].

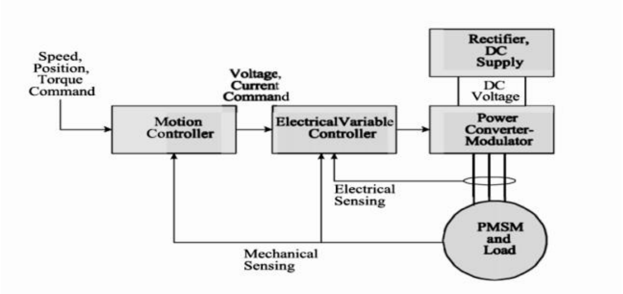


Fig. 2 Diagram of conceptual drive system

III. DETAILED MODELING OF PMSM

Detailed modeling of the PM motor drive system is required for proper simulation of the system. The d-q model has been developed on the rotor reference frame as shown in Fig.3At any time t, the rotating rotor d-axis makes an angle θr with the fixed stator phase axis and rotating stator MMF makes an angle α with the rotor d-axis. Stator MMF rotates at the same speed as that of the rotor.

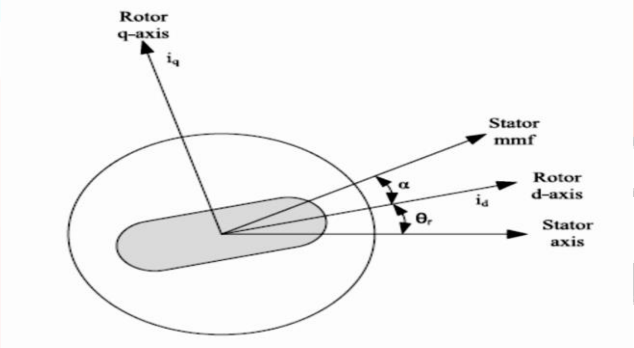


Fig. 3 Motor axis

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

1) Saturation is neglected.

2) The induced EMF is sinusoidal.

3) Eddy currents and hysteresis losses are negligible.

4) There are no field current dynamics.

Voltage equations are given by:

$$V_q= Rsi_q+\omega r\lambda_d+ \rho\lambda_q \qquad (1)$$

$$V_d= Rs\, i_d-\omega r\lambda_q + \rho\lambda_d \qquad (2)$$

Flux Linkages are given by

$$\lambda_q= L_q i_q \qquad (3)$$

$$\lambda_d = L_d i_d+\lambda_d \qquad (4)$$

Substituting equations 3.3 and 3.4 into 3.1 and 3.2

$$V_q= Rsi_q+\omega r\, (L_d i_d+\lambda_f) + \rho L_q i_q \qquad (5)$$

$$V_d= Rsi_d-\omega r L_q i_q+ \rho\, (L_d i_d+\lambda_f) \qquad (6)$$

Arranging equations in matrix form

$$\begin{pmatrix} V_q \\ V_d \end{pmatrix} = \begin{pmatrix} R_s+\rho L_q & \omega_r L_d \\ -\omega_r L_q & R_s+\rho L_d \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} \omega_r \lambda_f \\ \rho \lambda_f \end{pmatrix}$$

The developed torque motor is being given by

$$Te= (3/2)(P/2)X(\lambda_d i_q-\lambda q i_d)$$

The mechanical Torque equation is

$$Te= TL + B\omega m + j(\frac{d\omega m}{dt}) \quad (7)$$

Solving for the rotor mechanical speed form equation

$$\omega m = \int(\frac{Te-Tl-B\omega m}{J})dt \quad (8)$$

and $$\omega m =\omega r(\frac{2}{P}) \quad (9)$$

In the above equations, ωr is the rotor electrical speed whereas ωm is the rotor mechanical speed.

IV. MATHEMATICAL MODEL OF PMSM

The motor currents are decomposed into id and iq components which are respectively flux and torque components in the rotor based d-q coordinates system. Motor model is constituted with following equations:

$$T_e =\frac{3}{2}\frac{P}{2}[\lambda_m.i_q + (L_d - L_q)i_d.i_q] \quad (10)$$

$$d(id)/dt = (v_d - r_s.i_d + w_r.L_q.i_q)L_d \quad (11)$$

$$d(i_q)/dt = [v_q - r_s.i_s - w_r.(L_d.i_d + \lambda_m)]/L_q \quad (12)$$

$$d(\omega_r)/dt = (T_e - T_L - B.\omega_{rm})/ J \quad (13)$$

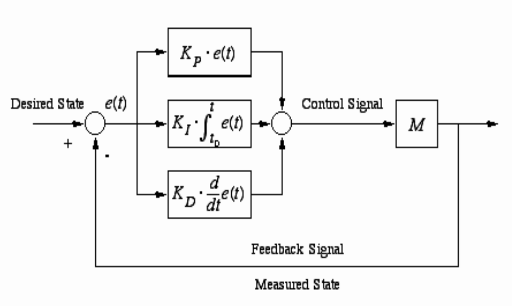
$$\omega_r = \frac{P}{2}X\omega_r \quad (14)$$

where,
TL = load torque,
B = viscous friction,
J = moment of inertia,
V_d & V_q = represent the d-q axis stator voltages,
I_d & i_q = the d-q axis stator currents.
L_d & L_q = the d-q axis inductances,
r_s = per phase stator resistance,
ω_r= velocity of the rotor.
λ_m = expression of the flux linkage due to the rotor magnets linking the stator,
T_e = motor produced torque
ω_{rm} = mechanical velocity of the rotor.

V. Conventional Controller

The most common controller action used in process control is one or a combination of continuous control modes and the method by which the controller counteracts a deviation from a setpoint is called a control mode. The three most commonly used modes of feedback control are proportional, integral, and derivative. Various combinations of these modes comprise mostly of the controllers found in industries. The various combinations generally found are:

PI (Proportional Integral) mode
PD (Proportional derivative) mode
PID (Proportional Integral Derivative) mode



VI. **Fig -4**: PID controller

The adoption of improved control algorithms has, however, been slow. Many computer control implementations have simply taken over the well-established analog three-term control algorithm (proportional + integral + derivative – PID). This has the general form

$$m = K_p (e +1/Ti\ e.\ dt + T_d\ .\ de/dt) \quad (15)$$

In 'proportional control', actuating signal at the output of the controller is related to the input of the controller by a proportional constant. A linear continuous-data controller should be also able to take a time derivative or a time integral of the input signal, in addition to the proportional and other simple algebraic operations, such as addition and subtraction. One of the best-known controllers used is the PID controller where the PID stands for Proportional, Integral, and Differential. The transfer function of PID is:

$$G(s) = Kp + \frac{ki}{s} + Kds \tag{16}$$

Where e = r-y and y is measured variable, r is reference value or setpoint, and e is error; Kp is the overall controller gain; Ti is the integral action time, and Td is the derivative action time. This algorithm can be expressed in another form. For example, derivative action is frequently not used, when de/dt is often replaced by dy/dt to avoid differentiating the set point.

The algorithm is normally implemented in DDC systems by using the difference equation equivalent to 1 above. If the sampling interval for computation is T seconds then the simple approximations.

VII. Fuzzy Logic Controller

Fuzzy logic is a thinking process or problem-solving control methodology incorporated in control system engineering, to control systems when inputs are either imprecise or the mathematical models are not present at all. Fuzzification is the process of making a crisp quantity into the fuzzy [18]. They carry considerable uncertainty. If the form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, then the variable is probably fuzzy and can be represented by a membership function. Defuzzification is the conversion of a fuzzy quantity to a crisp quantity, just as fuzzification is the conversion of a precise quantity to a fuzzy quantity [19]. There are many methods of defuzzification, out of which the smallest of the maximum method is applied in making a fuzzy inference system. The Fuzzy logic control consists of three main stages, namely the fuzzification interface, the inference rules engine, and the defuzzification interface. For speed control, the process operator is assumed to respond to variables error (e) and change of error (ce). The fuzzy logic controller with error and change in error is shown in fig. 5.

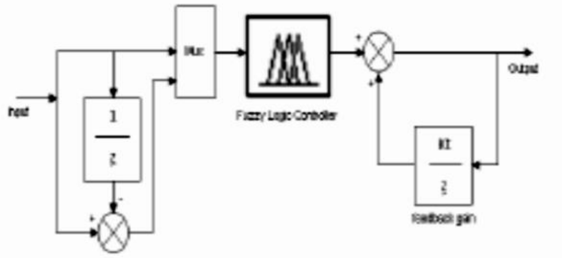


Fig. 5 Fuzzy Logic Controller

Taking the scaling gains into account, the global function of the FLC output signal can be written as.

$$\Delta Pc = F[n_c\, e(k), n_{ce}\, ce(k)] \tag{17}$$

Where n_e and n_{ce} are the error and error rate scaling gains, respectively, and F is a fuzzy nonlinear function. FLC is dependent on its inputs scaling gains [15]-[18,[19]. A label set corresponding to linguistic variables of the input control signals, e(k) and ce(k), with a sampling time of 0.01 sec is given Attempt has been made to examine with Seven number triangular membership function (MFs) namely Negative Big(NB), Negative Medium(NM), Negative Small(NS), Zero(ZO), Positive Small(PS), Positive Medium(PM) and Positive Big(PB) are used. The numbers of rules are 49. The membership functions (MFs) for the input variables are shown in Fig.6.

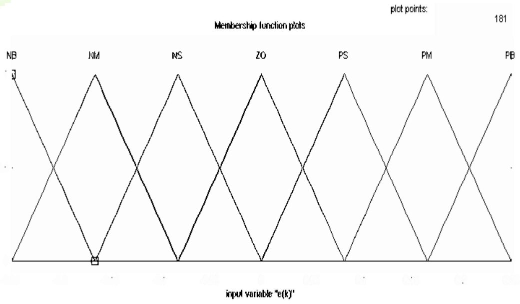


Fig. 6 Membership Function for the control input variables

Table 1 Fuzzy Inference Rule for Fuzzy Logic Controller

Input	e(k)							
ce(k)		NB	NM	NS	ZO	PS	PM	PB
	NB	PB	PB	PB	PB	PM	PM	PS
	NM	PB	PM	PM	PM	PS	PS	PS
	NS	PM	PM	PS	PS	PS	PS	ZO
	ZO	NS	NS	NS	ZO	PS	PS	PS
	PS	ZO	NS	NS	NS	NS	NM	NM
	PM	NS	NS	NM	NM	NM	NB	NB
	PB	NS	NM	NB	NB	NB	NB	NB

IV. RESULTS AND DISCUSSION

Speed controlling of permanent magnet synchronous motor has been observed using simulink software through different controllers i.e. using PID controller and Fuzzy logic controller,

Table 2: Permanent Magnet Synchronous Motor parameters

Mechanical input	**Torque**
Stator resistance Rs(ohm)	2.85
Inductances Ld(H) Lq(H)	8.5e-3, 8.5e-3
Flux induced by magnets(Wb)	.175
Ref Speed	800 RPM

7.1 Speed control model using PI and PID controller

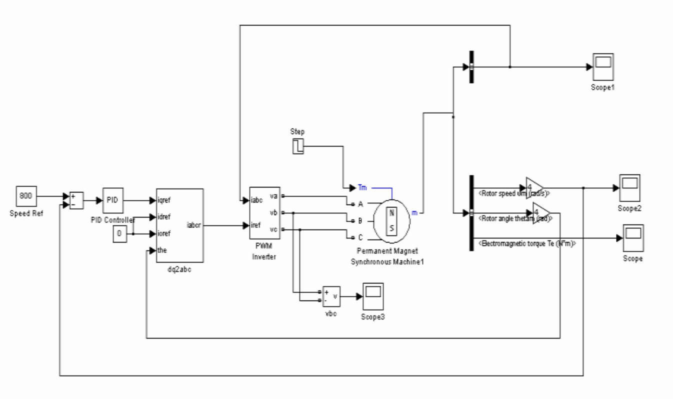


Fig. 7 MATLAB model of PMSM using PID controller

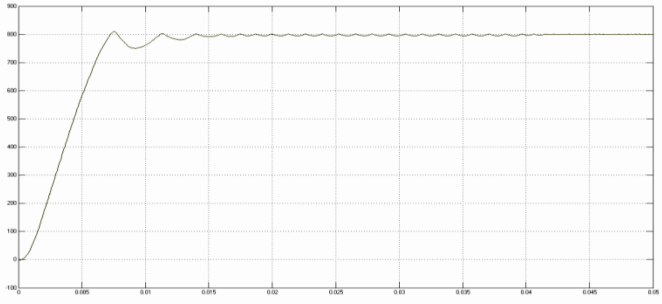


Fig. 8 Scope view of the speed of PMSM using a PI controller

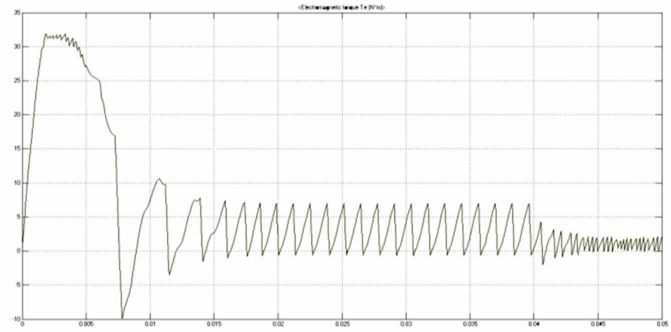


Fig. 9 Scope view of torque of PMSM using the PI controller

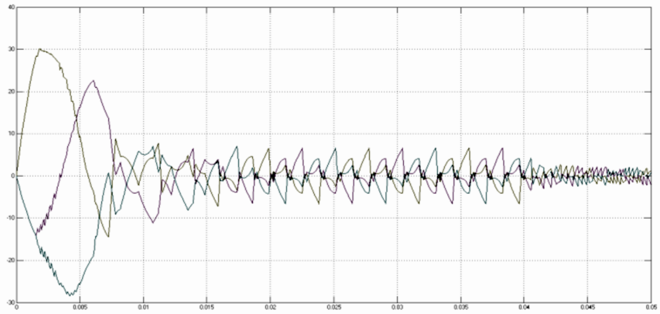


Fig. 10 Scope view of 3 phase current of PMSM using the PI controller

From the above model with PI controller and its response, we can see that the rising time and settling time with dampings comes after a long period so here we can say that controlling of permanent magnet synchronous motor is difficult using a PI controller.

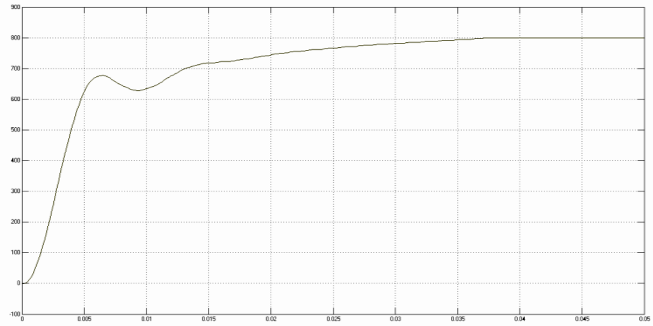


Fig. 11 Scope view of the speed of PMSM with PID controller

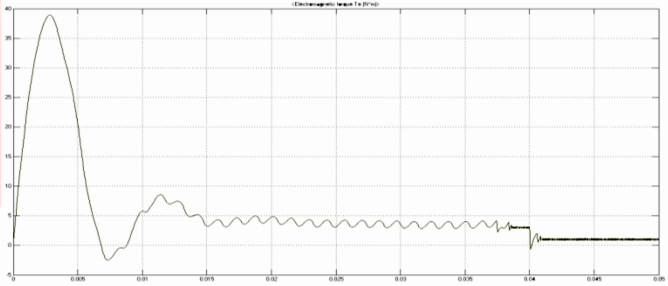


Fig. 12 Scope view of electromagnetic torque of PMSM with PID controller

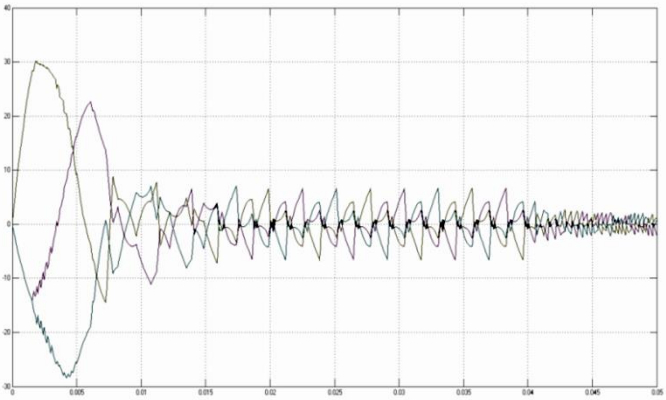


Fig. 13 Scope view of 3 phase current of PMSM with PID controller

From the above model with PID controller and its response, it is see that the raising time and settling time comes after.04 sec so here we can say that the controlling of PMSM.

7.2 Speed control model using Fuzzy Logic controller

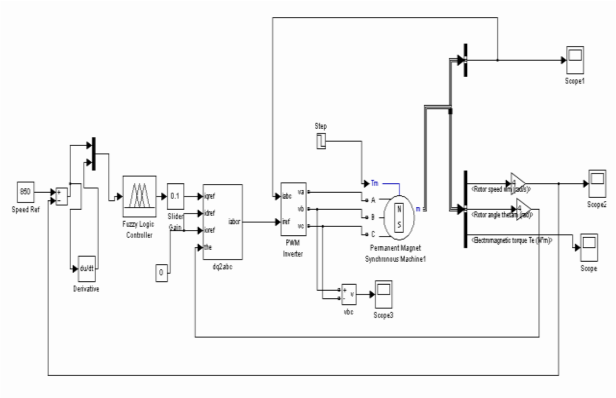


Fig. 14 MATLAB model of PMSM using Fuzzy logic controller

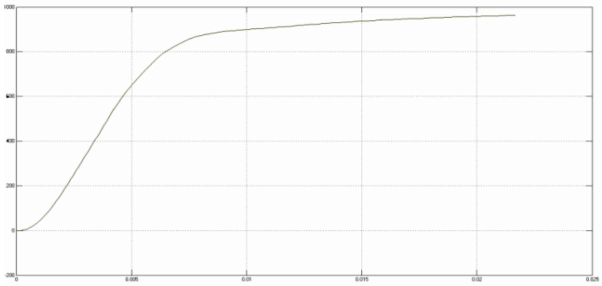


Fig. 15 Scope view of the speed of PMSM with fuzzy logic controller

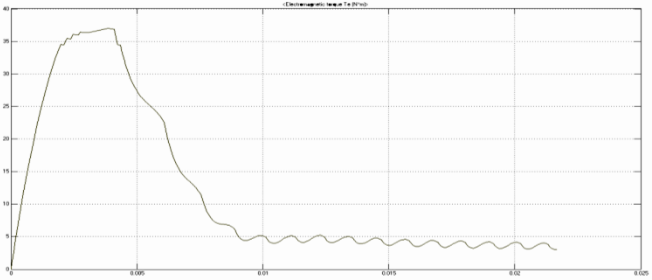


Fig. 16 Scope view of electromagnetic torque of PMSM with fuzzy logic controller

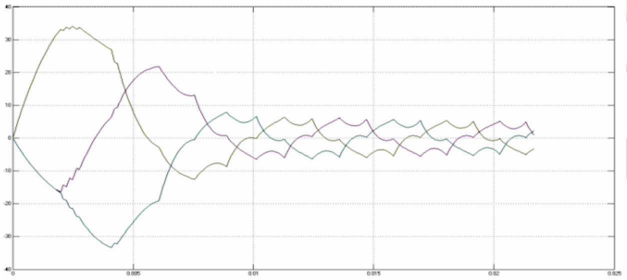


Fig. 17 Scope view of 3 phase current of PMSM with fuzzy logic controller

From the above model with fuzzy controller and its response, we can see that the rising time and settling time comes rapidly in comparison to PI and PID controllers so here we can say that the controlling speed of permanent magnet synchronous motor is much easy than the PI and PID controller.

8. CONCLUSIONS

The speed control of permanent magnet synchronous motor using fuzzy logic controller has been investigated in this work. Other conventional controllers were also used such as PI and PID. Comparison the result of speed control by all the three controllers, it is observed that fuzzy logic controller gave the best response as compared to other. The settling time of the speed was comparatively less than that of the other two controllers and it is also tabulated in 3.

Table 3: Comparison between PI and Fuzzy controller

Controller	Rise time (sec)	Settling time (sec)	Peak overshoot	Error(e_{ss}) %
PI controller	12	22	8	No Control
PID controller	0.6	4	1.32	21.27
Fuzzy controller	0.8	1.8	1.0	2.71

REFERENCES

[1] A. Karakaya, E. Karakas,'The Speed Control of Permanent Magnet Synchronous Motor Using Fuzzy Logic and Self Tuning Fuzzy PI Controller," Proc.ELECO'05.

[2] A. G. Aissaoui, M. Abid, H. Abid, A. Tahour, A. K. Zeblah, 'Speed Control of Synchronous Motor, IEEE International Conference, pp 1138-1142. (2007).

[3] Cao X, Fan L, 'A Novel Flux-weakening Control Scheme Based on the Fuzzy Logic of PMSM Drive", IEEE International Conference on Mechatronics and Automation, pp. 1228 – 1232. (2009).

[4] X, Fan L, 'Vector Controlled Permanent Magnet Synchronous Motor Drive Based on Neural Network and Multi Fuzzy Controllers', Fifth International Conference on Fuzzy Systems and Knowledge Discovery,(2008).

[5]Cao X, Fan L,'Novel Implementation of Adaptive fuzzy neural network for speed control of PMSM'IEEE International Conference, (2005).

[6] Chih-Hong Lin Chih-Peng Lin, 'The Hybrid RFNN Control for a PMSM Drive System Using Rotor Flux Estimator' IEEE International Conference,(2009).

[7]Chih-Hong Lin Chih-Peng Lin, 'Fuzzy Neural Network Control for a Permanent Magnet Synchronous Motor Drive System' ICIEA 2009, pp 2718-2723.

[8] Chuandong Ding, Jun Wang, Qi Wen, Hongmei Xiao, 'Fuzzy Sliding Mode Controller For Permanent Magnet Synchronous Motor' IEEE International Conference,(2008).

[9] Benchouia MT, Zouzou SE, Golea A, Ghamri A. 'Modelling and Simulation of Variable Speed Drive System with Adaptive Fuzzy Controller Application to PMSM", IEEE International Conference on Industrial Technology (ICIT), pp. 683 – 687, (2004).

[10] Bhim Singh, B.P. Singh, Sanjeet Dwivedi, 'Dsp Based Implementation Of Fuzzy Pre compensated PI Speed Controller For Vector Controlled Pmsm Drive.' international conference IEEE,(2006).

[11] Ding C, Wang J, Wen Q, Xiao H (2008), 'Application of Fuzzy Sliding Mode Controller in Permanent Magnet Synchronous Motor", IEEE 7th World Congress on Intelligent Control and Automation, pp. 4727 –473.(2006).

[12] Fan Liping, Jinxia Huang (2008), 'An Implementation of Neural Network and Multi-Fuzzy Controller for Permanent Magnet Synchronous Motor Direct Torque Controlled Drive' ,at Proceedings of the IEEE International Conference on Automation and Logistics Qingdao, China September 2008.

[13] FebinDaya J L, Dr.V.Subbiah, 'A Novel Fuzzy Logic Based Robust Speed Controller for Permanent Magnet Synchronous Motor Servo Drive", IEEE International Conference on Region 10, pp 1 – 4,(2009).

[14]Guang-Ye Li, Jian-RuWan,Ying-Pei Liu, ShenHong,Chen-Hu Yuan, 'Permanent magnet synchronous motor direct control with zero vector based on intelligent method' in Eighth International Conference on Machine Learning and Cybernetics, Baoding, 12-15 July 2009.

[15]GuoZhi-rong, Gao Wei, Xie Shun-yi1, 'Automatic Generation Fuzzy Neural Network Speed Controller for Permanent-Magnet Synchronous Motor Drive' in Second International Conference on Intelligent Computation Technology and Automation,(2009).

[16] I. Guney, Y. Oguz, F. Serteller, 'Dynamic Behaviour Model of Permanent Magnet synchronous Motor Fed by PWM Inverter and Fuzzy Logic Controller for Stator Phase Current, Flux and Torque Control of PMSM,' in Proc. IEMDC'01, pp. 479-485,(2001).

[17] Jiangtao Wang and Haiqin Liu, 'Novel Intelligent Sensorless Control of Permanent Magnet Synchronous Motor Drive' in The Ninth International Conference on Electronic Measurement & Instruments ICEMI'2009.

[18] Kamel HM, Ibrahim HEA, Hasanien HM, 'Speed Control of Permanent Magnet Synchronous Motor Using Fuzzy Logic Controller', IEEE Int. Conference Electric Machines Drives Syst., pp. 1587 – 1591,(2009).

[19] Kung YS, Wang MS, Huang CC. 'DSP-based Adaptive Fuzzy Control for a Sensorless PMSM Drive', IEEE International Conference on Control and Decision, pp. 2379 – 2384,(2009).

[20] Kuang-Yao Cheng,andYing-Yu Tzou (2004), 'Fuzzy Optimization Techniques Applied to the design of a digital PMSM Servo Drive',IEEE transactions on Power Electronics,vol-19,No.4

[21] Limei Wang, MingxiuTian and YanpingGao, 'Fuzzy Self-adapting PID Control of PMSM Servo System', IEEE International Conference,(2007).

[22] Lin Hai, Yan Wei-Sheng, LI Hong, 'Fuzzy and PNN-based Direct Torque Control for Permanent Magnet Synchronous Motor' in ICIEA, 2009.

[23] Liu YP, Wan JR, Yuan Ch, Li GY. "Fuzzy Based Direct Torque Control of PMSM Drive Using An Extended Kalman Filter", IEEE Eighth Int. Conference Machine Learning Cybernetics, pp. 647 – 651,(2009).

[24]M. Nour, I. Aris, N.Mariun, S. Mahmoud, 'Hybrid Model Reference Adaptive Speed Control for Vector Controlled Permanent Magnet Synchronous Motor Drive' IEEE conference,(2005).

[25] Ming Yang, Xing cheng Wang, 'Fuzzy PID Controller Using Adaptive Weighted PSO for Permanent Magnet Synchronous Motor Drives' Second International Conference on Intelligent Computation Technology and Automation,(2009).

[26] Rahideh A, Rahideh A, Karimi M, Shakeri A, Azadi M. 'High Performance Direct Torque Control of a PMSM using Fuzzy Logic and Genetic Algorithm', IEEE Int. Conference Electric Machines Drives Syst., pp. 932 – 937,(2007).

[27] SantAmit Vilas, K. R. Rajagopal, 'PM Synchronous Motor Speed Control Using Hybrid Fuzzy-PI With Novel Switching Functions', IEEE Transaction of Magnetics Vol. 45, No. 10, October 2009.

[28] SitiNoormiza Mat Isa, Zulkifilie Ibrahim, FazlliPatkar, 'Comparative Study of Fuzzy Logic Speed Controller in Vector Controlled PMSM Drive: Minimum Number of Fuzzy Rule-Base', in Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA) Monash University, Sunway campus, Malaysia, 25th & 26th July 2009.

[29] Song L, Peng J. 'The Study of Fuzzy – PI Controller of Permanent Magnet Synchronous Motor', IEEE International Conference on Power Electronics Motion Control, pp. 1863 – 1866,(2009).

[30] Wang L, Tian M, Gao Y, 'Fuzzy Self-adapting PID Control of PMSM Servo System', IEEE Int. Conference on Electric Machines and Drives Syst., pp. 860 – 863,(2007).

[31]Wang J, Wang HH, Yuan XL, Lu TH. 'Novel Intelligent Direct Torque Control for Permanent Magnet Synchronous Motor Drive', IEEE Fifth Int. Conference on Fuzzy Syst. Knowledge Discovery, pp. 226 – 203,(2008).

[32]Xianqing Cao, Liping Fan, Jinxia Huang (2008), 'An Implementation of Neural Network and Multi-Fuzzy Controller for Permanent Magnet Synchronous Motor Direct Torque Controlled Drive' Proceedings of the IEEE International Conference on Automation and Logistics Qingdao, China September 2008

[33]Yan Wei-Sheng, LI Hong, LIN Hai, 'Fuzzy and PNN-based Direct Torque Control for Permanent Magnet Synchronous Motor' IEEE International Conference.(2009).

[34]Ying-Shieh Kung, Ming-Shyan Wang, Chung-Chun Huang, 'DSP-based Adaptive Fuzzy Control for a Sensorless PMSM Drive' IEEE International Conference(2009).

[35]Yuan Xiao-ling,WangHong-hua, 'Intelligent Sensorless Control of Permanent Magnet Synchronous Motor Drive' Second International Conference on Intelligent Computation Technology and Automation(2009).

[36] Z. Ibrahim, E.Levi, D. Williams, 'A Self-Tuning Method for Fuzzy Logic Speed Controller in High Performance AC Drives,' Proc.UPEC'98, vol. 2, pp. 819-822,(1998).