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Comparison of Series & Parallel Hybrid PI Speed Controllers for Permanent Magnet Brushless DC Motor

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Abstract

This paper present Hybrid Proportional Integral (PI) controllers (with fuzzy controller) as Series Hybrid or Parallel Hybrid assortments, for speed control of Permanent Magnet Brushless DC Motor drive for application to intermitted duty loads. The introduced assortments have better performance compared to conventional PI controller amidst parametric variations and nonlinearities, when used as a continuous controller for the drive. Series Hybrid configuration fuzzy controller provides precompensated input to the PI controller to reduce oscillation and fast operation. Parallel Hybrid utilizes Fuzzy logic based increasing the solidity and on-line parameters tuning under severe unknown plant nonlinearities. The dynamic characteristics of BLDCM such as Torque, speed, Back EMF and Current are observed and analyzed through simulation under MATLAB Simulink environment.

Keywords-PI controller, Fuzzy logic controller, Series Hybrid, Self Tuning Parallel Hybrid, motor control, Permanent Magnet Brushless DC Motor.

I. Introduction

With rapid developments in power electronics technology and modern control theory for motors, the permanent magnet brushless DC (PMBLDC) drives has emerged as a suitable alternative for automotive, appliances, aerospace, consumer, medical, instrumentation, automation industries and Robotics applications [1]. Due to the advantages like small size, good performance, simple structure, high reliability and large torque to weight ratio, PMBLDC motors have attracted increasing attention. They have also been found in wide applications for Electrical Vehicles and automobiles industries especially in hybrid vehicles where space and weight are critical factor. PMBLDC motors have many advantages over induction motor, as they have better dynamic response, high efficiency, higher speed ranges, low rotor inertia, noiseless operation, low maintenance, long operating life and ease of control [2].Uses of induction motor or PMBLDC motor in hybrid vehicle goes hand in hand but near to ideal characteristics, flat torque speed curve, zero flux distortion, make PMBLDC unanimous choice for low power rating applications.

The PI controllers are inevitable in the industry applications owing to its continuous nature and simple structures along with good performances in a wide range of operating conditions. However in many applications the derivative term is being negated by setting the derivative gain to zero making PI a versatile controller [3]. Unknown nonlinearities, parameter variation and variable loading condition in plants often affect the performance of the PI controller; hence the need for adaptive control arises for suitable performance of the drive. These problems can be easily overcome by using fuzzy controller [4], which is based on linguistics rules obtained from the experience of system operator, but discreetness of control makes it unsuitable for electric drives where fast current changes are not permissible. Fuzzy have also been used as fuzzy precompensated [5], parallel Fuzzy [6], fuzzy logic based self tuning and fuzzy scheduled PID Controllers [7].The concept of optimizing the fuzzy controller is also reported using genetic algorithm in [8,9]. Fuzzy logic controller (FLC) exhibit offset in the response, whereas PI controller has superior performance near steady state conditions but suffers from sluggish response and occurrence of overshoot. Even though a FLC delivers fast response and functions well even in the presence of a nonlinearities, a PI controller is always preferred as the front end controller, supported by the FLC at the back end. The Hybrid of PI and fuzzy reap the benefit of both, where each complement the other's short coming [10,11]. Typically intermittent duty loads in process industry need fast acting and precise controller to ensure quality production with minimum time.

The quest for such fast controllers with precise operation is therefore requisite with PMBLDC motors envisaging enhanced production. A hybrid fuzzy- PI controller can be implemented as a speed controller for PMBLDC where the PI controller is active near the steady state conditions and the fuzzy controller active during transient conditions [12].

A hybrid combinations of the Fuzzy logic controller and a conventional PI controller for BLDCM drive is proposed in this paper, to have fast dynamics with minimum overshoot and good response amidst nonlinearities by keeping the continuous controller structure for the operation of the drives. In the first configuration the fuzzy controller processes the original speed error and provides a modified reference signal to the PI controller and the main control action is taken by the PI. This process of modifying the reference signal continuously is categorized as the series hybrid PI. The principal advantage in implementing this scheme of control embodies in modifying existing PID controller without the change in persisting hardware.

The FLC precompensation assumes modular structure inserted before the PI controller of already existing drives, upgrading its performance. The second configuration the fuzzy self tuning controller modifies the values of proportional and the integral gain online such that the rise time, overshoot, settling time and the effects due to unknown linearities is eliminated and the controller achieves adaptive nature to load variations and environment conditions. Such parallel hybrid controllers can easily be augmented with the existing PI controller. The individual controller have their own merits and demerits, so the choice of selection of the individual controller either series hybrid or parallel hybrid for an application should be based on the requirements.

II. SYSTEM CONFIGURATION

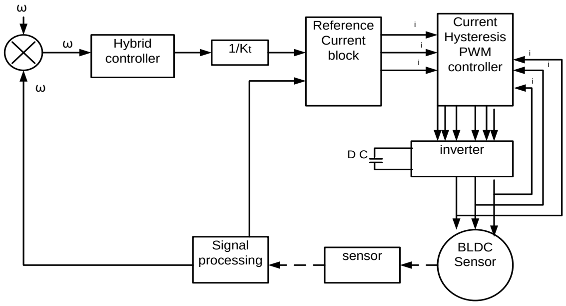


Fig.1 Block diagram of PMBLDCM drive.

The Fig.l describes the basic building blocks of the PMBLDCM drive. The drive consists of speed controller, reference current generator, PWM current controller, position sensor, the motor and IGBT based current controlled voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in a hybrid PI speed controller. The reference torque output of the controller limited to restrict the operation of the drive within permissible range of currents. The reference current block generates the three phase reference currents (ia * ,ib * ,ie *). Using the position sensor. The reference currents have the shape of a quasi-square wave in phase with respective back emfs to develop constant unidirectional torque. The hysteresis current controller regulates the winding currents (ia, ib, ie). within the small band around the reference currents (ia * ,ib *, ie *). The motor switching commands so generated drives the inverter connected to the PMBLDC drive [14].

III. MODELING OF BLDC DRIVE

In this section modeling of main components of PMBLDC
motor drive is presented.

The PMBLDCM produces a trapezoidal back electromotive force (EMF), and the applied current waveform is quasi-square shaped. A 3-phase 6-state V-connected PMBLDCM with twophase excitation as in considered [13]. The three-phase stator voltage equation can be expressed as following

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} p \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

where, Va, Vb, Vc are the phase voltage of three-phase windings, ia, ib, ie, are the phase current, ea, eb and ee are the phase back EMF and p is differential operator, R resistance of each windings , L self-inductance, and M mutual inductance.

The torque produced by PMBLDCM is described by following torque -motion equation.

$$T = K_T I = J\omega' + B\omega + T_1$$

(2)

Where, 1 is motor current, KT motor torque constant, Tj load torque, J rotational inertia of rotor and load, B viscous damping coefficient, ω angular velocity of motor which depend on the applied voltage V as given below.

$$\omega = K_V V$$

(3)

Here Kv is the motor voltage constant. Both Kt and Kv are important parameters for a PMBLDC are specified in the datasheet of the motor and there product is always same for all the motors.

A. Reference Current Block

The function of this block is to produce three phase reference currents. The magnitude of the three phases current (Io) is determined by reference torque computed by hybrid controller and rotor position signal (φ).

$$I_0 = T^* / K_b$$

(4)

where, T* is the reference torque and Kb is the back emf constant. The output of this block are three phase reference currents (ia*:, ib *, ie *). The output generated can have any of value from the set (Io,-Io, zero). Table-I shows corresponding relation between input rotor position (φ) and reference currents output generated.

TABLE 1 . REFERENCE CURRENT INPUT AND OUTPUT LOGIC

Input / Rotor Position (φ)	Output / Generated Reference Currents		
	ia *	ib *	ie *
0 to π/3	Io	-Io	0
π/3 to 2π/3	Io	0	-Io
2π/3 to π	0	Io	-Io
π to 4π/3	-Io	Io	0
4π/3 to 5π/3	-Io	0	Io
5π/3 to 2 π	0	-Io	Io

B. Modeling Fuzzy Logic Controller (FLC)

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system. Fuzzy controller design involves incorporating human expertise on how to control a system into a set of rules (a rule base). Generally the procedure for constructing a FLC consists of the following mechanism.

- Choosing the fuzzy controller inputs and outputs: The speed error 'e' and the change in speed error 'ce' are selected as the input variables. Asymmetrical triangular type of the membership functions has been chosen to fast converse the error towards the desired steady state condition as per Fig.2. The symbol GE is used for the scaling constant for the input e(n), and the symbol GCE, for the scaling constant for the input Δe(n).
- *Putting control knowledge into rule base:* "Linguistic variables" that describe each of the time varying fuzzy controller inputs and outputs is defined. Each input and the output variables are described using the variables {NH, NM, NL, ZE, PL, PM, PH}. Proper control rules are written using the variables in the "If-Then-Else" format then the rule table is presented in Table-IT.
- *Inference Mechanism:* It leads to determination of conclusions. This emulates the expert's decision making in interpreting and applying knowledge.
- *Converting decisions into Actions*: De-fuzzification is the final component of the fuzzy controller, operates on the implied fuzzy sets produced by the inference mechanism and combines their effects to provide the "most certain" controller output. The centriod method is used for defuzzification. FLC have three significant advantages over conventional techniques- they cover a wide range of operating conditions (i.e. are more robust), and they are more readily customizable in natural language.

TABLE II RULE TABLE FOR FUZZY LOGIC CONTROLLER

E CE	**NH**	**NM**	**NL**	**ZE**	**PL**	**PM**	**PH**
NH	NH	NH	NH	NH	NH	NM	PM
NM	NH	NH	NH	NM	NM	PL	PH
NL	NH	NH	NM	NL	ZE	PM	PH
ZE	NH	NM	NH	ZE	PL	PH	PH
PL	NH	NL	ZE	PL	PM	PH	PH
PM	NH	NL	PM	PM	PH	PH	PH
PH	NM	PM	PH	PH	PH	PH	PH

Development Of Hybrid Controller

The purpose of the hybrid control scheme is based on compensation for overshoots and undershoots in the transient response and minimizing the steady state error. A PI controller when used in combination with FLC such that near steady state operation, PI controller takes over the control eliminating the disadvantage of the FLC. Similarly when away from the operating point FLC dominates and eliminates the occurrence of overshoots and undershoots in drive response. Proposed hybrid controllers are described in the section below.

A. Series Hybrid Pi Controller

The Fig.3 illustrates the basic control structure of the Series Hybrid controller. The scheme consists of a conventional PI hybrid with proposed fuzzy pre-compensator. The fuzzy precompensator uses the command speed input Ym and the plant speed output YP to generate a pre-compensated command signal Yc, described by the following equations

$$e(n) = y_m(n) + y_p$$

$$\Delta e(n) = e(n) - e(n-1)$$

$$\gamma(n) = f\left[e(n), \Delta e(n-1)\right]$$

$$y_c(n) = y_m(n) + \gamma(n)$$

(5)

In the above e(n) is the tracking error between the command speed input ym(n) and the plant speed output yp(n) and Δe(n) is the change in the tracking error. The term f [e(n),Δe(n -1)] is a nonlinear mapping of e(n) and i'1e(n) based on fuzzy logic. The term γ(n)=f [e(n),Δe(n -1)] represents a compensation or correction term, so that the compensated command signal Yc(n) is simply the sum of the external command signal Ym(n) and y(n).The correction term is based on the error e(n) and the change of error Δe(n).

The compensated command yc(n) is applied to a conventional PI scheme, as shown in Fig.3. The equations governing the PI controller are as follow

$$e_2(n) = y_c(n) + y_P(n)$$

$$\Delta e_2(n) = e_2(n) - e_2(n-1)$$

$$u(n) = u(n-1) + K_P \Delta e_2(n) + K_1 e_2(n)$$

(6)

The quantity e2(n) is the precompensated tracking error between the precompensated command input yc(n) and the plant output yp(n) and Δe2(n) is the change in the precompensated tracking error. The control u(n) is applied to

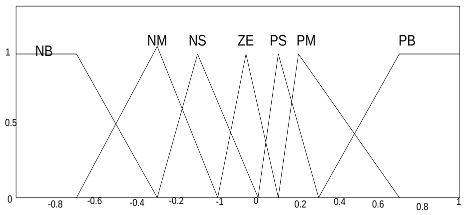


Fig.2 Membership function of input and output .

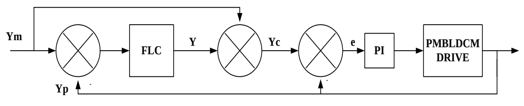


Fig.3 Block diagram of Series hybrid controller.

The input of the plant, where Kp is the proportional gain and K, is the integral .The purpose of the fuzzy precompensator is to modify the command signal to compensate for the overshoots and undershoots present in the output response when the plant has unknown nonlinearities. The precompensator uses fuzzy logic rules that are based on the above motivation.

B. Parallel Hybrid PI Controller

The structure is easy to understand and is capable of getting accommodated accommodating without much change in the hardware system as shown in Fig4. In stream controller continues to work as a PI controller, but unlike the conventional PI controller the values of the proportional and the integral gains are modified continuously based upon the operating condition. Intelligence inherited from FLC may be translated into Kp and Ki gains, which may be altered as per the situation before the drive.

$$e(t) = k_p e(t) + k_i \int e(t)dt \qquad (7)$$

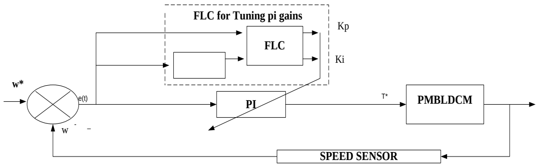


Fig. 4 Block diagram of parallel hybrid controller.

The control equation of a conventional PI controller in continuous time domain is represented as per (7). The proportional gain provides the control action effectively when the error is more (transient response) and the integral gain delivers efficiently when the system is operating near the set point value. FLC intelligence assigns the proportional gain (Kp) which must be maximum when the error is large and should start to vary to a value when the drive system is near to the set point. Similarly FLC assigns the integral gain continuously varying then in such a way that its value will be minimized, when the drive operates away from the set point and attains a higher value when it operates near to the set point. The rule base for parallel hybrid is prepared as shown in Table III & IV.

TABLE III. RULE TABLE FOR PROPORTIONAL GAIN Kp

E CE	**NH**	**NM**	**NL**	**ZE**	**PL**	**PM**	**PH**
NH	PH	PH	PM	ZE	ZE	PS	PH
NM	PH	PH	PL	NS	ZE	PM	PH
NL	PH	PH	PL	NM	ZE	PM	PH
ZE	PH	PH	PL	NB	PL	PH	PH
PL	PH	PM	ZE	NM	PL	PH	PH
PM	PH	PM	ZE	NS	PL	PH	PH
PH	PH	PL	ZE	ZE	PM	PH	PH

TABLE IV. RULE TABLE FOR PROPORTIONAL GAIN Ki

E CE	NH	NM	NL	ZE	PL	PM	PH
NH	NH	NH	NM	PL	PL	NL	NH
NM	NH	NH	NL	PL	ZE	NM	NH
NL	NH	NH	NL	PM	ZE	NM	NH
ZE	NH	NH	NL	PH	NL	NH	NH
PL	NH	NM	ZE	PM	NL	NH	NH
PM	NH	NM	ZE	PL	NL	NH	NH
PH	NH	NH	PL	PL	NL	NH	NH

TABLE V. PMBLDC MOTOR DRIVE PARAMETER

Resistance /ph (R)	2.8 □
Inductance /ph (L)	5.21 uH
No. of Pole Pairs	2
Back EMF Constant (Kb)	1.23 Vs/rad
Mechanical inertia (.I)	0.013 Kg m2
Friction Coefficient (B)	0.0003 N.m.s
Peak Stator Current (I)	4 A
Load Torque (Tl)	2Nm

IV. Performance Evaluation

Simulations were carried out for both type of hybrid speed control strategies implemented for the PMBLDC drive system with the parameters given in Table-V. The process was initiated development of hybrid controller with PI controller tuned to best possible condition with proportional gain as Kp =3 and integral gain Ki =45. The developed hybrid controllers are thus evaluated for comparison with PI controller tuned to best condition.

The response of PMBLDC drive for starting, speed reversal and load perturbations have been considered as evaluation criterion for comparison. The simulation time considered for result evaluation is limited to t= 4s. The PMBLDC drive is started at no load and the control is employed to track the shaft speed of 1000rpm by the series hybrid controller. It can be observed in Fig.5 that within 0.505s the drive reaches 1000rpm representing fast operation of the drive with small overshoot of 0.38rpm which is well within the acceptable limits.

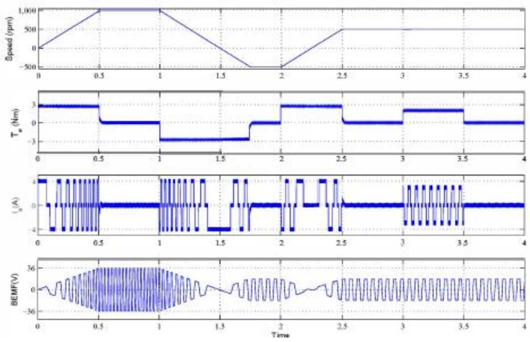
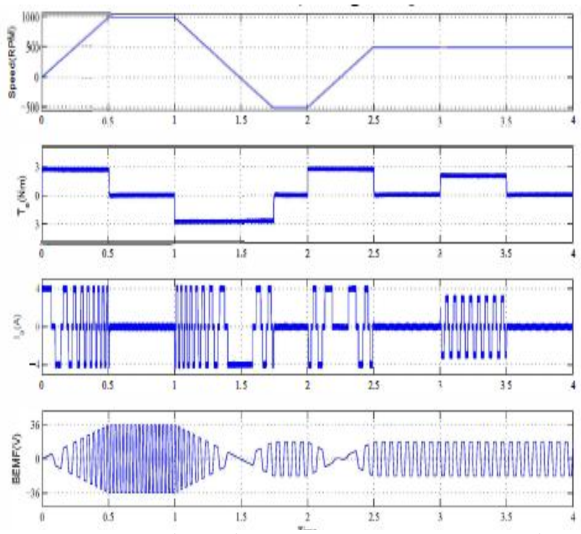


Fig. 6 Response of drive for Parallel hybrid speed controller for starting.
speed change and load perturbation.

It may also be observed that drive have not exhibited any oscillation while ramping up during acceleration. The state quo has been maintained till t= 1s, where the drive continues to operate with 1000rpm. At t= 1 command for speed change from 1000rpm to -500rpm is issued. It is evident from Fig.6 that drive decelerated first then accelerated without oscillations to - 500rpm and at t= 1.74s the drive settle down to the desired speed with a marginal overshoot of 0.49rpm. The time for such speed change is 1.24s. At t= 2s command for speed reversal was given, to which drive responded in 0.625s without oscillations during acceleration and deceleration with marginal overshoot of 0.53rpm. Further at t= 3s the drive is subjected to step load of 2Nm. It may be evident from Fig.5 that drive respond to such load perturbation within 0.16s with undershoot of 0.49rpm. Similarly when the load is suddenly removed from the shaft the drive recovers from transient within O.15s with overshoot of 0.4rp m.

On the similar conditions the drive is operated with parallel hybrid controller. It may be observed in Fig.6 that the motor is started at no load with reference speed of 1000rpm. The motor accelerates to reach 1000rpm with parallel hybrid controller in 0.6s with small overshoot of 0.65rpm which is well within the acceptable limits. It may also be observed that drive have not exhibited any oscillation while in acceleration. The state quo has been maintained till t=l s, where the drive continues to operate with 1000rpm. As a next transient for evaluation of performance the reference speed is changed to -500rpm, it is evident from Fig.8 that drive decelerated first then accelerated without oscillations to -500rpm within 1.24s with a marginal overshoot of 0.6rpm. At time t= 2s the reference speed is changed to 500rpm depicting the speed reversal to which the drive responded in 0.12Ss without oscillations with marginal overshoot of 0.57rpm. Further at t= 3s the drive is subjected to step load of 2Nm. It may be observed from Fig.6 that drive respond to such load perturbation within 0.12s with undershoot of 0.55rpm. Similarly when the load is suddenly removed from the shaft at t=3.5s the drive recovers from transient within0.13s with overshot of 0.56rpm.

A comparison is drawn to assess the relative performance of different controller for their employment with the considered PMBLDC drive. The relative performance evaluation is done for starting, speed reversal and load perturbations (step load of 2Nm and its removal form shaft). Fig.7 depicts the transient operation of the drive during starting when the drive reaching the steady state and during step loading and removal from shaft as aforesaid at the operational speed of l000rpm.



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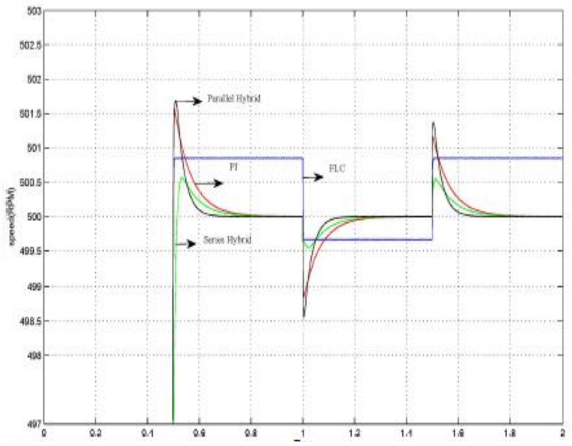

Fig. 7 PI controller, Fuzzy logic controller, Series Hybrid, Self Tuning Parallel Hybrid, motor control, Permanent Magnet Brushless DC Motor.

It may be observed that series hybrid is slightly better than parallel hybrid in the term of overshoot/undershoot, whereas, parallel hybrid exhibit better performance in term of settling time. Overall both series hybrid and parallel hybrid exhibit better performance than PI when both overshoot/undershoot and settling time are the considered criterion for the comparison. The detailed numerical observations are provided in Table-VI. The Table-VI also hosts the observations during speed changes and speed reversal transients.

V. Conclusion

Two hybrid controllers have been successfully implemented for the PMBLDC drive and a comparison has been drawn between conventional PI controller and the two proposed hybrid controller for various transients experienced by the drives, viz, starting, speed change and load perturbations to evaluate the performance of the drive. The observed performance of the Series and Parallel hybrid controllers have demonstrated the ability of the proposed controllers to track the command faster than the prevalent PI controller for the similar conditions with lesser overshoot and better settling time. The simulation study has been conducted for evaluation of effectiveness of the proposed hybrid schemes for the PMBLDC drive.

It has also been observed that the Series hybrid controller minimize the possibilities of overshoot/ undershoot amidst transients, whereas, Parallel hybrid controller operate the drive so as to attain the steady state in minimum possible time, and both the controllers drive the motor in acceleration and deceleration mode without oscillations. The proposed hybrid scheme has the advantage of flexibility and modularity, wherein, they may be appended to the existing PI controller without much alteration in the hardware structure of the existing drive. The scheme in general may be applicable to other drives and can effectively work under nonlinearities and parametric changes in the motor while in operation.

TABLE VI. COMPARISON OF PERFORMANCE OF PI, FLC, SERIES HYBRID AND PARALLEL HYBRID CONTROLLERS

Type of Controller	Starting		Load Perturbation		Speed Reversal	
	OS(rpm)	ST(s)	US(rpm)	ST(s)	OS(rpm)	ST(s)
PI	1.55	0.8	1.15	0.25	1.15	0.74
FLC	0.03	0.508	2(OF)	-----	0.03	0.70
Series Hybrid	0.38(OF)	0.65	0.49	0.14	0.49	0.65
Parallel Hybrid	0.65	0.6	0.55	0.12	0.6	0.62

OS: Overshoot; US: Undershoot; ST: Settling time; OF: Offset

References

[1] ADi.Napoli, ALidozzi , L.Solero and T.Bogani "Synergetic Control of PMSM drives for high dynamic applications," in

Proc. Electrical Machines and Drivers,pp. 710-717,Dec.2005.

[2] "AN885" Microchip Technology Inc. Chandler, Arizona, USA.

K. Kim and R. C. Schaefer, "Tuning a PID controller for a digital excitation control system," IEEE Trans. Ind. Appl., vol. 41, no. 2, pp. 485-492,Mar./ Apr. 2005.

[3] C.C.Lee, "Fuzzy logic in control systems: Fuzzy logic controller -Part I, Part II," IEEE Trans. Syst. Man. Cybern, vo1.20, pp.404-435, 1990.

[4] Jong-Hwan Kim, Kwang-Choon Kim and Edwin K. P. Chong,"Fuzzy Precompensated PID Controllers", IEEE Tranc. Control Systems Tech.,

vol. 2, no.4, Dec. 1994.

[5] Ahmed Rubaai, Abdul R. Ofoli and Marcel 1. Castro-Sitiriche,"Design and Implementation of Parallel Fuzzy PID Controller for HighPerformance Brushless Motor Drives: An integrated Environment for Rapid Control Prototyping "IEEE Trans. On Ind. App. Vol. 44, no.4, July/Aug. 2008.

[6] Nordin Saad and Oyas Wahyunggoro, "Evaluations of Fuzzy-LogicBased Self Tuning PI Controller and Fuzzy-Scheduled PID Controller for DC Servomotor", in Proc. Information Tech. ,1TSim, August 2008.

[7] G. Chen,H.-X. Li, L. Zhang, and K.-Y. Cai, "An improved robust fuzzyPID controller with optimal fuzzy reasoning," IEEE Trans.Syst.. Man,Cybern. B, vol. 35, no. 6, pp. 1283-1294, Dec. 2006.

[8] A Hazzab, B. Mazari, K. Bousserhane, M. Kamli and M. Rahli, "Adaptive PI Controller using Fuzzy System Optimized by Genetic Algorithm for Induction Motor Control" in Proc. CIEP,October 16-18, 2006.

[9] B. Singh, B. P. Singh, and S. Dwivedi, "DSP based implementation of hybrid fuzzy PI speed controller for direct torque controlled permanent magnet synchronous motor drive," Int. J Emerging Electric Power .

[10] Jianhui Wong,Kein Huat Chua, Stella Morris and Yun Seng Lim, "Improved Performance of PMSM Speed Responses Using a Hybrid Fuzzy/ PI Controller" in Proc. PECon2010, pp.474-479,Nov'/Dec .

[11] Amit Vilas Sant and K. R. Rajagopal" PM Synchronous Motor Speed Control Using Hybrid Fuzzy-PI with Novel Switching Functions" IEEE Trans. Magnetics, vo1.45, no. I 0, pp.4672-4675, Oct. 2009.

[12] Ji Hua and Li Zhiyong, "Simulation of Sensorless Permanent Magnetic Brushless DC Motor Control System", in Proc. ICAL 2008, pp.2847- 2851, September.

[13] A H N Reddy, Bhim Singh and S S Murthy, "Hybrid Fuzzy Logic Proportional Plus Conventional Integral-Derivative Controller for Permanent Magnet Brushless DC Motor", in Proc. Industrial Tech., pp. 185-191, Jan 2000.

[14] K. Kim and R. C. Schaefer, "Tuning a PID controller for a digital excitation control system," IEEE Trans. Ind. Appl., vol. 41, no. 2, pp. 485-492, Mar./Apr. 2005.