I J C T A, 10(8), 2017, pp. 49-58
ISSN: 0974-5572

Intelligent Optimum Control of Brushless DC Motor

Murali Muniraj* and R. Arulmozhiyal**

ABSTRACT

This paper present intelligent control algorithm namely particle swarm optimization (PSO) of fuzzy PID controller for controlling brushless direct current (BLDC) motor based actuation system. The performance and reliability of control actuation system is improved owing efficient controller and switching techniques. PSO optimization technique determines the optimum fuzzy-PID controller parameters of for position and speed control of BLDC motor drive. The proposed technique improves step response characteristics and further reducing steady rise time, steady error and overshoot of control actuation system. The verification of proposed fuzzy-PID controller optimization with PSO algorithm carried in models of MATLAB-SIMULINK. Experimental results illustrate superiority of fuzzy-PID controller and its optimization technique PSO for control actuation system.

Index Terms: BLDC motor, fuzzy, PID, PSO, MATLAB.

1. INTRODUCTION

Spurred in advancement of power electronics leads to many modern control methods such as nonlinear optimal and self-adaptive control is been widely proposed in control of speed and position in brushless permanent magnet DC motor [1]. However, a major limitation in the approach is based on complex and theoretical a basic which is difficult to implement [2]. In automated process industries are generally complex to implement process of control algorithm and its necessary to process a intelligent techniques with conventional controller for simple and effective system design.

PID controller with integral and derivative actions operates efficiently on transient and steady-state response for sudden load changes conditions [3]. In advantages to simple the structure, tuning gains of PID controllers is relatively difficult and drawbacks to traditional system. Recently, the intelligence techniques have proposed in various controller design leads to improvement in overall motor drive performance of controller. An intelligent control technique imitates the experience of the intelligence as human knowledge expert to acquire improved performance in the controlled real time applications [4].

Fuzzy controller particularly suitable for various control drive applications with simple mathematical model due to its superiority and effective working leads to nonlinearity and precision. Hence, the Fuzzy is used as a self drive mechanism for various applications in actuation and automation engineering applications. It is widely adaptable and effective in many system applications [5]. Further fuzzy control reduces extra intelligent system and provides real-time processing compared with a classical PI, PD, or PID controllers. It is necessary to design a traditional and intelligent control approach in a single control to provide better performance of control drive. To tune fuzzy-PID gain parameters a neural based artificial technique Particle Swarm Optimization (PSO) is proposed [6].

Permanent magnet Brushless Direct Current motor (PMBLDC) has been widely used in many applications because a PMBLDC has some advantages over others such as speed torque charters tics, high

*,** Department of Electrical and Electronics Engineering, *Emails: muralimunraj@gmail.com, arulmozhiyal@sonatech.ac.in*

efficiency, and robustness. Permanent Magnet Brush Less Direct Current (PMBLDC) has less inertia suitable for various process industries and automation applications. Many working technologists have proposed a various advanced techniques in controlling and electronics commutation of PMBLDC. For an example of PID control, fuzzy control, fuzzy-PI control [7], fuzzy-PID [6], neural network control [8].

This paper shows a PSO based fuzzy PID controller design method for a PMBLDC. Initially, PID control is designed based on the common control parameters (P and I) and tuning of BLDC motor parameters based on knowledge transient performance is performed using gains are increased [9]. Fuzzy based error values and membership is forms and fine tuned using PSO algorithm. Initially PSO algorithm with fuzzy PID controller is designed in MATLAB-SIMULINK and verified its feasibility as per block diagram shown in fig.1. Experimental results screening the proposed intelligent control method will be capable of successfully applied to PMBLDC motor in real-time control under changing load torque variation.

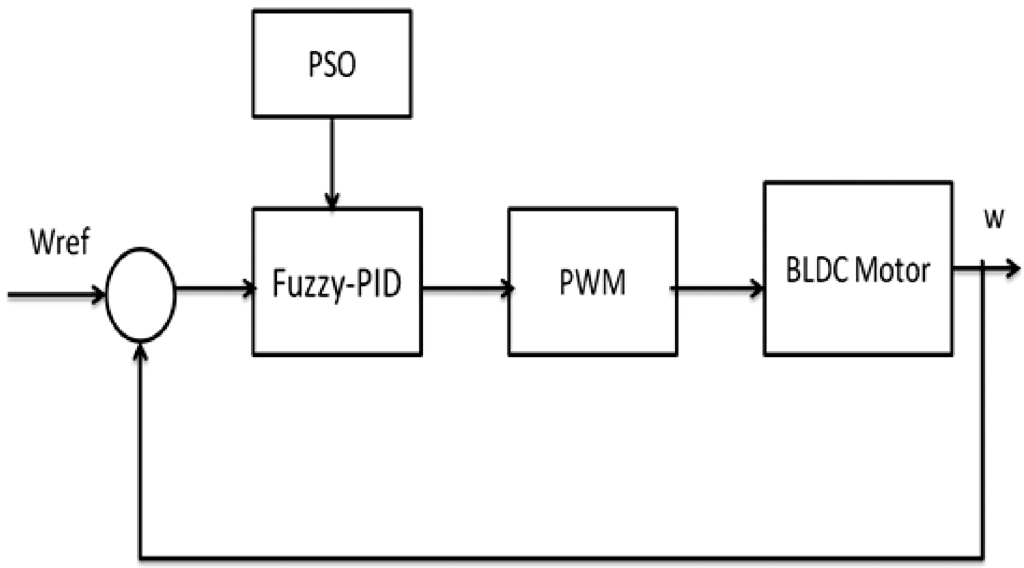

Figure 1: Block diagram for optimum PSO-fuzzy PID controller

2. MODELING OF FEEDBACK CONTROLLER

Feedback is the process of measuring the actual variable and reference variables using the information to change corresponding controlled variables.

2.1. PID controller

In preceding research, there has been performed combination of the PID position controller with nonlinear real time simulation model. Since the current motor driver is inherently nonlinear due to two level current output,

Conventional PID controller is considers current controllers in both speed and current controllers but their gains parameters K_p, K_i and K_d differ as per the desired speed and current magnitude effective ranges.

According to PID control law, the mathematical formulation of discrete controller is obtained by the eq.1. The control gain values are determined using Ziegler-Nichols method of tuning.

$$C(z) = K_p + K_i T \frac{z}{z-1} + \frac{K_d}{T}\frac{z-1}{z} \tag{1}$$

K_p-P-gain

K_i-I-gain

K_d- D-gain

T-Sampling time in seconds

2.2. Fuzzy-PID Controller

Fuzzy-PID controller is better performance oriented adaptation of PID and therefore is likely to replace the conventional PID controller. Fig. 2 shows combination of fuzzy PID where gains of controller is associated for control derivative and integral action in motor [10]. With the inputs like error and change of error in dimension are the inputs to the fuzzy-PID controller. The range of membership function used as unity ±1 with corresponding membership values, and hence it is required to tune the control variables to obtain necessary step responses before implementing fuzzy variables.

Here, magnitude current I_{dc}* is the output position control loop of BLDC motor according to which a gate pulse and its duty cycle is operated by controller. Fuzzy controller is degree is adjusted through normalization factor GE as error and normalization factor GCE for measurement of block. Output response of proposed fuzzy-PID controller signal is tuned in the course of response of de-normalization factor GU and its corresponding response to de-normalization factor GCU. This tuned factor is significant response through modeling of the fuzzy PID controller and which are to be operated simulators for different operating changing loads.

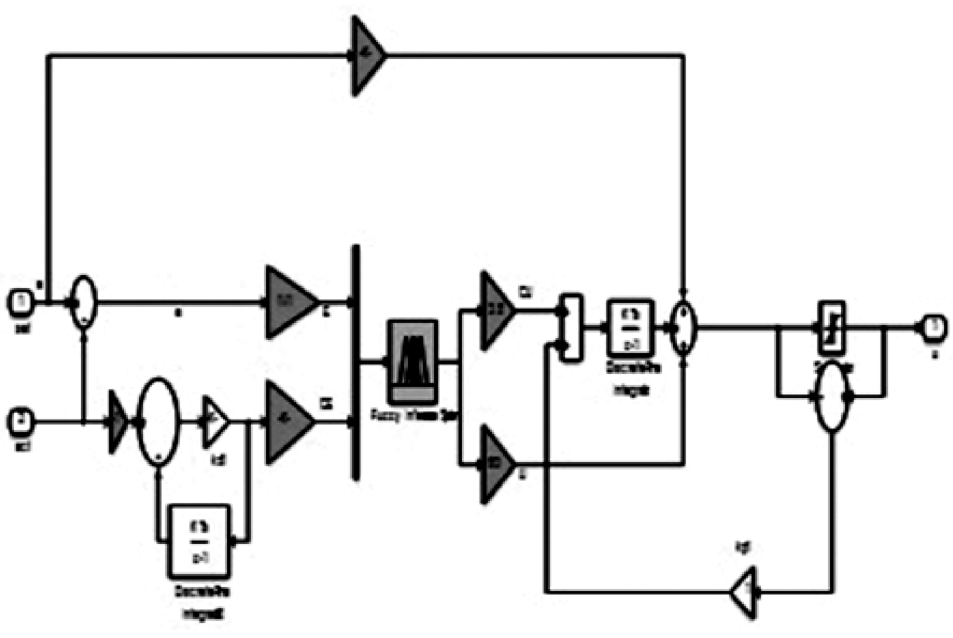

Figure 2: Fuzzy PID controller

The tuned factor is consequent from the gain information of PID controller as relates in equation (2)-(5). A feed forward path is offered to make certain the operational of proportional and derivative actions during fuzzy PID controller and step response is in linear. Anti-windup is a features in conventional controller which integrated to control gains of saturation level for BLDC motor step response signal, to formulate the quick response of the fuzzy PID controller a fine tune gains and its normalization factors is needed.

$$CE = \frac{1}{\max.\text{error}} \tag{2}$$

$$GCE = GE * \left(K_p - \sqrt{K_p^2 - 4K_iK_d}\right)\frac{K_i}{2} \tag{3}$$

$$GU = \frac{K_d}{GCE} \tag{4}$$

$$GCU = \frac{K_i}{GE} \tag{5}$$

GE - Normalization error factor

GCE - Change normalization factor

GU - De-normalization factor

GCU - response of change in de-normalization factor

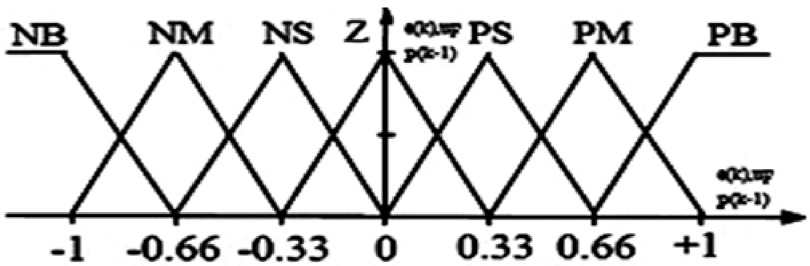

Figure 3: Membership functions of proposed fuzzy-PID controller

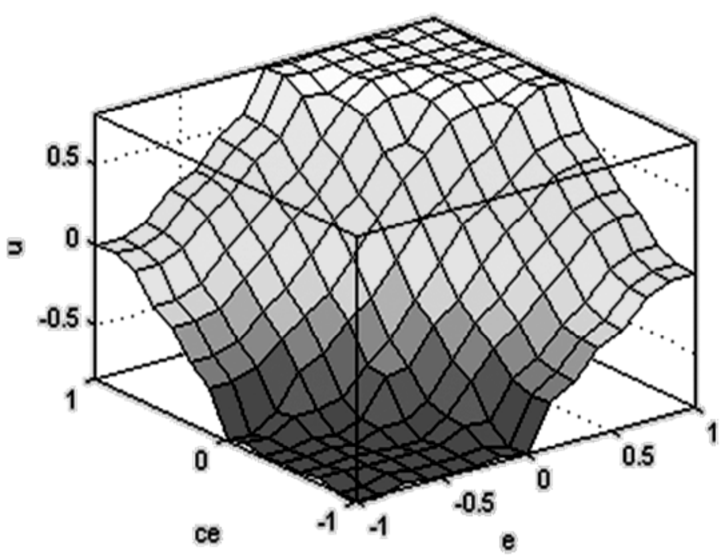

Figure 4: Surface viewer of PSO-Fuzzy PID controller for BLDC drive

Corresponding input and output system variables are charted using membership functions to implement a fuzzy action for proposed drive system. The membership obtained a triangular and neighbor sets of a membership value is between (+1,-1) as shown in figure 3. Mamdani type inference is proposed as a inference engine and center of gravity method for defuzzification of fuzzy sets, Further the linguistic variables is subdivided into three groups and they are nl – large in negative, ns – small in negative, z- zero, ps- positive small, and pl - positive large as shown in Table I and its surface viewer is shown in fig. 4 represents stability of system [11].

2.3. PSO algorithm

To investigate for a optimal fuzzy-PID controller, PSO algorithm is proposed. Here the main working principle is particles, where it is symbol of fish in a training block. Particles are arbitrarily initialized in a multidimensional given space. During which the particles update its swiftness and point based on its own experience for the whole population [12]. Proposed system optimizes certain fitness function of fuzzy variables and membership functions known its preeminent significance (Sbest) of its multidimensional abc position. This information is resemblance of artificial experiences of each particle and corresponding membership functions. Moreover, algorithm knows the absolute value so far in the group (Tbest) among Sbests[13].

This information is particle and its knowledge was however the other particles around them have performed satisfactorily to achieve desired response. The preeminent previous position of particle and corresponding position is represented in equation as below:

$$\text{Sbest} = (\text{Sbest1}, \text{Sbest2}, ..., \text{Sbestn}) \tag{6}$$

The weighting function of swarn particle is usually proposed as:

$$V\text{i} = w\, x\, V_i + C_1 \,\text{rand}_1\, X\, (S_{\text{besti}} - si) + C_2 \,\text{rand}_2 \tag{7}$$

the current positions (a, b, c), the current velocities (va, vb, vc)

$$\text{W} = \text{w}_{\text{max}} - \frac{w\text{max} - w\text{min}}{\text{iter max}} X \text{ iter} \tag{8}$$

where: wmax: weight at final state, wmin: weight at initial state, itermax: iteration at maximum number, iter: iteration at current number. Using the above equation, a certain speed, which gradually gets close to sbest and tbest is calculated and using flow chart of PSO-PID controller is shown in Fig. 5 will determine the best Ki, Kd and Kp values.

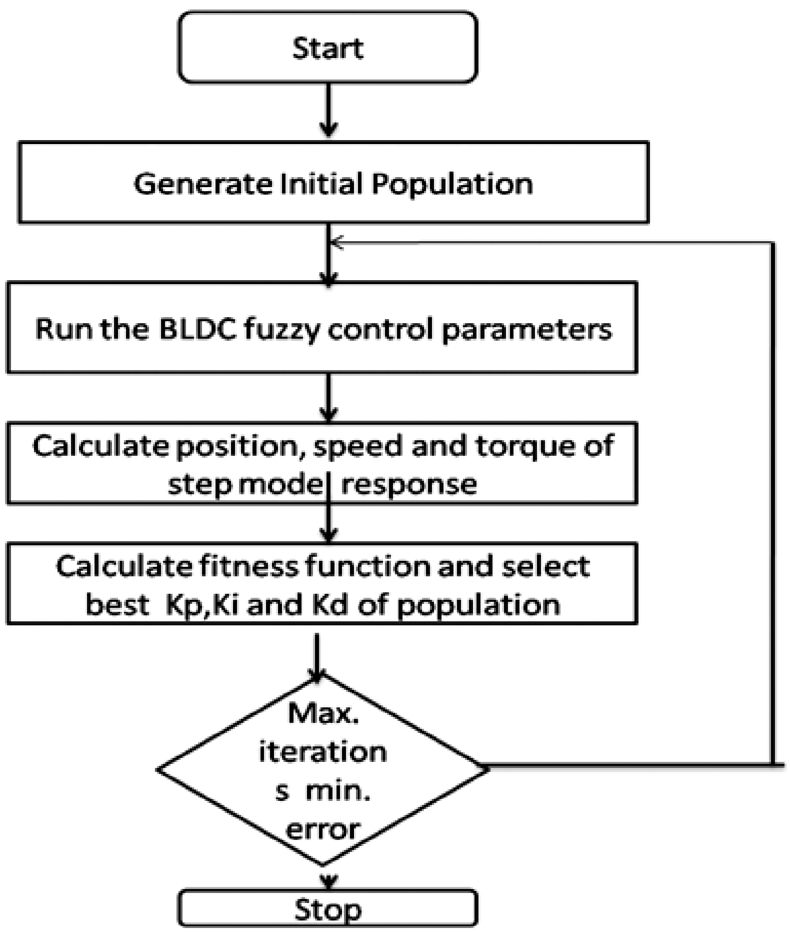

Figure 5: PSO algorithm for fuzzy-PID controller

3. BLDC MOTOR CONTROLLER DRIVE

BLDC motor is with stator and rotor as construction in which stator is made up of winding coils and the rotor is the permanent magnet. The position of rotor is sensed using Hall position sensor detects the rotor position and commutates with power processing electronic unit [14]. BLDC motors parameter equation is (9-12) are given as

$$Va = Ra\ Ia + La\ dia/dt + Mac\ dib/dt + Mbc\ dic/dt + ea \tag{9}$$

$$e_a = f_a(\theta)\ Ke\ \omega \tag{10}$$

$$Te = Tl - Co - Cv \tag{11}$$

$$P = T\,e * \ \omega \tag{12}$$

Where, ϖ is an angular velocity of the motor in radians per second, P- Total power output. *Ra-b*: Resistance per phase, equal to all phases, *La-b*: Inductance per phase equal to all phases. *Mac, Mbc*: Mutual inductance. For BLDC motor net effect value will be Zero. *ia, ib, i c*: Stator current/phase. Va, Vb, Vc: are the phase voltage of the winding. The motor is simulated with data sheets as in table 2.

Table 2
Motor Specifications

Motor Phase Voltage	30V dc
Motor speed	11300 rpm
Motor Torque	0.3 Nm
Poles number	2
Voltage constant (Ke)	24 V/Krpm
Torque constant (Kt)	0.49 Nm/A
Motor ph resistance	2.07 Ω
Motor ph inductance	6.57 mH
Moment of inertia (Jm) of Rotor	1.8 Kg cm^2

4. SIMULATION OF PROPOSED ALGORITHM

Simulation is carried out for the discrete step time in MATLAB-SIMULINK. In this model, BLDC motor fed DC power supply of inverter supplied through three phase AC voltage source. The speed and position

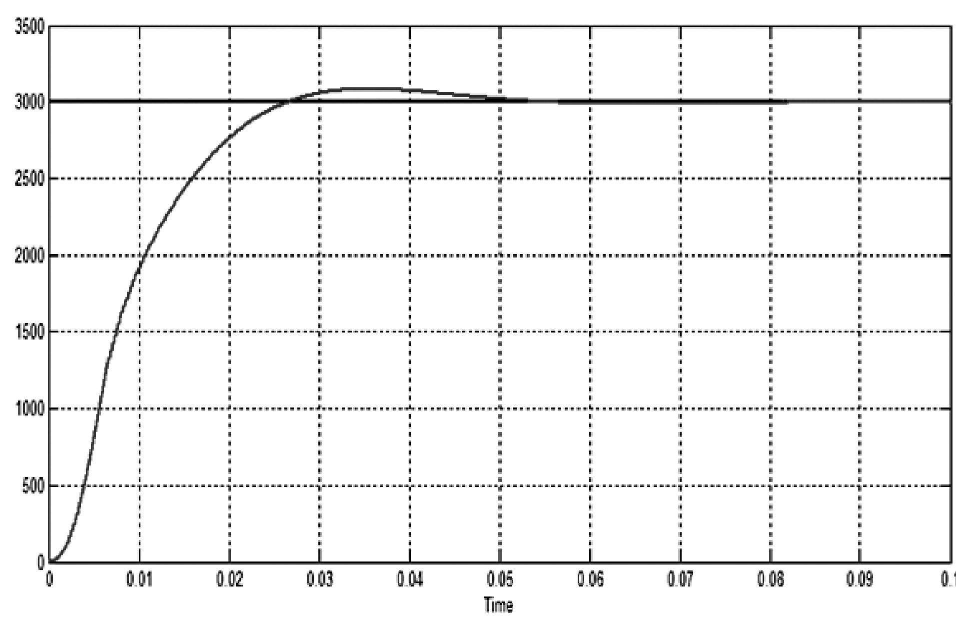

Figure 6: Step response of the closed loop system with PSO-PID controller

information retrieved using decoder circuit and hall sensor information. The output of position, speed and stator current of BLDC motor parameters is observed.

To evaluate the system performance a series of measurements is validated for fuzzy-PID and PSO based fuzzy-PID controller. Simulation is performed and responses are drawn. Fig. 6 shown step responses for PSO based fuzzy-PID controller of closed loop system. Fig. 7 & Fig. 8 effect of torque variation for 1 N.m and no load conditions is observed. It is observed that torque ripples of BLDC motor is reduced in PSO based fuzzy-PID controller.

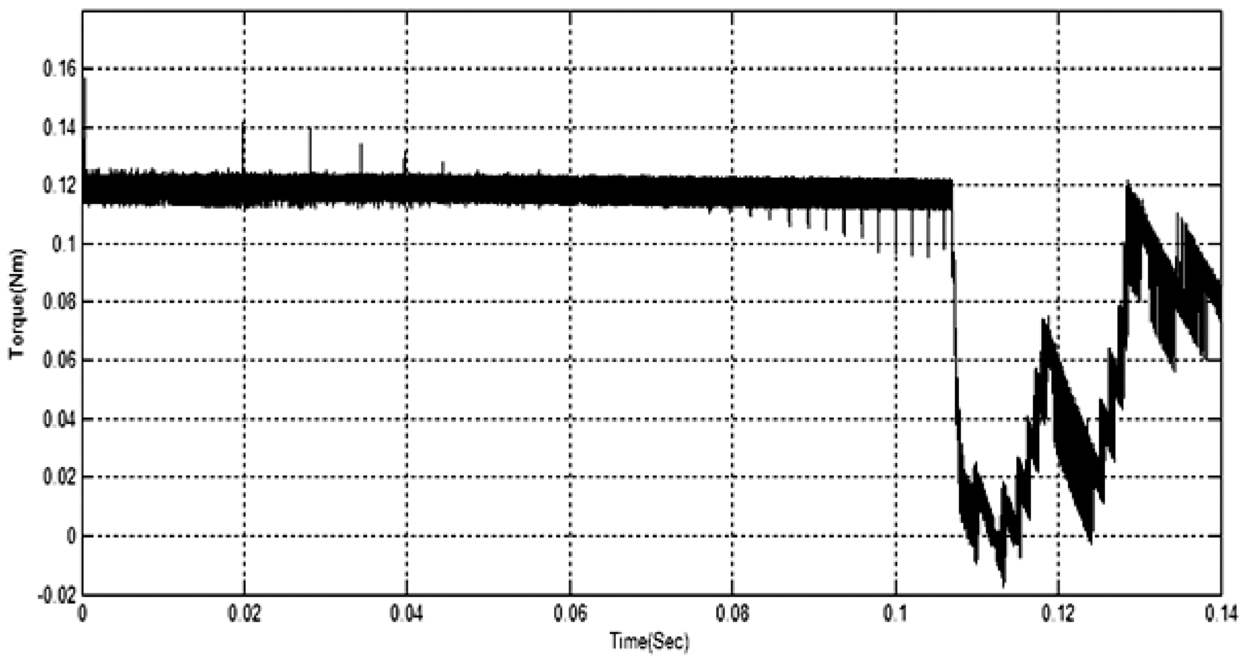

Figure 7: Torque response for 10000 rpm at no-load conditions

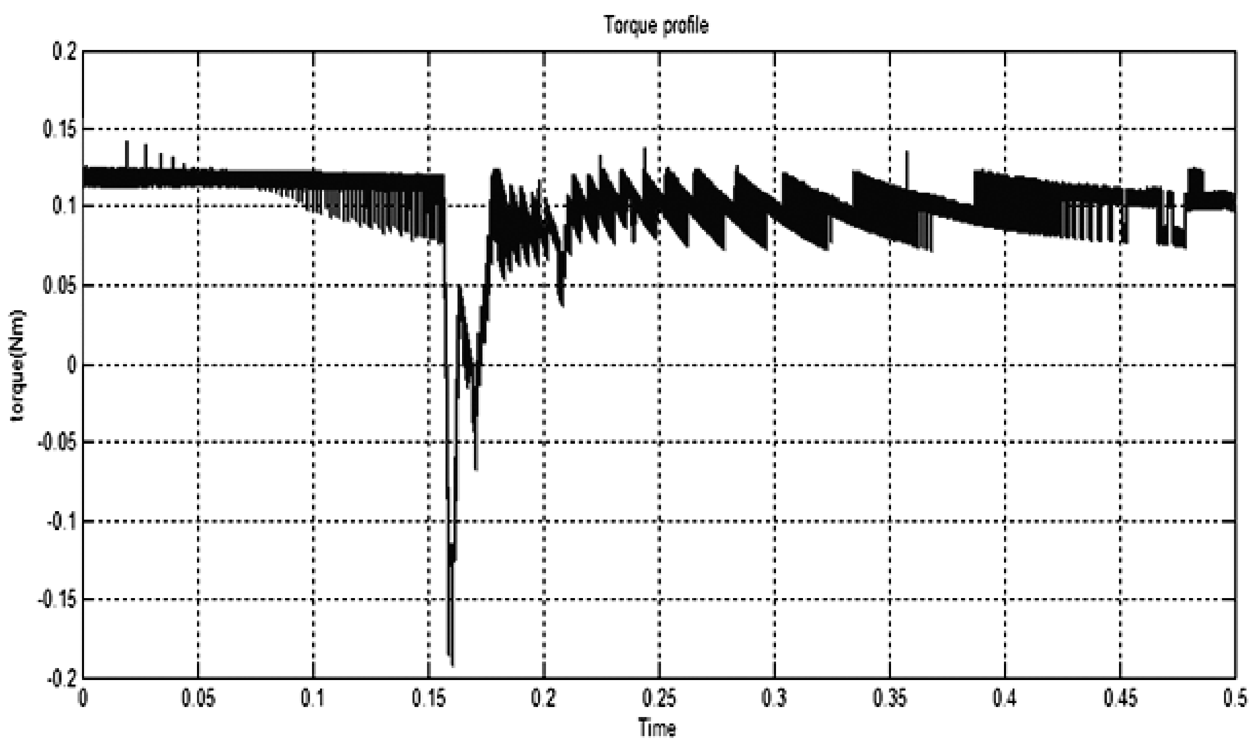

Figure 8: Torque response for 10000 rpm at 1 N-m load conditions

Fig. 9 & Fig. 10 show the speed and position counts for 4100 at no-loaded condition. The settling time and steady state error is measured for position and speed of BLDC motor with reduced error 2.5% with fuzzy-PID controller and PSO- based fuzzy-PID controller as tabulated in III.

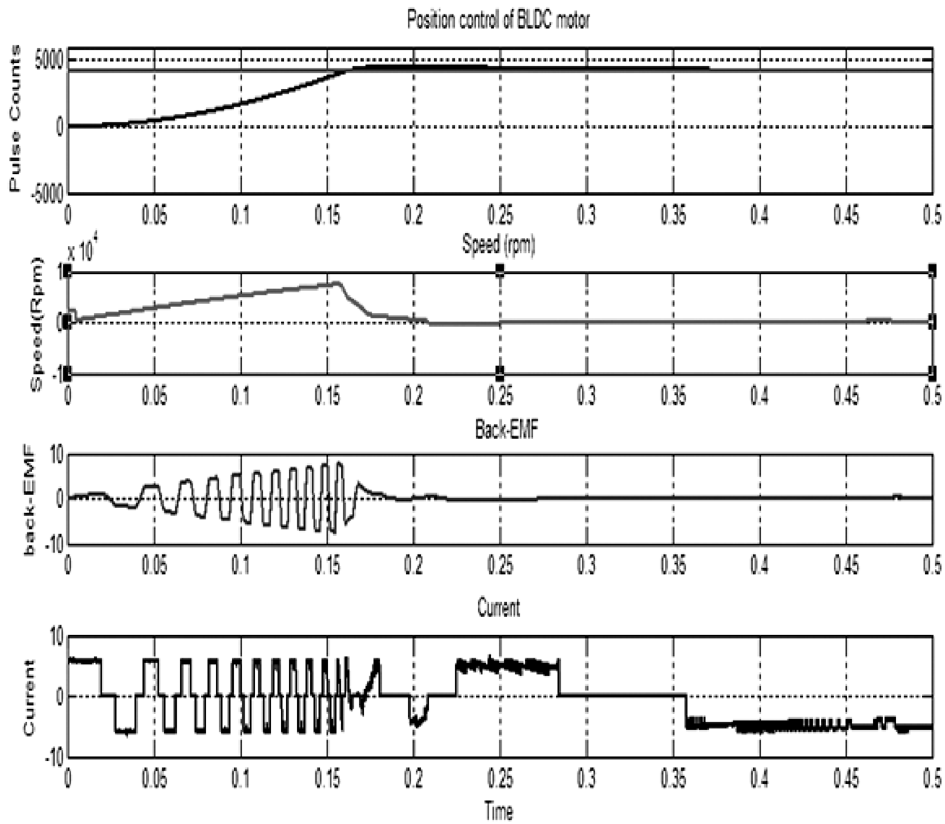

Figure 9: BLDC motor response for fuzzy-PID controller

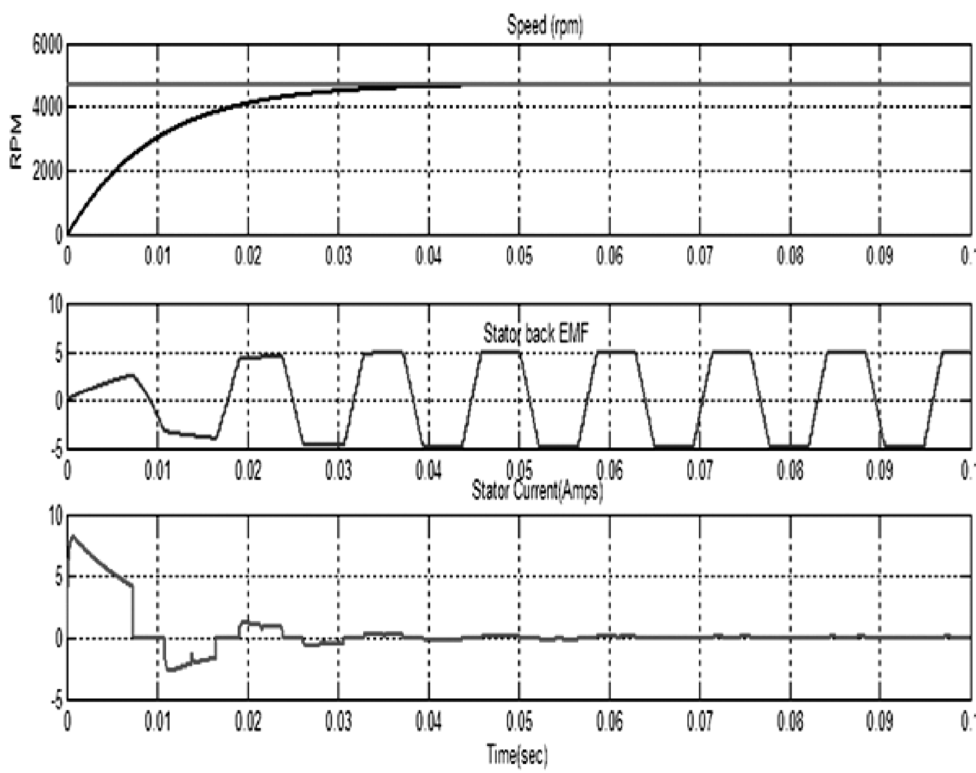

Figure 10: BLDC motor response for PSO based fuzzy-PID controller

Fig. 11 & Fig 12 show the sinusoidal input response for fuzzy-PID and PSO based fuzzy PID controller. The value of steady error in the fuzzy-PID controller response is 2.5% and 0.8% for PSO based fuzzy-PID controller. From the observation, it is noticed that fuzzy-PID controller at the position counts settles at 0.5 sec. PSO based fuzzy-PID controller settles at 0.125 sec for forward and reverse conditions.

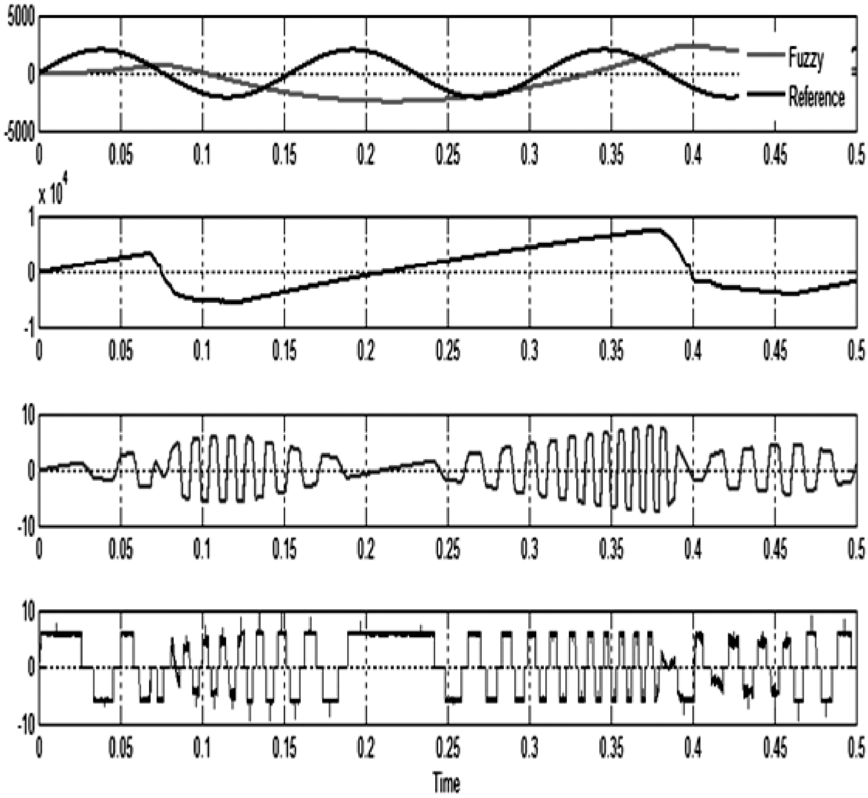

Figure 11: BLDC motor response for fuzzy-PID controller

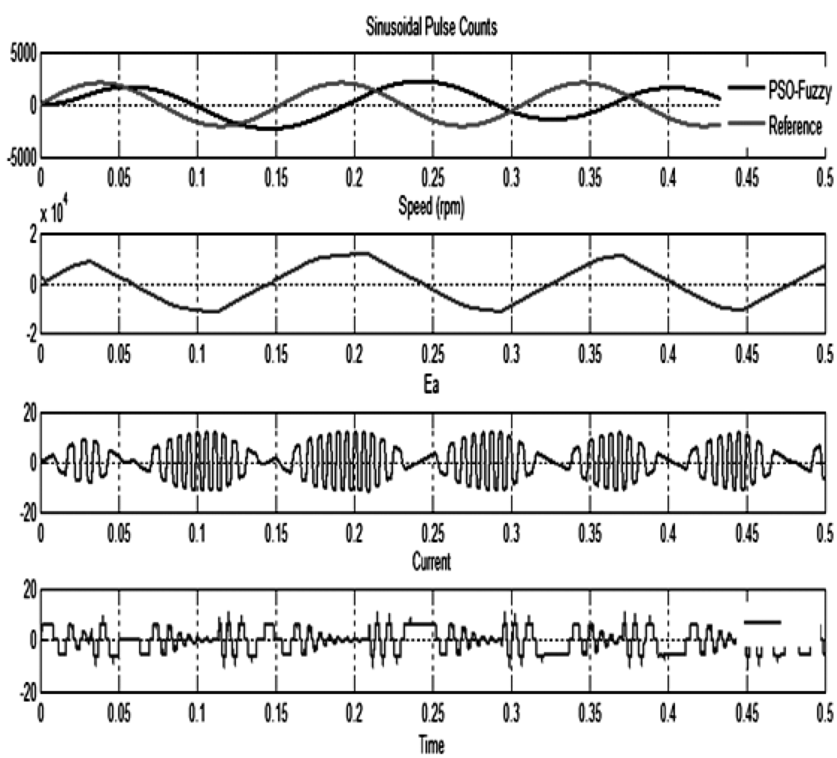

Figure 12: BLDC motor response for PSO based fuzzy-PID controller

Table 3
Performance of BLDC motor drive

Controller	*Fuzzy PID*				*PSO based Fuzzy PID*			
Parameter Set Position	*Tr (sec)*	*Mp (%)*	*Ts (sec)*	*± Error (%)*	*Tr (sec)*	*Mp (%)*	*Ts (sec)*	*±Error (%)*
Without load	0.12	1.02	0.25	5.26	0.04	0.16	0.52	0.66
With 1 Nm load	0.55	3.76	1.04	10.45	0.0892	0.2.9	0.145	1.01

5. CONCLUSION

In this paper, fuzzy PID controllers with high gain self-tuning mechanism by PSO algorithm is developed and experienced experimentally for the BLDC motor drive system. PSO based tuning gains will simplify design and corresponding program complexity of the fuzzy-PID controller and further reducing fuzzy sets parameters with improvement in system performance and stability. The proposed system is implemented in MATLAB-SIMULINK and results obtained using BLDC motor drive efficient gain parameter values Ki,Kp and Kd of fuzzy PID controller. Proposed PSO technique improved the dynamic performance of BLDC motor. With the experimental analysis in each results states the proposed scheme is outperforms the traditional controller.

REFERENCES

[1] S. Skoczowski, S. Domek, K. Pietrusewicz, and B. Plate, “A Method for Improving the Robustness of PID Control,” IEEE Trans. Ind.Electron, vol. 52, no. 6, pp. 1669-1676, 2005.

[2] V. Tipsuwanporn, W. Piyarat, C. Tarasantisuk, “Identification and control of brushless DC motor using on-line trained artificial neural networks”, in: Proceedings of Power Conversion Conference(3) Apr., pp. 1290-1294, Osaka, 2002.

[3] 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. 485–492,2005.

[4] M. J. Castro-Sitiriche, A. Rubaai, M. J. Castro-Sitiriche, and A. Ofoli, “Design and implementation of parallel fuzzy-PID controller for high performance brushless motor drives: An integrated environment for rapid control prototyping”. *IEEE Trans. Ind. Appl.*, vol. 44, no. 4, pp. 1090–1098,2008.

[5] H.-X. Li, L. Zhang, K.-Y. Cai, and G. Chen, “An improved robust fuzzy- PID controller with optimal fuzzy reasoning”, *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 35, no. 6, pp. 1283–1294, 2006.

[6] Mongkol Konghirum, “Automatic Offset Calibration of Quadrature Encoder Pulse Sensor for Vector Controlled Drive of Permanent Magnet Synchronous Motor”. *TENCON, IEEE Region* 10, pp. 1-5, 2005.

[7] Nasri M, Nezamabadi-pour H, Maghfoori M., “A PSO—based optimum design of PID controller for a linear brushless DC motor”, World Acad Sci, Eng Technol (2): 211–5, 2007.

[8] L. Gao, H. Gao, C. Zhou, “Particle swarm optimization based algorithm for machining parameter optimization”, in: Proceedings of the 5th World Congress on Intelligent Control and Automation (4) June 15-19, pp. 2867-2871, 2004.

[9] H.E.A. Ibrahim, F.N. Hassan, Anas O. Shomer, “Optimal PID control of a brushless DC motor using PSO and BF techniques”, World Ain Shams Engineering Journal, Vol. 5, 391–398, 2014.

[10] J. Jantzen, “Tuning of Fuzzy PID Controllers,” Technical Report, University of Denmark, pp. 1-22, Apr. 1999.

[11] L. V. Hongli, D. Peiyong, C. Wenjian, and J. Lei, “Direct conversion of PID controller to fuzzy controller method for robustness,” in *IEEE Conference on Industrial Electronics and Applications*, pp. 790-794, 2008.

[12] M. Hu, J. Qiu, and C. Shi, “A comparative analysis of fuzzy PI and PI speed control in Brushless DC motor based on dSPACE,” in *International Conference on Electrical Machines and Systems*, pp. 1-5, 2011.

[13] Ker-Wei, Yu, Shang-Chang Hu, “An application of AC servo motor by using particle swarm optimization based sliding mode controller”, in: Proceedings of IEEE Conference on Systems, Man and Cybernetics (5), pp. 4146-4150, 8-11, October 2006.

[14] T. Kenjo and S. Nagamori, *Permanent Magnet Brushless DC Motors*, Oxford Science Publisher, 1985.