www.s2is.org
International Journal on Smart Sensing and Intelligent Systems
ISSN 1178-5608

IMPERIALIST COMPETITIVE ALGORITHM-BASED FUZZY PID CONTROL METHODOLOGY FOR SPEED TRACKING ENHANCEMENT OF STEPPER MOTOR

Amir Mehdi Yazdani, Ahmadreza Ahmadi, Salinda Buyamin, Mohd Fua'ad Rahmat, Farshad Davoudifar
and Herlina Abd Rahim

Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor
Malaysia
Emails: yazdani@fkegraduate.utm.my, ar.ahamadi62@gmail.com, salinda@fke.utm.my,
fuaad@fke.utm.my

Submitted: June 20, 2012 ***Accepted: Aug. 1, 2012*** ***Published: Sep. 1, 2012***

ABSTRACT- Precise control of the stepper motor has always been a topic of interest and also a challenging issue among control engineering researchers due to the nonlinear nature of the motor dynamic. Abrupt influences of the uncertainties on the model's dynamic and control performance, on the other hand, must be taken into account for providing a control methodology including the characteristics of adaption and flexibility. Lack of these items in most of the classic control approaches results in degradation of the control action. The main purpose of this paper is to provide an intelligent approach for improving the functionality of conventional PID controller in the problem of trajectory tracking in permanent magnet stepper motor (PMSM). Combination of a meta-heuristic algorithm called imperialist competitive algorithm (ICA) and fuzzy logic is employed for online tuning of PID controller. This, consequently, establishes an intelligent structure, fuzzy-PID controller (FPID), which is more flexible and accurate both in certain and uncertain situations. Using a systematic approach in designing the optimal fuzzy structure based on the ICA is our contribution here which leads to better performance of PMSM. Comparing the results of simulations, done in Matlab Simulink, between the suggested control strategy and performance of the PID, expresses the remarkable capability of FPID in overcoming the complexity of control of the nonlinear and uncertain systems.

Index terms: PMSM, trajectory tracking, ICA, FPID controller, perturbation

I. INTRODUCTION

Excellent attributes of stepper motors such as high accuracy, quick response, small size and mechanical structure make them very useful in robotic, aerospace, and numerical machine applications. Stepper motors are nonlinear incremental motion actuators compatible with digital electronic circuits. In simple point-to-point position applications, they produce an acceptable response based on the open loop control. In this configuration, stepper motor receives a rectangular train of pulse, and then, rotates its shaft without using any information on the motor shaft position or speed [1]. Undoubtedly, open loop configuration cannot guarantee functionality of the stepper motor where it is susceptible to internal and external variations. In other words, feedback is an essential part to obtain the information on losing step or when oscillation occurs in stepper motor. Closed loop configuration was suggested for upgrading the accuracy of trajectory control by decreasing the sensitivity in the presence of variations [2,3]. The linear and nonlinear algorithms were developed by the advancements in power electronic and data processing. Feedback linearizing technique, in which the dynamic of stepper motor is linearized around its operating point, offered superior results in comparison with open loop configuration [4]. However, this scheme did not present the ability of adaption for different operating points. As a matter of fact, in most of the industrial environments, presence of uncertainties in the form of external and internal disturbances is inevitable. Uncertainties in the physical parameters of a system may be introduced from discrepancies between the manufacturer data and the actual system; furthermore, load torque disturbance and also different kinds of noises, suddenly exerted on the model, are categorized in the class of the external ones. Mainly, in industrial applications, the plant to be controlled is often unknown in consequence of its nonlinearity and its characteristics may change due to aging, wear and tear, etc. Although control strategies based on the knowledge of the dynamic model of the systems, known as model-based controllers, can present some advantages in practical applications, however, the performance of the system is highly dependent upon the accurate representation of the model's dynamic, which includes precise knowledge of the inertial parameters. In practice, obtaining such a model is a challenging task which involves modeling physical processes that are not well understood or difficult to model, such as friction and backlash. Therefore, assumptions concerning these effects are often made to simplify the modeling process, leading to inaccuracies in the model. Changes to operating conditions can also cause the structure of the system model to change, thus resulting in degraded performance [5].

The above mentioned statements show that the classic types of controllers, tuned for a pre-specific operating point, do not have enough flexibility to adapt themselves when the system is undertaking the variations on its dynamic. In recent decades, artificial intelligence (AI) has attracted a large group of researchers who has been trying to find new alternatives for solving complex problems. Fuzzy logic, definitely, is considered as one of the most prominent AI approaches. It mimics the human way of thinking and decision-making. Fuzzy logic controller emulates the behavior of the experts in controlling of the system. Not needing the precise mathematical modeling is a remarkable merit that makes fuzzy controller more flexible in dealing with complex nonlinear problems. There are several attempts in applying fuzzy logic in controlling various electrical drives [6]. Famously enough, fuzzy logic can additionally be applied to the rigid structure of conventional controllers to compensate their deficiencies and improve their performance by online tuning of their gains. For instance, PID gain scheduling based on the fuzzy logic controller has shown an acceptable functionality in the state of the art [7,8]. Even though fuzzy logic offers a simple computation for nonlinear applications, however, lack of systematic approaches in designing of the membership functions and arranging the inference rules is still a challenging issue. Having been more efficient to find optimum solutions in complicated problems based on their heuristic search constructions, evolutionary algorithms such as GA, PSO and ICA are of the powerful techniques in designing optimum fuzzy structures as well. In this paper, ICA is utilized for optimum design of the membership functions and scaling factors so that the proposed FPID can provide more accurate and acceptable response with regarding any arbitrary reference signal of PMSM. In other words, the main objective of this study is to provide an intelligent strategy based on fuzzy logic and ICA to improve the deficiencies of PID tracking performance. Functionality of FPID is investigated on certain and uncertain condition. Mechanical configuration changes, such as variations of load inertia and also load torque disturbance, are applied on the system to examine the robustness property of FPID. The achieved results are compared with those obtained based on the PID. The results are provided by the simulation of PMSM dynamic model and aforementioned controllers in Matlab Simulink.

II. MATHEMATICAL MODELING OF PMSM

In this section, a physical modeling approach is used to describe the dynamic behavior of the PMSM in the form of a set of equations. Fundamental of physical modeling is based on the division of the system into subsystems with comprehensible properties. This is a general approach which results in the construction of mathematical model of the systems.

Basically, the model of PMSM comprises two parts; an electrical and a mechanical part. The structure of the dynamic model is nonlinear originally. Moreover, there are some physical parameters in the model that their values vary with the elapsing of the time. These two directly affect the control objective and make it difficult. Figure 1 depicts the outer and cutaway view of two-phase PMSM. It consists of two phases A and B in the stator. The rotor has (2Nr) magnetic poles, while the stator has a set of identical poles and windings equally arranged at intervals (λ) [9,10]. In order to constitute a state space representation, the state variables of the model are defined as below:

$$X=[i_a i_b \omega \theta]^T \quad (1)$$

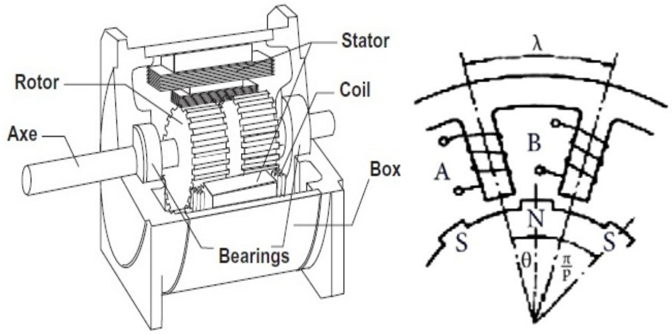


Figure 1. Schematic of two-phase PMSM

Where, θ represents the angular position of the rotor, ω is angular velocity of the rotor, i_a represents current in winding A and i_b is current in winding B. Then, the state space model of the system can be written as shown in equation 2 [7,10,11].

$$\begin{aligned}
\frac{di_a}{dt} &= \frac{1}{L}(V_a - Ri_a + K_m \omega \sin p\theta) \\
\frac{di_b}{dt} &= \frac{1}{L}(V_b - Ri_b + K_m \omega \cos p\theta) \qquad (2) \\
\frac{d\omega}{dt} &= \frac{k_m}{J}(-i_a \sin p\theta + i_b \cos p\theta) - \frac{F}{J}\omega - \frac{T_L}{J} \\
\frac{d\theta}{dt} &= \omega
\end{aligned}$$

Where, V_a and V_b are voltages of phase A and B, j is inertia of the motor, F is viscous friction coefficient, K_m is motor torque constant, R is resistance of the phase winding , L is inductance of the phase winding, P is number of rotor teeth, and finally, T_L indicates load torque.

DQ transformation converts the set of equation into a new frame which is called DQ model. It transforms vectors (V) and (i) which are carried in the fixed stator frame (a, b) into vectors carried in a frame (d, q) that rotates along the fictitious excitation vector [7,10,11]. Therefore, the phase voltages and currents are transformed in DQ frame based on equations 3 and 4.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(p\theta) & \sin(p\theta) \\ -\sin(p\theta) & \cos(p\theta) \end{bmatrix} \begin{bmatrix} i_a \\ i_b \end{bmatrix} \qquad (3)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos(p\theta) & \sin(p\theta) \\ -\sin(p\theta) & \cos(p\theta) \end{bmatrix} \begin{bmatrix} V_a \\ V_b \end{bmatrix} \qquad (4)$$

Consequently, a new set of state equations is appeared in equation 5.

$$\frac{di_d}{dt} = -\frac{R}{L}i_d + p\omega i_q + \frac{V_d}{L}$$

$$\frac{di_q}{dt} = -\frac{R}{L}i_q - p\omega i_d - \frac{K_m}{L}\omega + \frac{V_q}{L} \qquad (5)$$

$$\frac{d\omega}{dt} = \frac{K_m}{J}i_q - \frac{F}{J}\omega - \frac{T_L}{J}$$

$$\frac{d\theta}{dt} = \omega$$

III. CONTROLLER DESIGN STRATEGY

In the first step, the recommended PID controller based on the dynamic model of PMSM, called static PID, is introduced. It generates two control signals (V_d and V_q), depicted in figure 2, under normal and static system performance described in equation 6 [10].

$$V_d = -pL\omega i_a - k_4(i_d - i_{dr}) - k_5\int_0^t [i_d(\tau) - i_{dr}(\tau)]dr$$

$$V_q = K_m\omega - k_4(i_q - i_{qr}) - k_5\int_0^t [i_q(\tau) - i_{qr}(\tau)]d\tau \qquad (6)$$

With i_{dr} = 0

$$i_{qr} = -\frac{J}{K_m}\{k_1(\theta - \theta_r) + k_2\int_0^t [\theta(\tau) - \theta_r(\tau)]d\tau + k_3(\omega - \omega_r)\}$$

Where ω_r and θ_r denote the reference angular speed and displacement, ω and θ express the actual angular speed and displacement, i_{dr} and i_{qr} are the reference current in rotating set of (d,q) and finally i_d and i_q represent the actual current in rotating set of (d,q) respectively. In addition, k_1, k_2, k_3 are introduced as proportional, integral and derivative gains correspondingly [10]. The values of the related gains are given in Table 1.

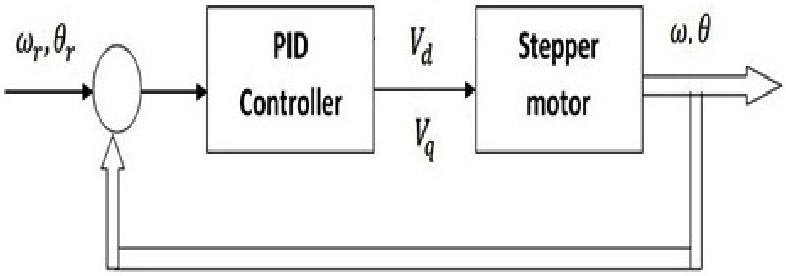


Figure 2. Closed loop block diagram with static PID controller

Table1. Parameters of the system and static PID controller

PMSM parameters	**Static PID controller parameters**
R Resistance of the phase winding (Ohm) 3	k_1 Proportional gain 80000
L Inductance of the phase winding (Henry) 0.0006	k_2 Integral gain 65*k_1
J Inertia of the motor ($Kg \cdot m^2$) 0.01	k_3 Derivative gain 500
K_m Motor torque constant (Nm/rad) 2	k_4 Gain L/T
F Viscous friction coefficient (Nms/rad) 0.01	k_5 Gain R/T
P Number magnetic poles 6	T Time constant (sec) 0.0005

In the second step, proposed FPID is presented. Designation is due to the fact that three fuzzy logic controllers - for online tuning of the gains k_1, k_2 and k_3- are assigned to generate i_{qr} which directly affects the control force as mentioned in (6). In other words, each of the proposed gains is modeled based on the separate fuzzy structure in which position error (PE) and speed error (SE) are antecedents and variations of the gain is consequent.

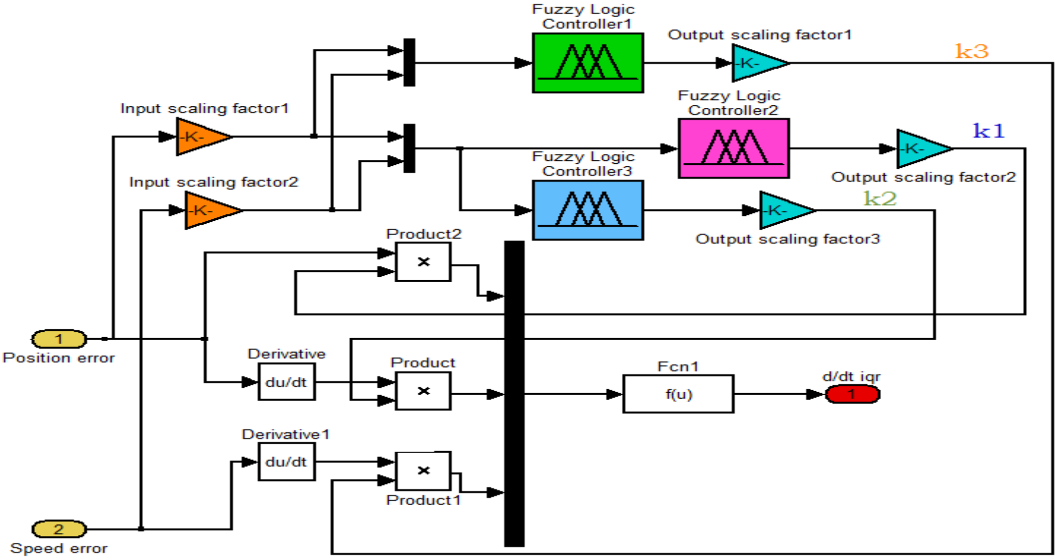
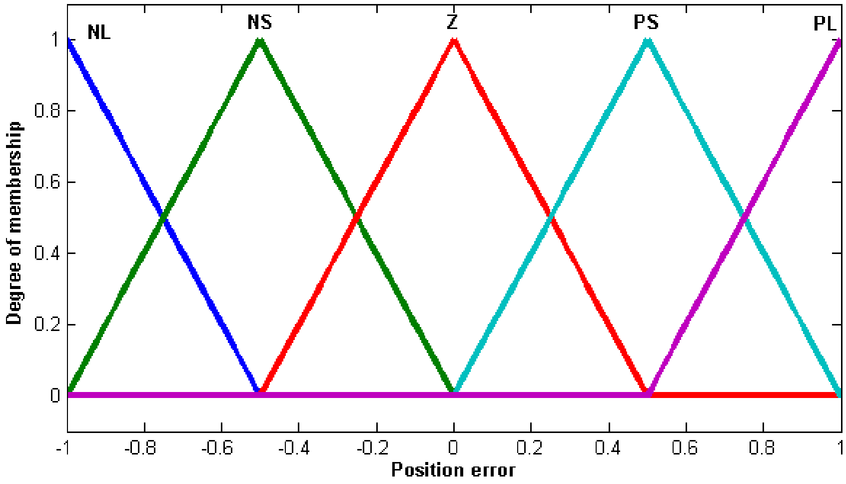


Figure 3. Simulink block diagram of the proposed FPID

Triangular membership functions are used for the inputs of all three fuzzy logic controllers and also for the output of the proportional gain. Consequent of the integral and derivative gain comprise Gaussian membership functions in order to get smoother response. Variations of the PE and SE are normalized in the interval of [-1 1] and then membership functions are defined in this interval. This procedure is, also, done for the consequents ,considering the fact that changes of the membership functions occur in normalized interval of [0 1].



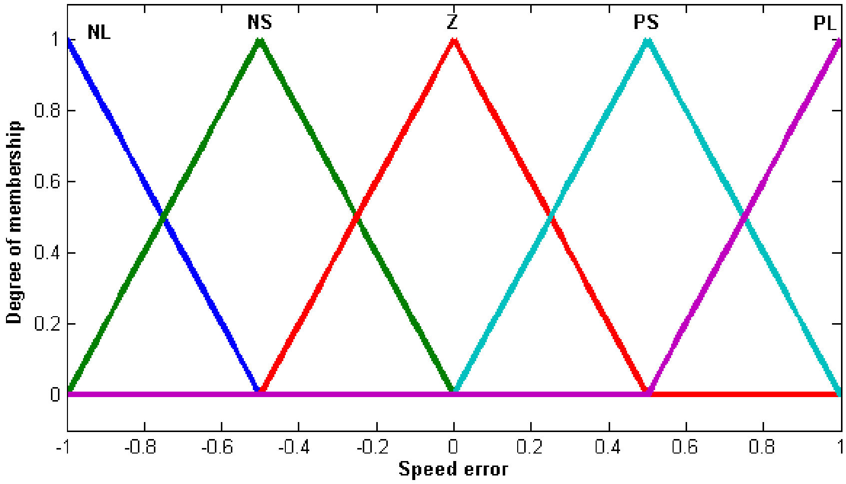
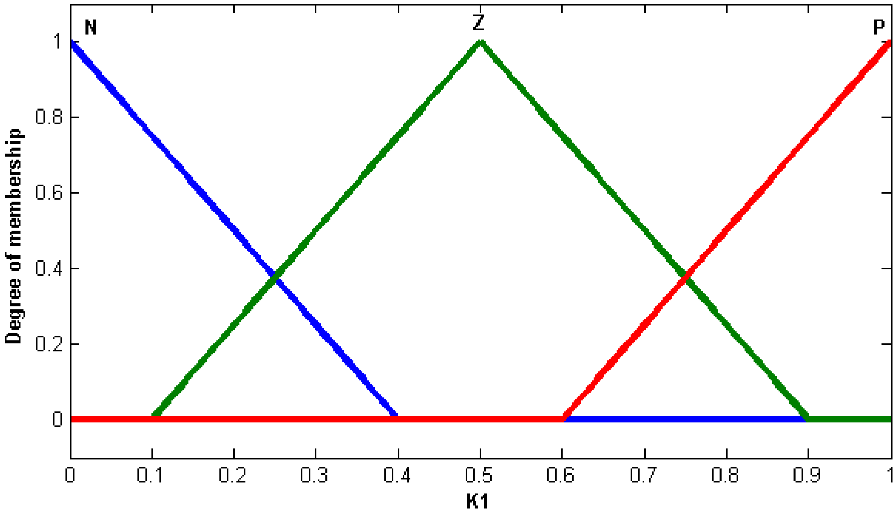


Figure 4. Preliminary membership functions for the antecedents of the FPID



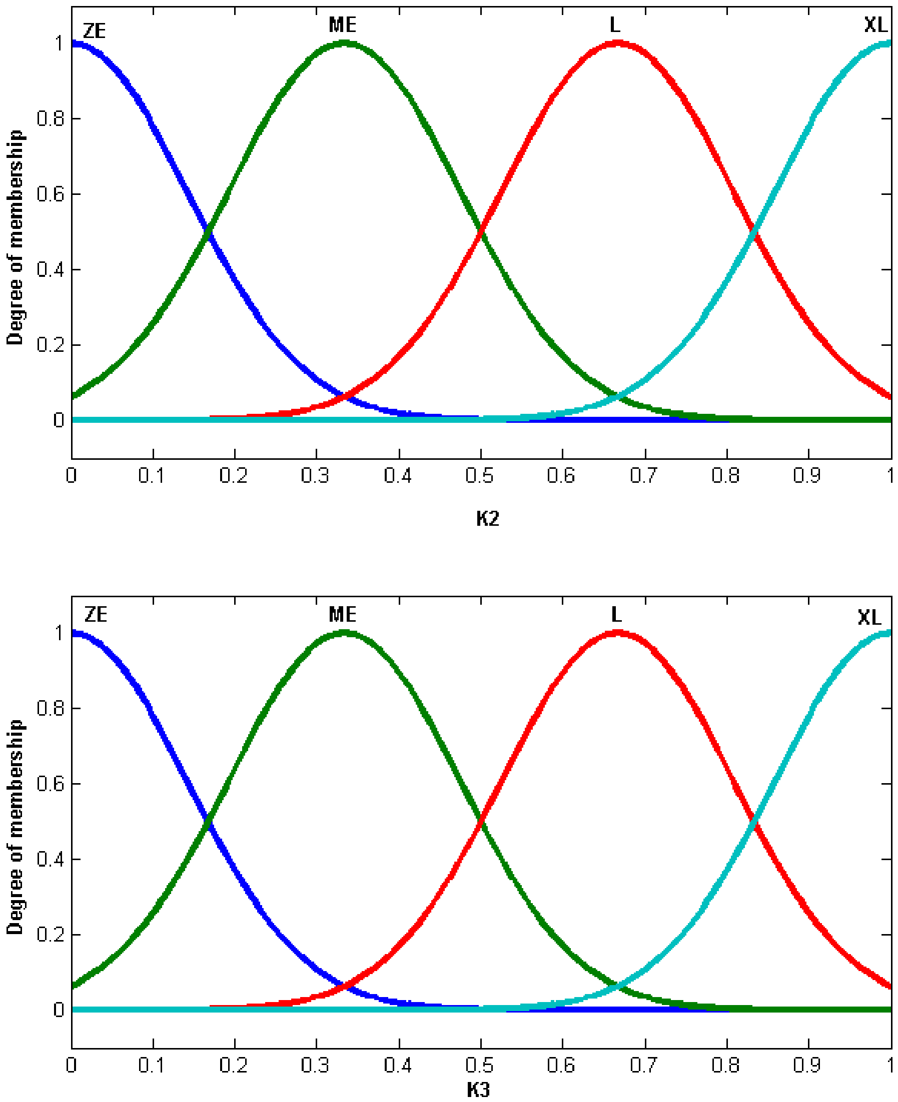


Figure 5. Preliminary membership functions for the consequents of the FPID

Figures 4 and 5 demonstrate the assigned membership functions for the antecedents and consequent of the gains, respectively. The criteria for selecting of the number of membership functions are based on the trial and error. Rule bases, however, are defined corresponding to the concept of PID controller [12] in which two functions $F(e(t))$ and $G(e(t))$, formulated in 7 and 8, are used for the integral and derivative gain, in turn; a_1, a_2, b_1 and b_2 are all positive constants. Aforementioned statements express that when the error is maximum the integral and the derivative part must be maximum and minimum respectively and when the error is minimum the integral part must be minimum and derivative part should be maximum.

Table 2. Rule base for k1

SE **PE**	NL	NS	Z	PS	PL
NL	P	P	P	Z	P
NS	P	P	Z	Z	P
Z	P	P	Z	Z	Z
PS	P	Z	Z	N	N
PL	Z	Z	Z	N	N

Table 3. Rule base for k2

SE **PE**	NL	NS	Z	PS	PL
NL	XL	L	L	L	XL
NS	L	ME	ME	ME	L
Z	ME	ZE	ZE	ZE	ME
PS	L	ME	ME	ME	L
PL	XL	L	L	L	XL

Table 4. Rule base for k3

SE **PE**	NL	NS	Z	PS	PL
NL	ZE	ME	ME	ME	ZE
NS	ME	L	L	L	ME
Z	L	XL	XL	ZE	L
PS	ME	L	L	L	ME
PL	ZE	ME	ME	ME	ZE

$$F(e(t)) = a_1 \times (|e(t)|) + a_2 \qquad (7)$$

$$G(e(t)) = b_1 \times (1 - |e(t)|) + b_2 \qquad (8)$$

Table 2,3 and 4 demonstrate the proper rule bases for the Mamdani fuzzy inference engine of proportional, integral and derivative gains.

Regarding the fact that the optimum design of the mentioned fuzzy structures leads to the better tracking performance of the FPID, the preliminary membership functions and scaling factors of fuzzy parts are desired indexes defined in the form of the optimization problems. In the next part, brief introduction of ICA and its application together with strategy of solving our problem with this heuristic approach will be discussed.

IV.BRIEF DESCRIPTION OF IMPERIALIST COMPETITIVE ALGORITHM

Imperialist competitive algorithm was introduced first time by E.A.Gargary and C.Lucas in 2007 [13]. It is a global heuristic search method that uses imperialism and imperialistic competition process as a source of inspiration.

This algorithm starts with some initial countries. Some of the best countries are selected to be the imperialist states and all the other countries form the colonies of these imperialists. The colonies are divided among the mentioned imperialists based on their power. After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their relevant imperialist state. This movement is a simple model of assimilation policy. The algorithm can be described in flowchart illustrated in figure 6. The movement of a colony towards the imperialist is shown in (9). Figure 7 also illustrates this structure. In this movement, θ and x are random numbers with uniform distribution and d is the distance between colony and the imperialist.

$$\begin{aligned} &x \sim (0, \beta \times d) \\ &\theta \sim U(-\gamma, \gamma) \end{aligned} \tag{9}$$

Where β and γ are arbitrary numbers that modify the area that colonies randomly search around the imperialist. β and γ are 2 and 0.5 (rad), in our implementation, respectively.

The total power of an empire depends on both the power of the imperialist country and the power of its colonies. This fact is modeled by defining the total power of an empire by the power of imperialist state plus a percentage of the mean power of its colonies. In imperialistic competition, all empires try to take possession of colonies of other empires and control them. This competition gradually brings about a decrease in the power of weak empires and an increase in the power of more powerful ones. This competition is modeled by just picking some (usually one) of the weakest colonies of the weakest empires and making a competition among all empires to possess these (this) colonies. Figure 8 shows a big picture of the modeled imperialistic competition.

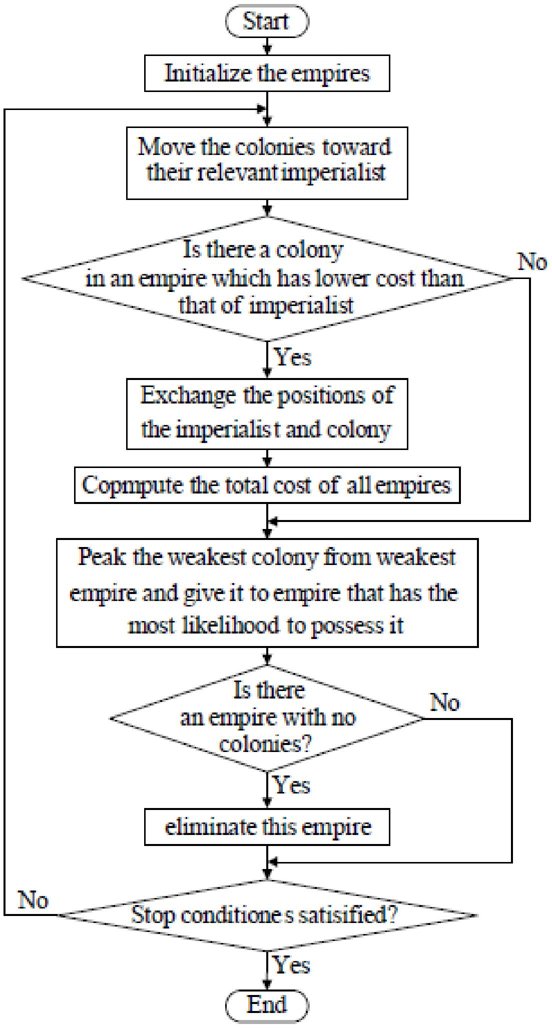


Figure 6. Pseudo code for ICA

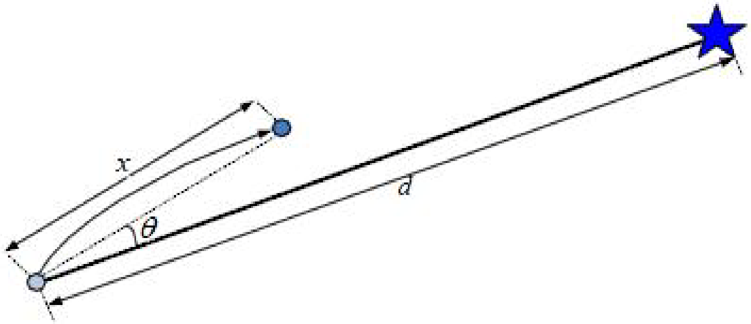


Figure 7. Movement of colonies toward their relevant imperialist in a randomly deviated direction

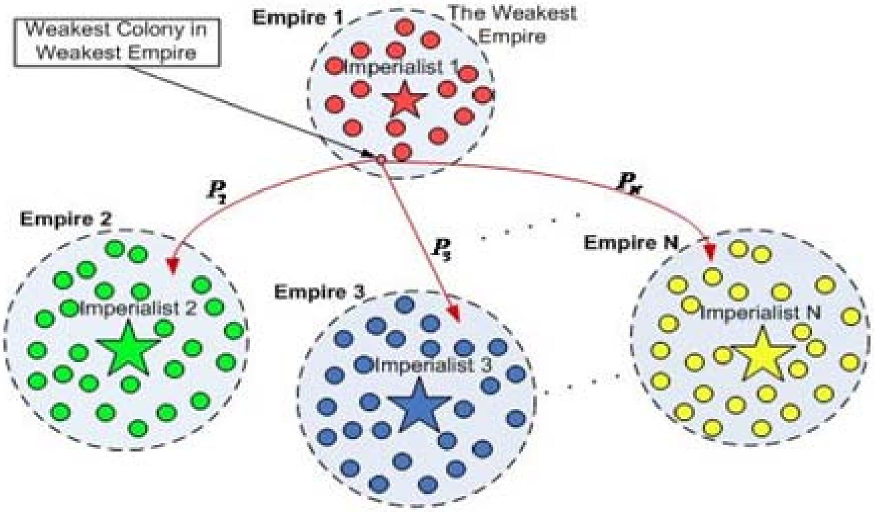


Figure 8. Imperialistic competition: The more powerful an empire is, the more likely it will possess the weakest colony of weakest empire

Based on their total power, in this competition, each of empires will have a likelihood of taking possession of the mentioned colonies. The more powerful an empire, the more likely it will possess these colonies. In other words these colonies will not be certainly possessed by the most powerful empires, but these empires will be more likely to possess them. Any empire that is not able to succeed in imperialist competition and cannot increase its power (or at least prevent decreasing its power) will be eliminated. The imperialistic competition will gradually result in an increase in the power of great empires and a decrease in the power of weaker ones. Weak empires will gradually lose their power and ultimately they will collapse.

The movement of colonies toward their relevant imperialists along with competition among empires and also collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are its colonies. In this ideal new world colonies have the same position and power as the imperialist [13], [14].

Before utilizing ICA, incontrovertibly, the proposed problem of optimum design of the membership functions must be arranged in the form of an optimization problem. For this purpose, the parameters of the membership functions are coded to form the array country [15]. All of the preliminary membership functions are specified by 112 points which are the coded parameters in reaching the best position for each membership function. Cost function, moreover, is defined with respect to the performance indices which are important in the problem of tracking. Combination of absolute error, maximum overshoot, settling time and rise time, here, forms a proper cost function.

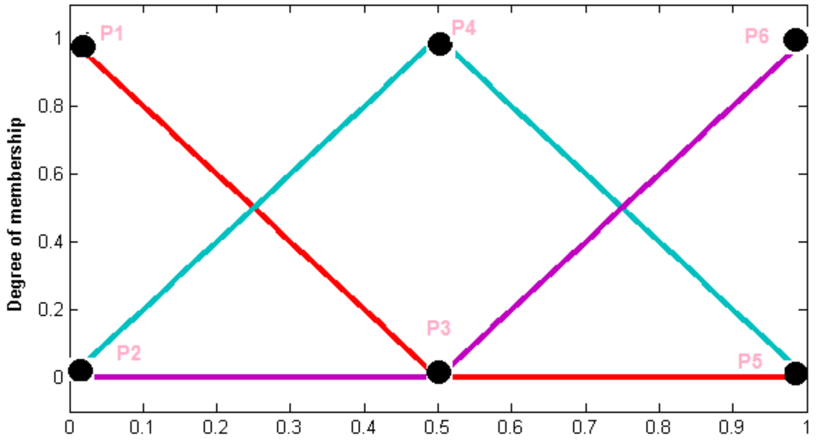


Figure 9. Definition of the coded parameters on the membership function

Through the global search of the ICA, in order to find the best parameters, the position of the coded parameters are being changed and finally when the cost function will be minimized the best solution , which are the best position for the membership functions, are revealed. In this study, ICA is initialized by the number of 300 countries, 10 empires, 80 iterations and revolution rate equal to 0.5. It must be noted that after finding the best membership functions, the scaling factors are subsequently put in a separate run of the ICA and will be optimized. In the next part, the outcomes of the optimization can be observed.

V. SIMULATION AND RESULTS

In this part, static PID and recommended FPID are applied to the PMSM and their performances are compared in different situations. Before describing the ideal and uncertain environments allocated as the test beds for evaluation of the functionality of the proposed controllers, the modified membership functions are illustrated. As mentioned in the previous section, the problem of determining optimum membership functions is related to the problem of settling 112 points. The fact is that the coded parameters which construct the country array lead to the best solution. The strategy, here, is new and comparable with expert designation. The best fitness of the cost function in each decade for FPID optimization is shown in figure10.

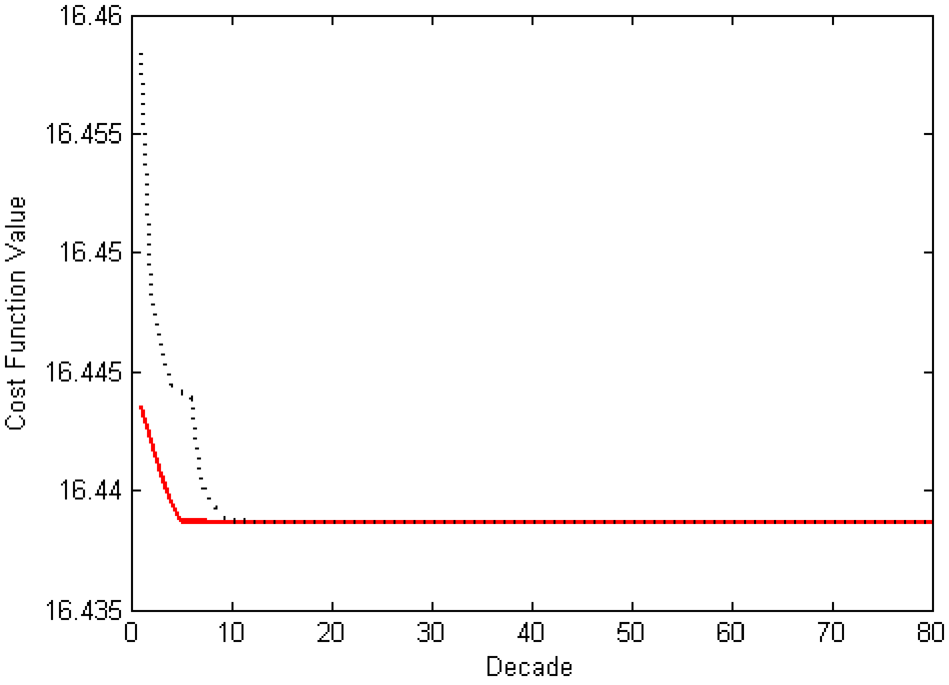


Figure 10. Best fitness of the cost function for determining of the best membership functions

Figures 11 , 12 and 13 represent the modified antecedent and consequent partitions for proportional, integral and derivative gains, respectively.

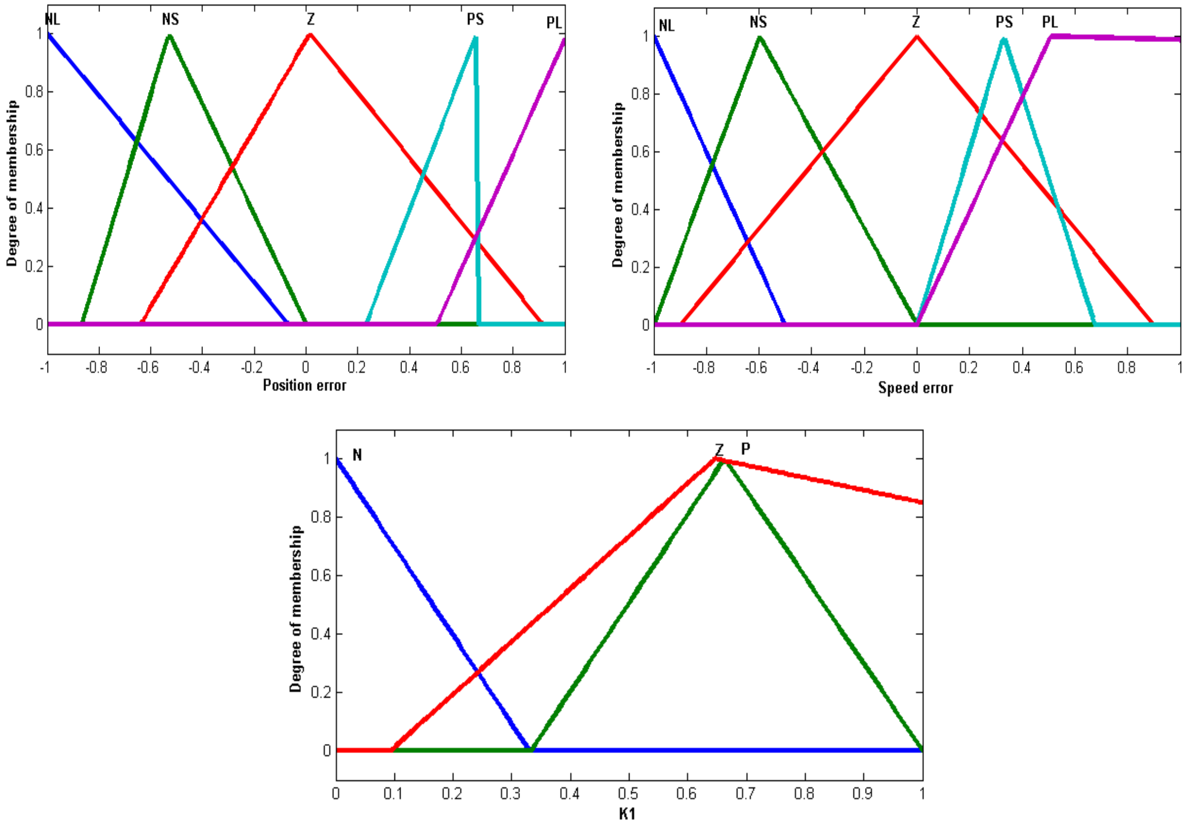
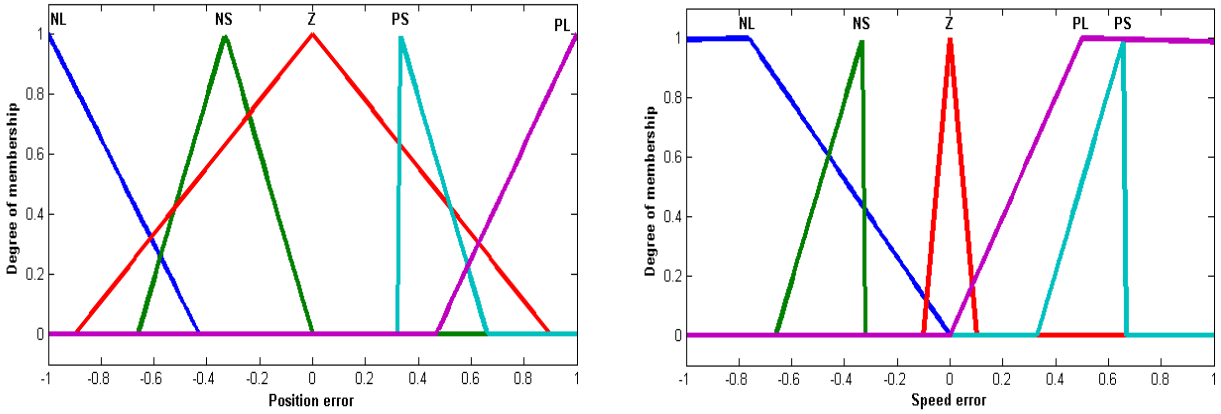


Figure 11. Modified membership functions of K1

In the following of the discussion, an ideal situation is provided in which there is no disturbance and noise affect the PMSM. A trapezoidal signal which covers the characteristics of increasing, constant and decreasing is chosen as an appropriate reference speed signal. PMSM is run under completely certain condition. Both static PID and FPID controllers are tuned based on this condition.



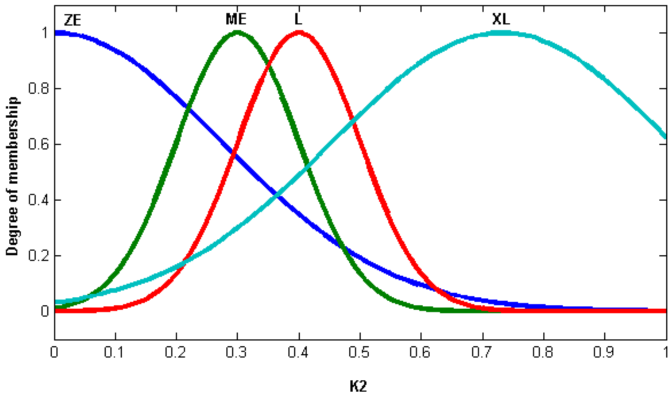


Figure 12. Modified membership functions of K2

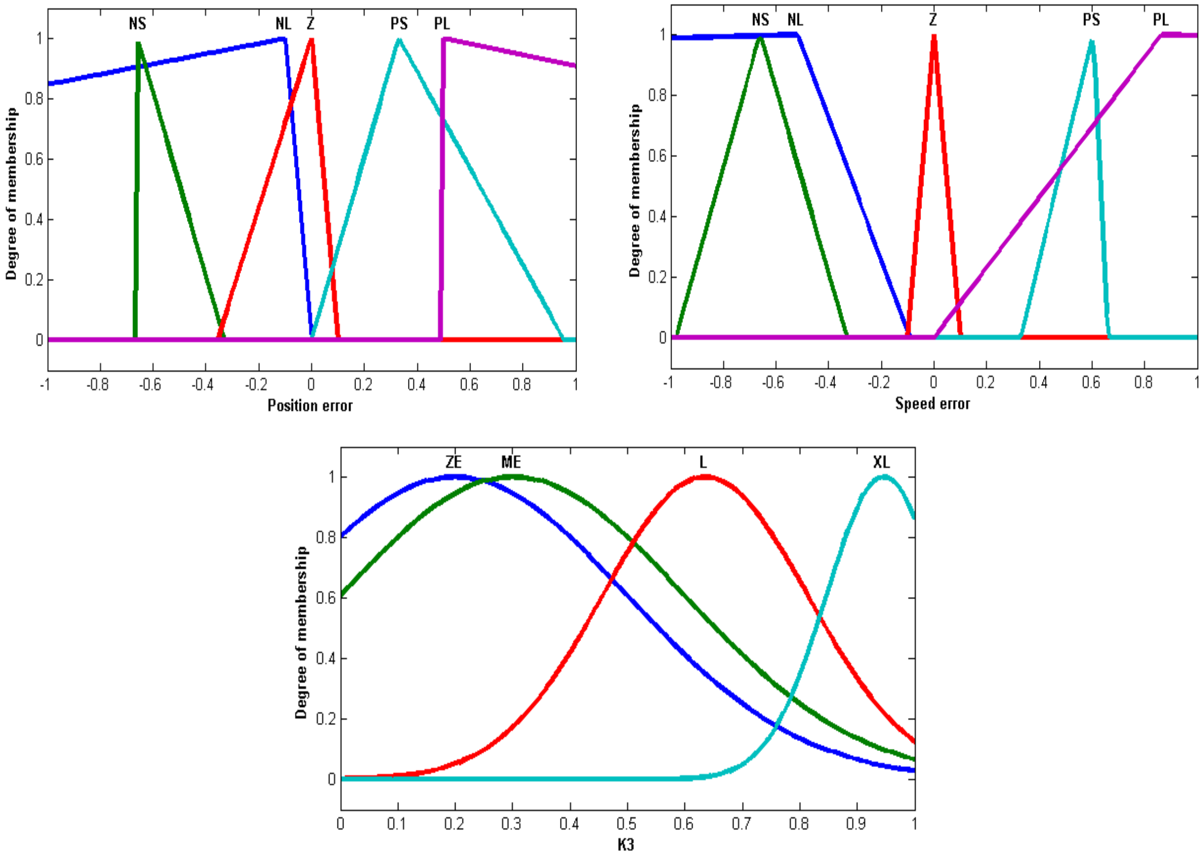


Figure 13. Modified membership functions of K3

Figure14 depicts tracking performance of the static PID and FPID under the ideal condition. The trapezoidal reference signal is tracked by the controllers without presenting any dynamical perturbation and load torque disturbance. As can be seen, FPID tracks the reference trajectory with more accuracy than classic counterpart. It is obvious that response from static PID suffers from considerable overshoot, undershoots and significant deviation of reference signal. As it is deduced from figure 15, in changing of the set point from constant to ramped-shape part and vice versa, the command voltage (V_d) in both controllers shows substantial peaks and this is because of the fast changes in the reference signal in a short period of time. Therefore, the voltages injected to the inputs of PMSM encompass increases in the certain times to support the actual speed in reaching to the reference signal. These ranges of increases are acceptable for PMSM drive. Over all, in this situation, FPID offers more exact trajectory tracking with approximately same effort in command voltage in comparison with static PID.

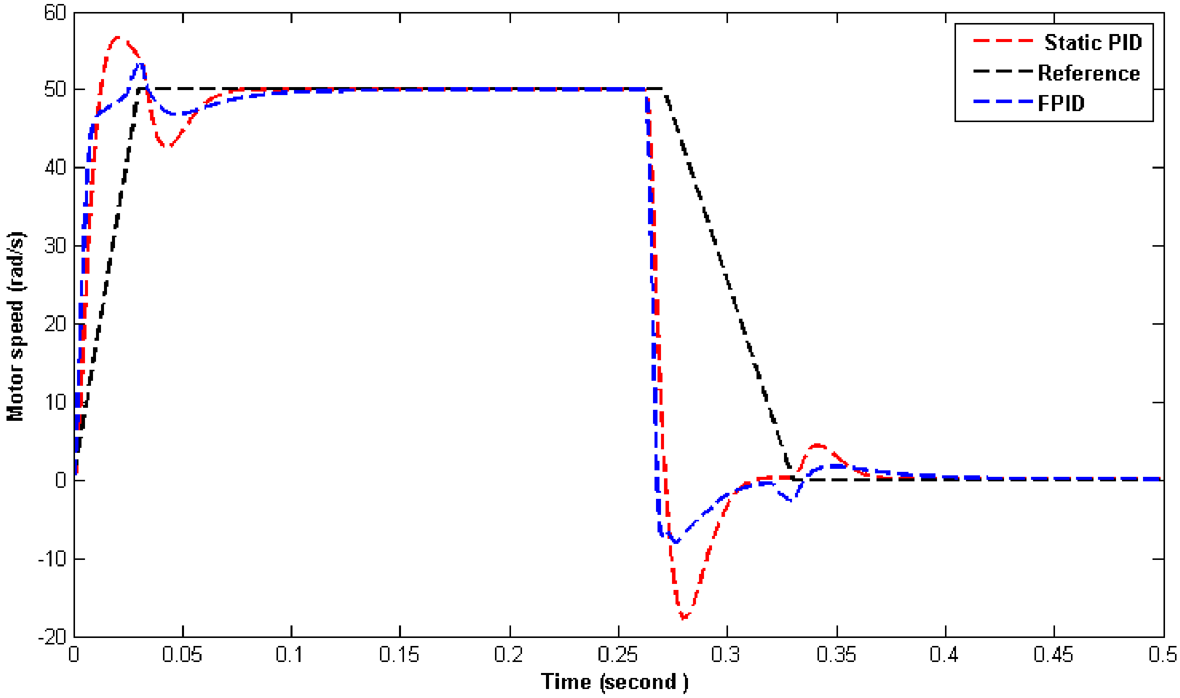


Figure 14. Trajectory tracking performance evaluation under the certain condition

Incontrovertibly, absence of load torque disturbance and functional changes of system's parameters in certain condition, affect positively in generating proper command voltages to reach the desired response. However, in real environment the presence of uncertainties in the form of external and internal disturbances is inevitable. The plant to be controlled is often unknown due to its nonlinearity. Moreover, presence of the different noises in the industrial environments must be taken into consideration. To simulate the real circumstances, the issue of uncertainties is followed by parameter changes in PMSM and applying the random load torque as the external disturbance.

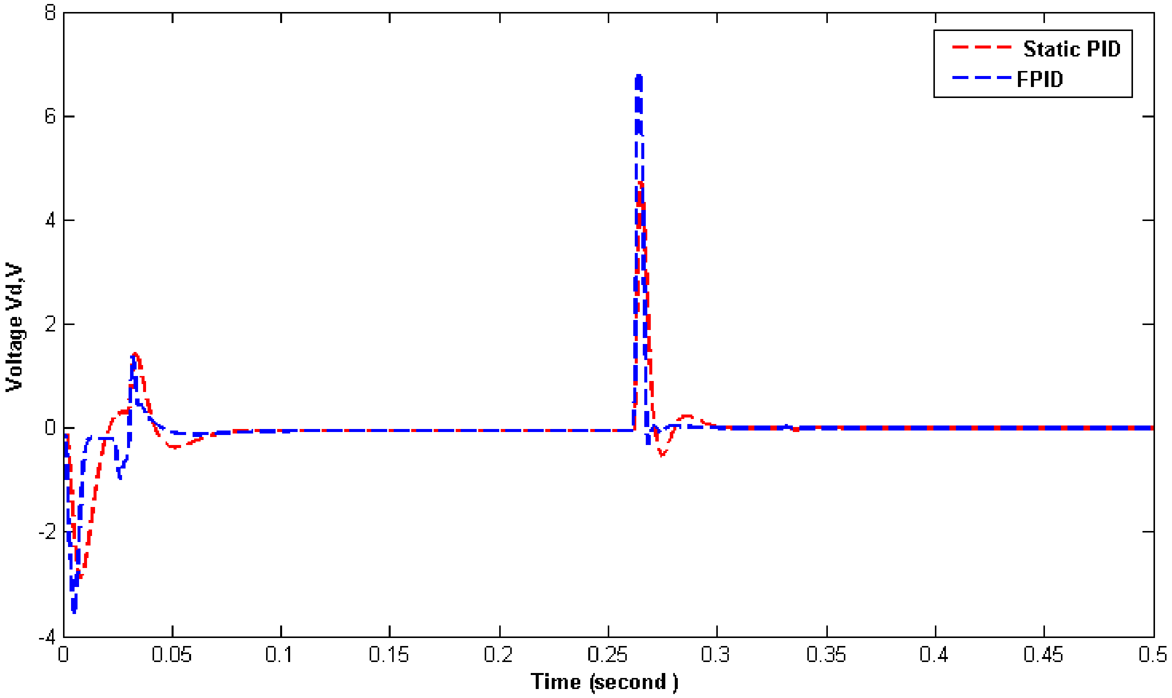


Figure 15. Variations of Direct voltage (Vd) under the certain condition

The parametric uncertainties are related to the variations of the parameters J, K_m, R and L around their nominal values assumed to have slower dynamics than the state dynamics and the step form load torque disturbance, depicted in figure 16, is exerted on the model, as an external disturbance, during trajectory control. Model parameter perturbations are described in equation 10 in which $\lambda_1, \lambda_2, \lambda_3$ and λ_4 are constant parameters equal to 0.1 , 0.2 , 0.5 and 1.5 respectively.

$$J_1 = \lambda_1 . J$$

$$K_{m1} = \lambda_2 . K_m \qquad (10)$$

$$R_1 = \lambda_3 . R$$

$$L_1 = \lambda_4 . L$$

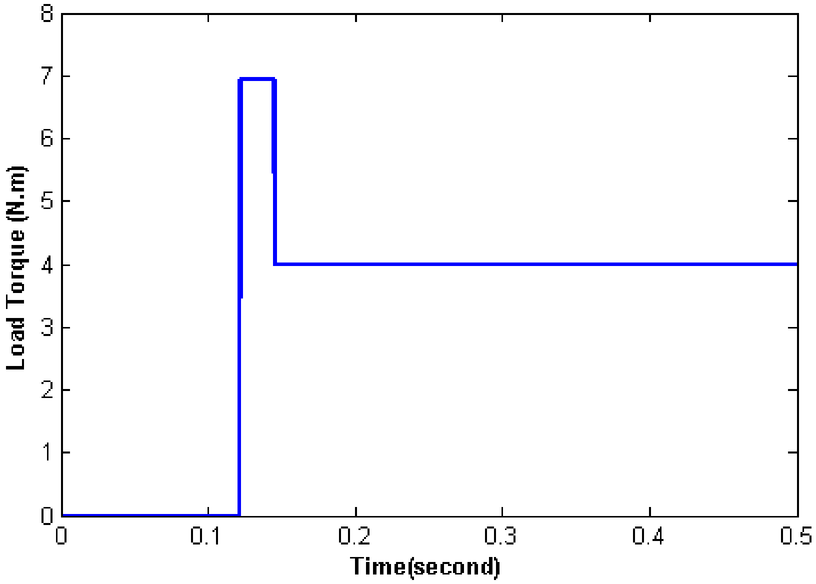


Figure 16. Load torque disturbance

Figure 17 illustrates the functionality of the proposed controllers under the uncertain condition. Remarkable deviation of the rotor speed in the time in which the load torque is applied on the model can clearly be inferred in performance evaluation of the static PID while FPID is extremely capable in disturbance handling. Degradation of operating performance, based on the static PID, is due to the sensitivity of classic type of controllers to mechanical configuration changes. This weakness, particularly when the fast excitation changes are applied on the motor, affects rotor movement and PMSM might loss its steps, stability and synchronization. The main reason for the explanation of this phenomenon is inflexible structure of classic controller. In other words, fixed gain static PID is tuned for a pre-specified operating point of the system. Therefore, when the system encounters large abrupt changes, the controller cannot guarantee a robust behavior.

In another perspective, under the uncertain environment, FPID is superior in term of the burdening insensitivity against model dynamic perturbations and unforeseen disturbance.

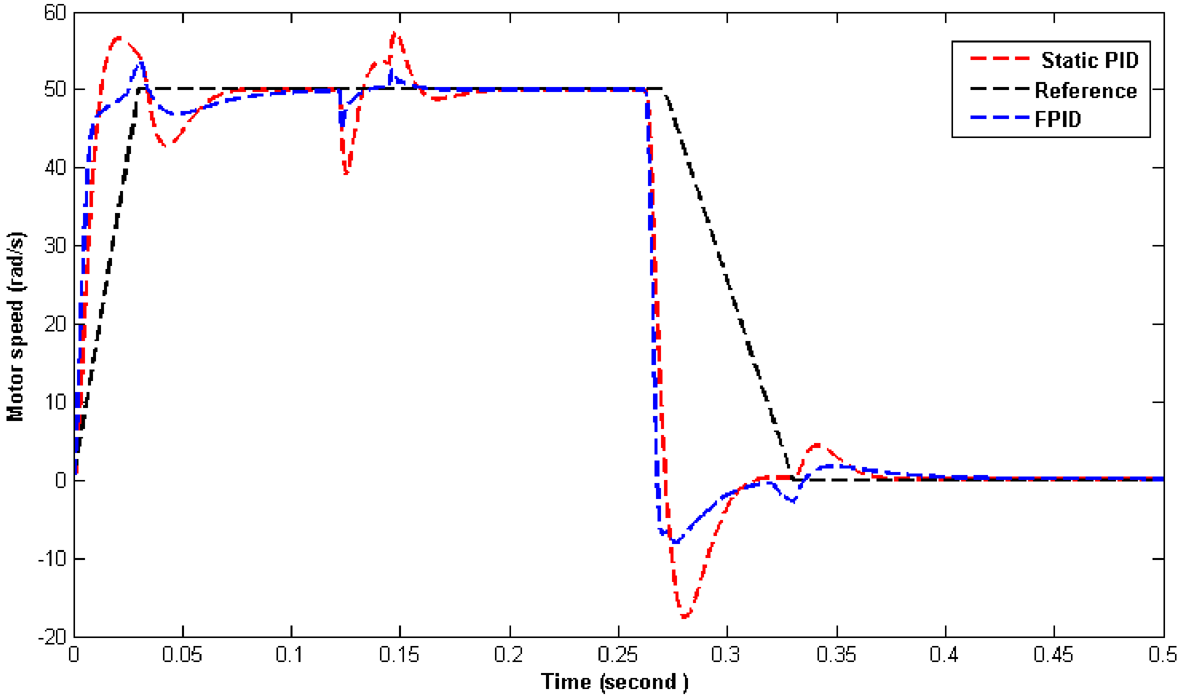


Figure 17. Trajectory tracking performance evaluation under the uncertain condition

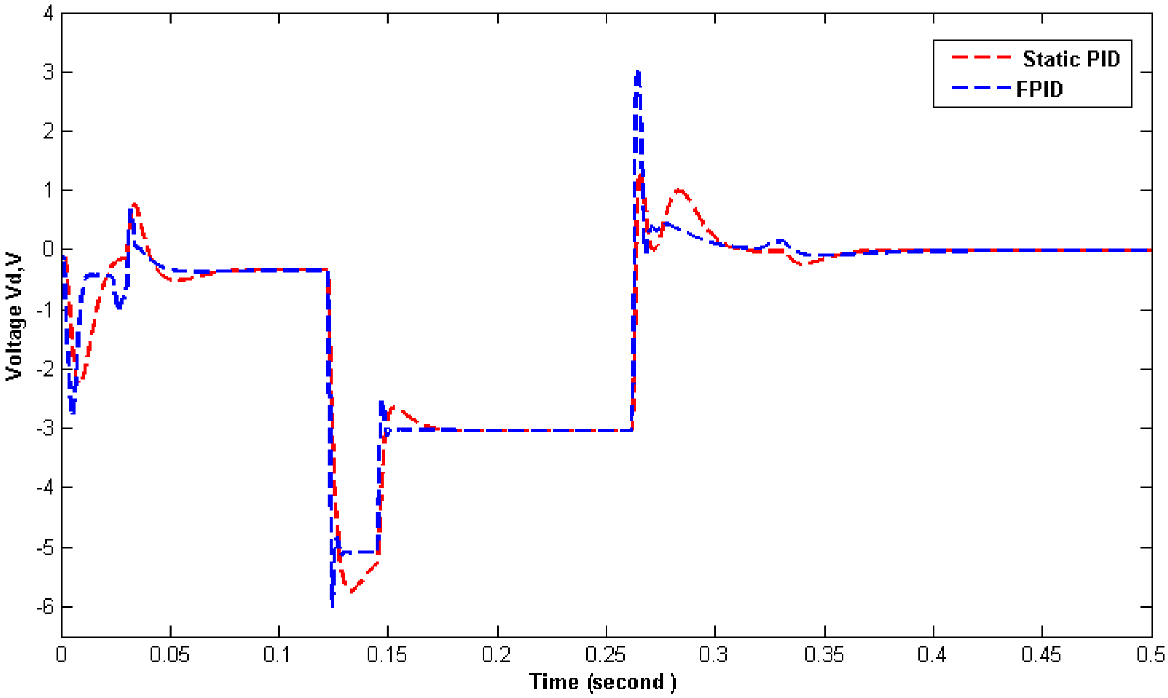


Figure 18. Variations of Direct voltage (Vd) under the uncertain condition

The flexibility in the structure of the FPID gains, clarified in figure 19, which are not strict based on the pre-determined value for a pre-specified operating point, is main reason of FPID mastery.

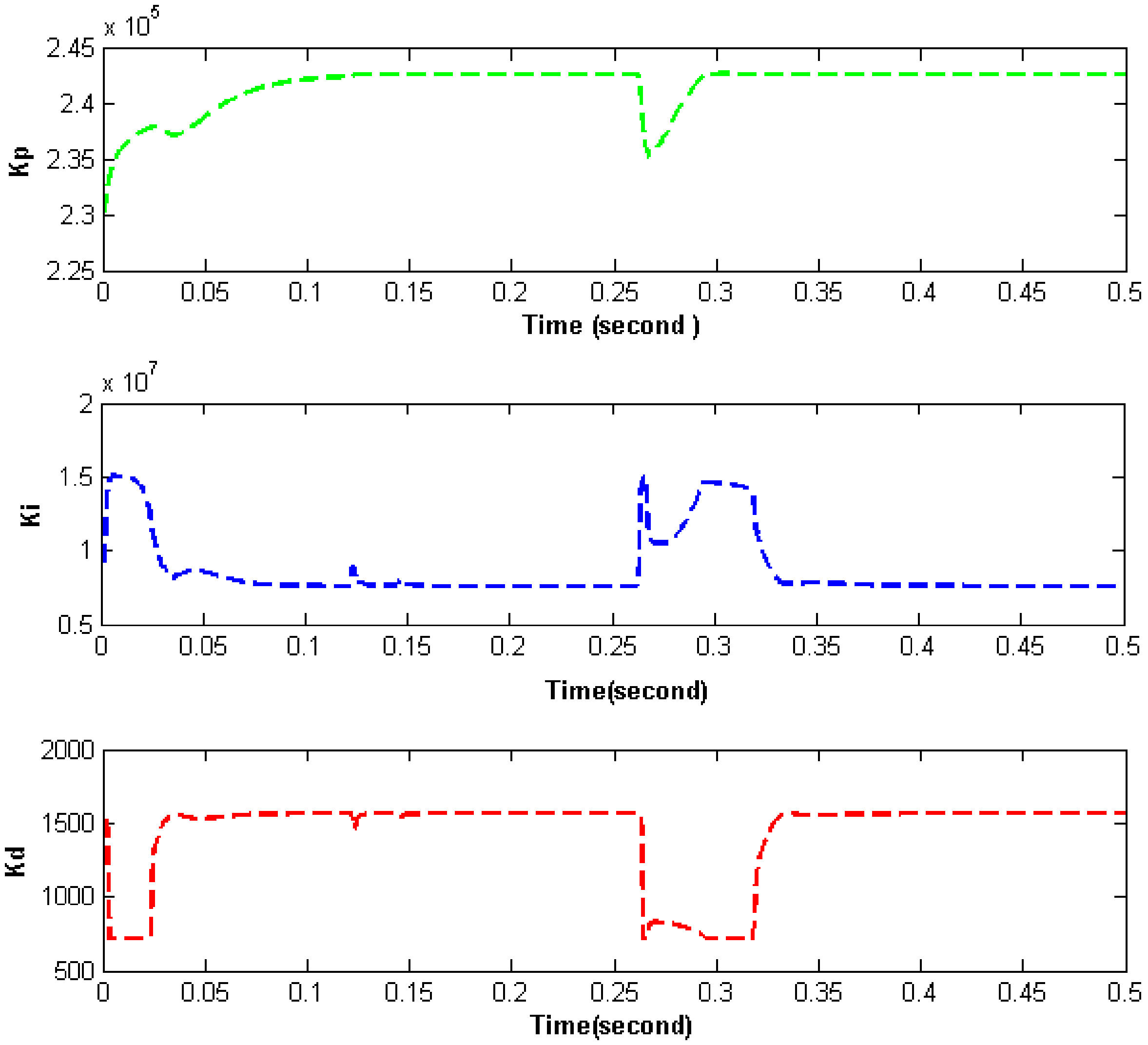


Figure 19. Gains' variations under the uncertain condition

VI.CONCLUSIONS

In this research two control strategies, classic and intelligent, have been applied on the intrinsic nonlinear model of PMSM for speed tracking evaluation. Novel heuristic search algorithm, ICA, has been employed to contribute the optimum design of the intelligent FPID controller. In other words, the crucial task of determining the best partition locations in membership functions and tuning the scaling factors have been done by ICA. Comprehensive comparison has been done in different circumstances between the recommended intelligent controller and classic one to evaluate their performance. Simulated results indicated that in both certain and uncertain condition, FPID offered superior performance in comparison with static PID. In dealing with mechanical perturbations, sensitivity and lack of adaption in static PID controller caused significant deviations of speed response from the reference signal. The structure of FPID supported good freedom in terms of control objectives. This flexibility is a meritorious property and useful for the broad range of the industrial applications.

REFERENCES

[1] S.Ghafari, M.Behzad , "Investigation of the micro-step control positioning system performance affected by random input signal ", Mechatronics, Vol.15, pp. 1175-1189, 2005.

[2] TR. Fredriksen, " Applications of the Closed-Loop Stepping Motor", *IEEE Transactions on Automatic Control*, Vol.13 , No.5, pp. 464-474, 1968.

[3] PJ.Clarkson, PP.Acarnley, " Closed-Loop Control of Stepping Motor Systems" , *IEEE Transaction on Industry Applicatio*ns , Vol.24, No.4,pp. 685-691,1988.

[4] M. Zribi, J. Chaisson, " Position Control of a PM stepper motor by exact linearization ", *IEEE Transaction on Automatic Control*, Vol. 36, pp. 620-625, 1991.

[5] J. Cruz, D.Kulic ,W.Owen, " Online Incremental Learning of Inverse Dynamics Incorporating Prior Knowledge ", *International Conference on Autonomous and Intelligent Systems*, 2011.

[6] F. Betin, D. Pinchon, GA. Capolino, " Fuzzy Logic Applied to Speed Control of a Stepping Motor Drive" , *IEEE Transaction on Industrial Electronics*, Vol. 47, No.3,pp. 610-622, 2000.

[7] S.F.Rezeka, N.M.Elsodany, and N.A.Maharem , " Fuzzy Gain Scheduling Control of a Stepper Motor Driving a Flexible Rotor", *European Journal of Scientific Research* , Vol.39, pp.50-63,2010.

[8] M.F.Rahmat, A.M.Yazdani,M.Ahmadi Movahed,S.Mahmoudzahe, "Temperature Control of a Continuous Stirred Tank Reactor by means of Two Different Intelligent Strategies" , *International Journal on Smart Sensing and Intelligent Systems*, Vol. 4, No. 2,pp. 244-267, 2011.

[9] T. Kenjo, " Stepper Motors and their Microprocessor Controllers ".ISBN: 0-19-859326-0, *Clarendon Press ,Oxford* 1984.

[10] R.Marino, S.Peresada, P.Tomei, " Nonlinear adaptive Control of Permanent Magnet Step Motors" , *Journal of Automatica*, Vol.31, No.11, pp.1595- 1604, 1995.

[11] S.Kamalasadan , " A New I intelligent Control for the Precision Tracking of Permanent Magnet Stepper Motor", IEEE, *Power Engineering Society General Meeting*, 2007.

[12] Zh.Woo, H.Chung ,J.Lin , "A PID type fuzzy controller with self-tuning scaling factors ", *Fuzzy Sets and Systems*, Vol.115, pp. 321-326, 2000.

[13] E.Atashpaz-Gargari,C. Lucas,"Imperialist Competitive Algorithm: An Algorithm for Optimization Inspired by Imperialistic Competition". *IEEE ,CEC, Singapore*,2007.

[14] E.Atashpaz-Gargari, F. Hashemzadeh, and C. Lucas, "Designing MIMO PIID Controller using Colonial Competitive Algorithm: Applied to Distillation Column Process" IEEE, World Congress on Computational Intelligence,2008.

[15] A.MohammadZadeh, E.Atashpaz Gargari, C.Lucas, "Vehicle Fuzzy Controller Design Using Imperialist Competitive Algorithm", IEEE, *World Congress on Computational Intelligence*,2008.