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A Particle Swarm Optimization (PSO) Based Optimum of Tuning PID Controller for a Separately Excited DC Motor (SEDM)

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Abstract

The PID algorithm is the most popular feedback controller used within the process industries. It is robust easily understood algorithm that can provide excellent control performance despite the varied dynamic characteristics of process plant. But the tuning of the PID controller parameters is not easy and does not give the optimal required response, especially with non-liner systems. In the last years emerged several new intelligent optimization techniques like, Particle Swarm Optimization (PSO) techniques. This paper deals the non-liner mathematical model and simulation for speed control of separately excited D.C. motor with closed loop PID controller. The conventional PID tuning technique is represented as a point of comparison. The intelligent optimization technique: PSO is proposed to tune the PID controller parameters. The obtained results of the closed loop PSO-PID Controller response shows the excellent response with comparing to the conventional PID, a good results gives in PSO-PID Controller. The simulation results presented in this paper show the effectiveness of the proposed method, which has got a wide number of advantages.

Keywords: Particle Swarm Optimization (PSO), PID Controller, Optimal Control, Separately excited D.C. motor (SEDM).

الأسناد الأفضل لتحقيق أمثلية حشد الجزيئات في توليف جهاز السيطرة التناسقي التكاملي التفاضلي (بي آي دي) للسيطرة على سرعة محرك التيار المستمر ذو الاثارة المنفصلة

الخلاصة

إنّ خوارزميةَ جهازُ سيطرة التغذية المرتدة (بي آي دي) الأكثر شعبيةً يستعملَ ضمن العمليات الصناعية. هي خوارزميةٌ سهلة ُالفهم ومتينة والتي يُمْكِنُ أَنْ تُزوّدَ أداءَ سيطرةِ ممتازِ على الرغم مِنْ الخصائصِ الديناميةِ المختلفةِ لوحدة العمليةِ. لكن عملية توليف معاملات (بارامتراتِ) جهازِ سيطرة (بي آي دي) لَيست سهلةَ ولا تعطي الاستجابة المثاليَة المطلوبَة، خصوصاً مع الانظمة اللاخطية. في السَنَوات الأخيرة ظَهرَت عِدّة تقنيات ذكيةِ جديدةِ لتحقيقِ الاستجابة المثلى, من هذه التقنيات، تقنيات تحقيق أمثلية حشدِ جزيئةِ (بي إس أو). يعالج هذا البحث نموذج رياضي لاخطي ومحاكاةَ لسيطرةِ سرعةِ محرك ذو أثارة مُنفصلة مع جهازِ السيطرة ذو الحلقةِ المُغلقةِ (بي آي دي). إنّ تقنيةَ توليف جهاز السيطرة (بي آي دي) التقليدي مُمَثّلةٌلاستخدامها كنقطة مقارنةِ للنتائج. تقنيةِ تحقيقِ الأمثلية الذكيةِ: تحقيق أمثلية حشدِ جزيئةِ يُقتَرحُ لتوليف معاملات (بارامتراتِ) جهازِ سيطرة (بي آي دي). تبين النَتائِجُ استجابة ممتازة من جهازِ سيطرة(بي إس أو بي آي دي) بالمُقَارنَة إلى استجابة جهاز السيطرة (بي آي دي) التقليدي، في هذاالبحث بينت نَتائِج المحاكاةَ فعالية الطريقةِ المُقتَرحةِ، التي لَها عدد واسع مِنْ الفوائدِ.

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1. Introduction

The desired torque-speed characteristics could be achieved by the use of conventional proportional integral- derivative (PID) controllers. As PID controllers require exact mathematical modeling, the performance of the system is questionable if there is parameter variation [1].However the PID (proportional-integral-derivative) controller is still extensively used in the industry this is due to its simplicity and the ability to apply in a wide range of situations. On the other hand tuning a PID controller is rather difficult and can be a time consuming process. The speed of DC motor can be adjusted to a great extent so as to provideeasy control and high performance. There are several conventional and numeric controller types intended for controlling the DC motor speed at its executing various tasks [2, 3].

There are several optimization algorithms which can be used for searching the optimal gain parameters a very basic one is the random search [4].

In recent years, many intelligence algorithms are proposed to tuning the PID parameters. Tuning PID parameters by the optimal algorithms such as the Simulated Annealing (SA), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) algorithm [5]. The PSO technique can generate a high quality solution within a shorter calculation time and have a stable convergence characteristic than other methods. The PSO algorithm is applied to search a best PID control parameters. PSO is characterized as a simple concept, easy to implement, and computationally efficient. Unlike the other heuristic techniques, PSO has a flexible and well-balanced mechanism to enhance the global and local exploration abilities [6, 7, and 8].

In this paper, a scheduling PID tuning parameters using particle swarm optimization strategy for a D.C. motor speed control is proposed, a conventional method for tuning PID controller of non-linear separately excited D.C. motor system control is represented. Then, the PSO based method for tuning the PID controller parameters are proposed as a modern intelligent optimization algorithm.

2. Model of D.C. Motor

DC machines are characterized by their versatility. By means of various combinations of shunt, series, and separately-excited field windings they can be designed to display a wide variety of volt-ampere or speed-torque characteristics for both dynamic and steady-state operation. Because of the ease with which they can be controlled systems of DC machines have been frequently used in many applications requiring a wide range of motor speeds and a precise output motor control [9].

In this paper, the separated excitation DC motor model is chosen according to his good electrical and mechanical performances more than other DC motor models. The speed of a separately excited dc motor could be varied from zero to rated speed mainly by varying armature voltage in the constant torque region [10]. The motor drives a mechanical load characterized by inertia j, friction coefficient Dm and load torque TL. The specifications of the dc motor are detailed as follows:

Shaft power ----- 4hp.
Rated voltage ----- 220 volt.
Armature resistance (Ra) ----- 2Ω.
Armature inductance (La) ----- 0.0162H.
Field resistance (Rf) ----- 210Ω.
Field inductance (Lf) ----- 5.47H.
Total inertia (J) ----- 0.117Kgm2.
Viscous friction coefficient (B) --- 0.01115Nm.

A model based on the motor specifications needs to be obtained, and the basic equations of the dc motor are:

$$v_a = e_g + R_a I_a + L_a \frac{dia}{dt} \quad \text{-------} \quad (1)$$

$$e_g = K\theta\omega \quad \text{--------} \quad (2)$$

$$T_d = K\,\theta I_a \quad \text{------} \quad (3)$$

$$T_d - T_L = j\frac{dw}{dt} + B\omega \quad \text{------} \quad (4)$$

Where v_a the voltage supplied by the power source, e_g the back electromotor force, (Ra and L_a) the equivalent armature coil resistance and inductance respectively, T_d the initial torque, ω the output motor speed rad./sec., T_L is torque of the mechanical load, J inertia of the rotor and B is the damping coefficient associated with the mechanical rotational system of the motor. Fig. (1) Shows the equivalent circuit of separately excited dc motor, Fig. (2), shows the transfer function MATLAB/SimPower Systems of separately excited dc motor (SEDM) circuit, and Fig. (3), shows the speed response without controller at no-load and full load.

3. Conventional Tuning of the PID Controller

Proportional Integral Derivative (PID) controllers are widely used in industrial practice over 60 years ago, today; PID is used in more than 90% of practical control system, ranging from consumer electronics such as cameras to industrial such as chemical process [11]. The (PID controller) is a genetic control loop feedback mechanism widely, and attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly, the PID controller helps get our output (velocity, temperature, position) in a short time, with minimal overshoot, and while little error [12].

The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values. Proportional value determines the reaction to the current error the Integral value determines the reaction based on the sum of recent errors and the Derivative value determines the reaction to the rate at which the error has been changing [13].The general equation of PID controller is [11,13]:

$$U(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \text{-}(5)$$

Where: K_P =Proportional gain; K_i = Integral time $(1/\ T_i)$; K_d = Derivative time (T_d).

The variable $e(t)$ represents the tracking error which is the difference between the desired input value and the actual output, this error signal will be sent to the PID controller and the controller computes both the derivative and the integral of this error signal. The signal $U(t)$ from the controller is now equal to the proportional gain(K_P)

times the magnaitude of the error plus, the integral gain*(K_i)*times the integral of the error plus, the derivative gain *(K_d)* times the derivative of the error [14, 15].There is difficulty when using the traditional method because this method cannot deal with any application that using complex mathematical model, in spite of PID framework solves many problems and sufficiently flexible to incorporate additional capabilities [11, 13]. Fig. (4) Shows the block diagram of the goal of this research.

In this paper, a good result when using trial and error method of the PID controller parameters, to achieve a suitable output speed performance of the separately excited dc motor system are:

K_p =0.6, K_i =8, K_d =0.2, that the transient response gives by the unit step input;

- Rise time = 0.5 Sec.
- Maximum overshot = 20%.
- Settling time = 3.5 Sec.
- Steady state error = 0%.
- ITSE = 0.0251

The simulation of PID controller is shown in Fig. (5).

The output speed performance of conventional PID Tuning of separately excited dc motor under no-load and full load conditions is shown in Fig. (6).

4. Fitness Function

The most common performance criteria are Integrated Absolute Error (IAE), the Integrated of Time weight Square Error (ITSE) and Integrated of Square Error (ISE) that can be evaluated analytically in frequency domain [5, 15, and 16].

These three integral performance criteria in the frequency domain have their own advantage and disadvantage. For example, disadvantage of IAE and ISE criteria is that its minimization can result in a response with relatively small overshot but a long settling time, because the ISE performance criteria weights all errors equally independent of time. Although, the ITSE performance criterion can overcome the disadvantage of ISE criterion. The performance criterion formula for, IAE, ISE, and ITSE are as follows [15]:

$$IAE = \int_0^t |r(t) - y(t)|dt = \int_0^\infty |e(t)|dt \qquad \text{…..} \ (6)$$

$$ISE = \int_0^t e^2(t)dt \qquad \text{… …} \ (7)$$

$$ITSE = \int_0^t t.e^2(t)dt \qquad \text{……} \ (8)$$

In this paper the *(ITSE)* time domain criterion is used as a *Fitness Function (FF)* for evaluating the PID Controller performance, a set of good controller parameters K_P, K_i, and K_d can yield a good step response that will result in performance criteria minimization the *FF* in the time domain;

$$FF = ITSE \qquad \text{…..} \ (9)$$

These performance criteria is include the over shoot, rise time, settling time, and steady-state error.

5. Particle Swarm Optimization:

PSO is a population-based optimization method first proposed in [17]. Some of the attractive features of PSO include the ease of implementation; it can be used to solve a wide array of different optimization problems. Like evolutionary algorithms. Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change their positions by flying around in a multidimensional search space until computational limitations are exceeded.

PSO is one of the modern heuristic algorithms; it was inspired by the social behavior of bird and fish schooling, and has been found to be robust in solving continuous non-linear optimization problems [5, 11]. PSO simulates the behaviors of the bird flocking. Suppose the food group of birds is randomly searching food in an area, all the birds do not know where the food is. But they know how each iteration. PSO learned from the scenario and used it to solve the optimization problems; solution is "bird" in the search space. We call it "particle" all of particles which are evaluated by the fitness function to be optimized, and have velocities flying of the particles [18]. PSO is initialized with a group of random particles (solution) and then sear updating generations, in every iteration; each particle is updated by following, and the first one is the ***best*** solution (fitness) it has achieved so far, called ***pbest*** value. Another ***"best"*** value that is tracked by the particle the pest value, obtained so far by any particle in the population, this best value called ***gbest.***

In the PSO algorithm, instead of using evolutionary operators such as mutation and crossover, to manipulate algorithm, for d-variable optimization problem, a flock of particles are put into the d-dimensional search space with randomly chosen velocities and positions knowing their best values so far ***(pbest)***,
and the positions in the d-dimensional space. The velocity of each particle, adjusted according to its own flying experience and the other particle's flying experience. For example; the *i* th particle is represented as:

$x_i = (x_{i,1} , x_{i,2} ,\ldots\ldots\ldots,x_{i,d})$ …….. *(10)*

In the d-dimensional space, the best previous position of the *i* th particle is recorded and represented as:

$Pbest_i=(Pbest_{i,1},Pbest_{i,2},\ldots\ Pbest_{i,d})$..*(11)*

The best particle among all of the particles in the group is ***gbest***

The best particle among all of the particles in the group is $\boldsymbol{gbest_d}$, the velocity for particle ***i*** is represented as:

$v_i = (v_{i,1} , v_{i,2} ,\ldots\ldots\ldots,v_{i,d})$ ….. *(12)*

After finding the two best values, the particle updates its velocity and position, and then each particle can be calculated using the current velocity and the distance from $\boldsymbol{Pbest_{i,d}}$ to $\boldsymbol{gbest_d}$ as shown in the following formula[5,11,12,19].

$$V_{i,m}^{(It.+1)} = W * V_{i,m}^{(It.)} + c1 * rand * \left(P_{best_{i,m}} - x_{i,m}^{(It.)}\right) + c2 * rand * \left(g_{best_m} - x_{i,m}^{(It.)}\right) \quad \ldots\ldots\ldots \quad (13)$$

$$x_{i,m}^{(It.+1)} = x_{i,m}^{(It.)} + v_{i,m}^{(It.)} \quad \ldots. \quad (14)$$

i=1, 2,….., n
m=1, 2,….., d

Where;
n = Number of particles.
d =Dimension.
It. =Iterations pointer.
$V_{i,m}^{(It.)}$=Velocity of particle no.*i* at iteration It.
W = Inertia weight factor.
c1, c2 = Acceleration constant.
Rand = Random number between 0-1.
$x_{i,m}^{(It.)}$ = Current positions of particle *i* at iteration it.
P_{best_i}= Best previous position of *i* $_{th}$ particle.
g_{best_m} = Best particle among all the particles in the population.

6. Scheduling PSO for PID controller parameters:

In this paper the particle swarm optimization algorithms (PSO), each particle contains three members ***P, I, D***, it means that the search space has three dimension and particles must *'fly'* in a three dimensional space, *(PSO are applied to search globally optimal* *parameters of PID)* [20].Used PSO Algorithms to find the optimal parameters of DC Motor speed control system. The structure of the PID controller with PSO algorithm is shown in figure (8). The control system performance is poor in characteristics and even it becomes unstable, if improper values of the controller tuning constants are used. Every time, the particles assume new positions, it is ensured to update the best particle by comparing the costs corresponding to these positions with the previously selected best particle cost [21].

The flowchart of the PSO-PID control system is shown in figure (9).

7. Simulation Results:

7.1. Implementing PSO Tuning for *PID controller:*

To control the speed of (SEDM) at (per. unit), according to trials, the system must be examined in each iteration and particles position during the optimization algorithm. Table (1) shows the PSO parameters, which used to verify the performance of PSO-PID controller parameters.

The simulation results are obtained for 10 second range time, the speed response of PID controller tuning parameters using Particle Swarm Optimization (PSO) strategy is shown in figure (10), output performance of the system under no-load and full-load conditions.

Particle Swarm Optimization (PSO) algorithm, parameter values are: K_p =2.5267, K_i =6.3101, K_d =0.5647, that the speed response gives by the unit step input;

* Rise time = 0.6 Sec.
* Maximum overshot = 6.4%.
* Settling time = 2.2 Sec.
* Steady state error = 0%.
* ITSE = 0.0160.

7.2. Comparison between PSO Tuning PID Controller with PID-Conventional controller:

A comparison is made to approach the effectiveness of the proposed; the performance comparison between PSO-PID Controller and PID-Conventional controller is shown in table (2).

The speed response of PSO-PID Controller comparing with the speed response of PID-Conventional controller is shown in figure (11).

8. Conclusions

The speed of a DC Motor drive is controlled by two methods in this paper, one PID- Conventional Controller and PSO-PID Controller, and comparison between them, then they obtained through simulation of DC Motor are;

* The results show that the proposed controller for the response speed of DC Motor an efficient for the optimal PID Controller because can be improve the dynamic performance of the system in a better way.

* By comparison with PSO-PID, PSO is much more robust in finding optimal control parameters where the quality of PID results differ each run significantly and the PSO results remain relatively stable.

* That the results give in PSO-PID Controller: Maximum overshoot=6.4%, Rise time=0.6Sec., Settling time=2.2Sec. Whereas, in the conventional PID Tuning: Maximum overshoot=20%, Rise time=0.5Sec., Settling time=3.5Sec.

* The advantage of using PSO Tuning PID is the computational efficiency, because it is very easy of the implementation and the computation processes is very fast, comparison with the conventional method especially for non-linear system.

* The PSO-Tuning PID Controller is the best because it has satisfactory performance and very robust (no overshoot or very small, minimal rise time, minimal settling time, and steady state error is zero).

* The advantage of using PSO Tuning PID is minimized the error when we calculate the step response of the system because the iterations are continuously run till the error minimizes.

* Finally, the proposed controller (PSO-PID) gives a very good results and possesses good robustness.

9. References

[1] Nabil A. Ahmed, ***"Modeling and Simulation of ac-dc buck-boost converter fed dc motor with uniform PWM technique",*** Electric Power Systems Research, Vol.73, issue 3, Mar., 2005.

[2] Henao H. Capolino G. A., ***"Methodologie et application du diagnostic pour les systems electriques",*** Article invite dans Revue de 1Electricite et de 1Electronique (REE), No.6, (in French), Jun., 2002,

[3] Raghavan S., ***"Digital Control for Speed and Position of a DC Motor",*** MS Thesis, Texas A&M University, Kingsville, Aug.2005.

[4] Y. Yan,W.A. Klop,M.Molenaar, P. Nijdam, ***"Tuning a PID Controller: Particle Swarm Optimization versus Genetic Algorithms ",*** tudelft. nl, February ,2010.

[5] M. Nasri, H. Nezamabadi and M. Maghfoori, ***"A PSO-Based Optimum Design of PID Controllerfor A Linear Brushless DC Motor",*** World Academy of Science, Engineering and Technology kerman university, kerman,Iran, 2007.

[6] Clerc, M. And Kennedy, J. ***"The Particle Swarm- Explosion, Stability, and Convergence in a Multidimensional Complex Space",*** IEEE Transactions on Evolutionary Computation, Vol. 6, 2002.

[7] Liu, Y. Zhang, J. and Wang, S., ***"Optimization Design Based on PSO Algorithm for PID Controller",*** 5th World Congress on Intelligent Control and Automation, Vol.3, 2004.

[8] M. A. Abido, ***"Optimal Design of Power-Stabilizers Using Particle Swarm Optimization",*** IEEE Trans. Energy Conversion. Vol. 17, Sep., 2002.

[9] Halila A., ***"Etude des Machines a Courant Continu",*** MS Thesis, University of LAVAL, May, 2001.

[10] J. Santana, J. L. Naredo, F. Sandoval, I. Grout, and O. J. Argueta, ***"Simulation and Construction of a Speed Control for a DC Series Motor",*** Mechatronics, Vol.12,issues 9-10, Nov.-Dec.,2002.

[11] B. Allaoua, B. Gasbaoui, and B. Merbarki, ***"Setting Up PID DC Motor Speed Control Alteration Parameters Using Particle Swarm Optimization Strategy",*** Leonardo Electronic Journal of Practices and Technologies, Issue, 14, 2009.

[12] B. Nagaraj And N. Murugananth, ***"Soft Computing-Based Optimum Design of PID Controller For A Position Control of DC Motor",*** Mediamira Science Publisher, Volume 51, Number 1, 2010.

[13] Nelendran Pillay, ***"A Particle Swarm Optimization Approach for Tuning of SISO PID Control Loop",*** MSc. Thesis, Durban University of Technology, 2008.

[14] Ang K. Chong G., Li Y., ***"PID Control System Analysis, Design, and Technology",*** IEEE Trans. Control System Technology, Vol.13, Jul.2005.

[15] Popov A., Farag A., Werner H., ***"Tuning of a PID Controller Using a Multi- Objective Optimization Technique Applied to A Neutralization Plant",*** 44th IEEE Conference on Decision and Control, and the European Control Conference, 2005.

[16] Lieslehto J., ***"PID Controller Tuning Using Evolutionary Programming",*** American Control Conference, VA June 25-27, 2001.

[17] Yoshida H. Kawata K., Fukuyama Y., Takayama S., Nakanishi Y., ***"A particle Swarm Optimization for reactive power and voltage control considering voltage security assessment",*** IEEE Trans. On power Systems, 2000.

[18] Pisut Pongchairerks, ***"Particle Swarm Optimization Algorithm Applied to Scheduling Problems"*** in Science Asia 35, 2009.

[19] Z-L Gaing, ***"A particle Swarm Optimization approach for optimumdesign of PID Controller in AVR System",*** IEEE Trans. Energy Conversion, Vol.19, June 2004.

[20] Kim T. H., Maruta I., Sugie T., ***"Robust PID Controller Tuning Based on the constrained Particle Swarm Optimization",*** Automatica Vol.44, Issue 4 Apr.2008.

[21] Mukherjee V., Ghoshal S. P. ***"Intelligent Particle Swarm Optimized Fuzzy PID Controller for AVR System",***Electric Power System Resrarch, Vol.77,Issue 12,Oct.2007.

Table (1) parameters of PSO algorithms

Number of iterations	***50***
Population Size	***20***
w_{max}.	***0.5***
$c_1 = c_2$	***1.2***

Table (2) Performance of PSO-PID Controller and PID -Conventional Controller at no-load and full- load

Results	*N0-LOAD*		*FULL-LOAD*	
	PID-Con.	*PSO-PID*	*PID-Con.*	*PSO-PID*
aximum ershot (%)	*20 %*	*6.4 %*	*2.6%*	*1.4%*
Rising time (Sec.)	*0.5 Sec.*	*0.6 Sec.*	*0.3 Sec.*	*0.25 Sec.*
Settling time (Sec.)	*3.5 Sec.*	*2.2 Sec.*	*1.9 Sec.*	*1.7 Sec.*
Steady state error (%)	*0 %*	*0 %*	*0 %*	*0 %*
ITSE	*0.0251*	*0.0160*	*0.0256*	*0.0163*

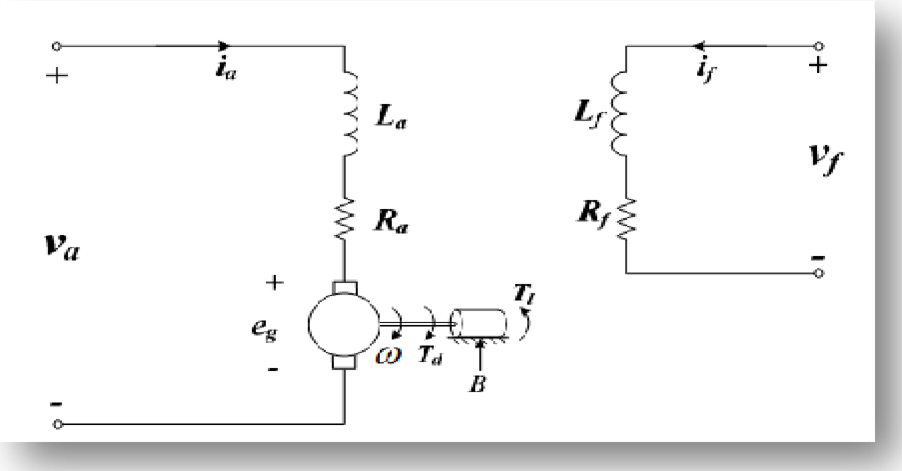

Figure (1) the equivalent circuit of separately excited dc motor.

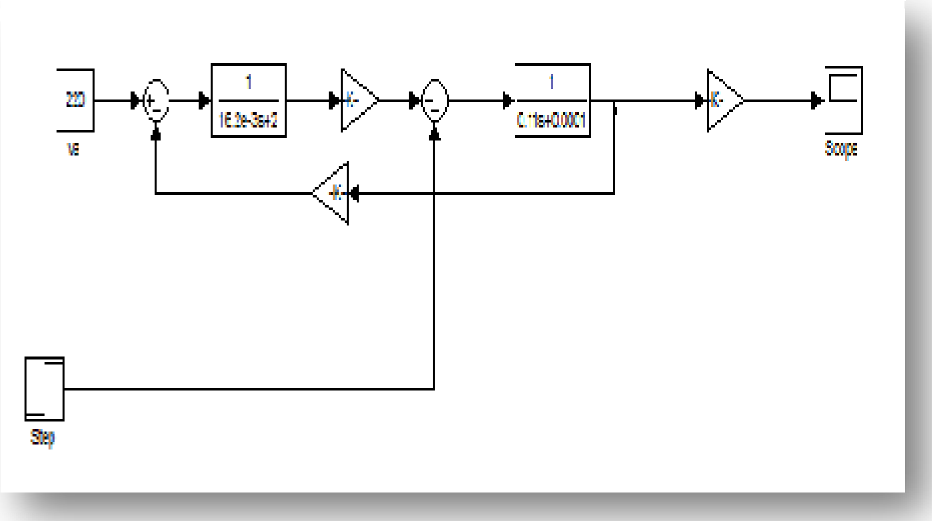

Figure (2) Separately excited dc motor (SEDM) simulation.

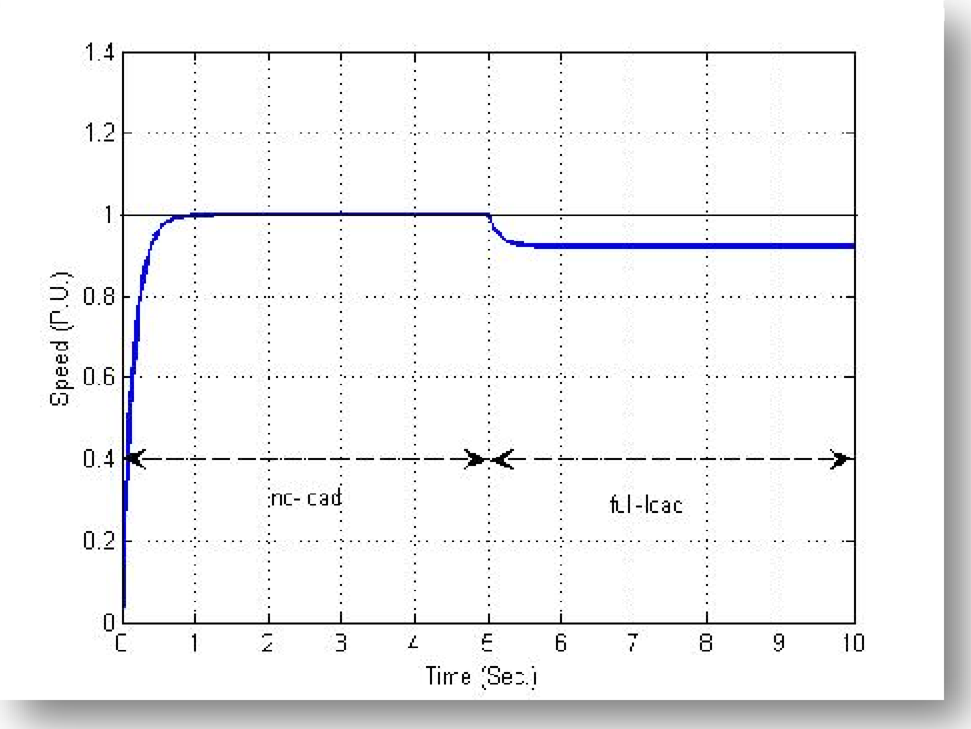

Figure (3) Open Loop Speed response of (SEDM) without control at no-load and full load

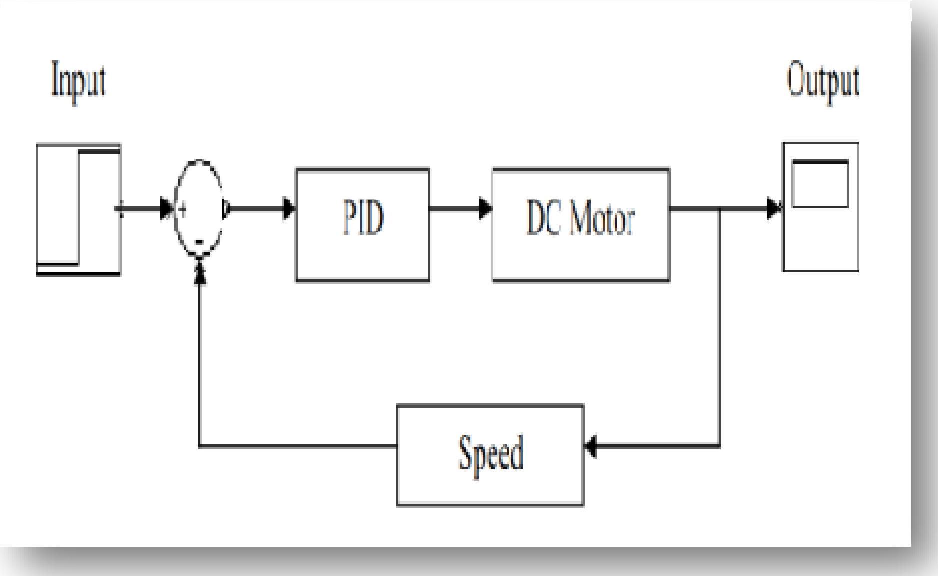

Figure (4) Block diagram of the system

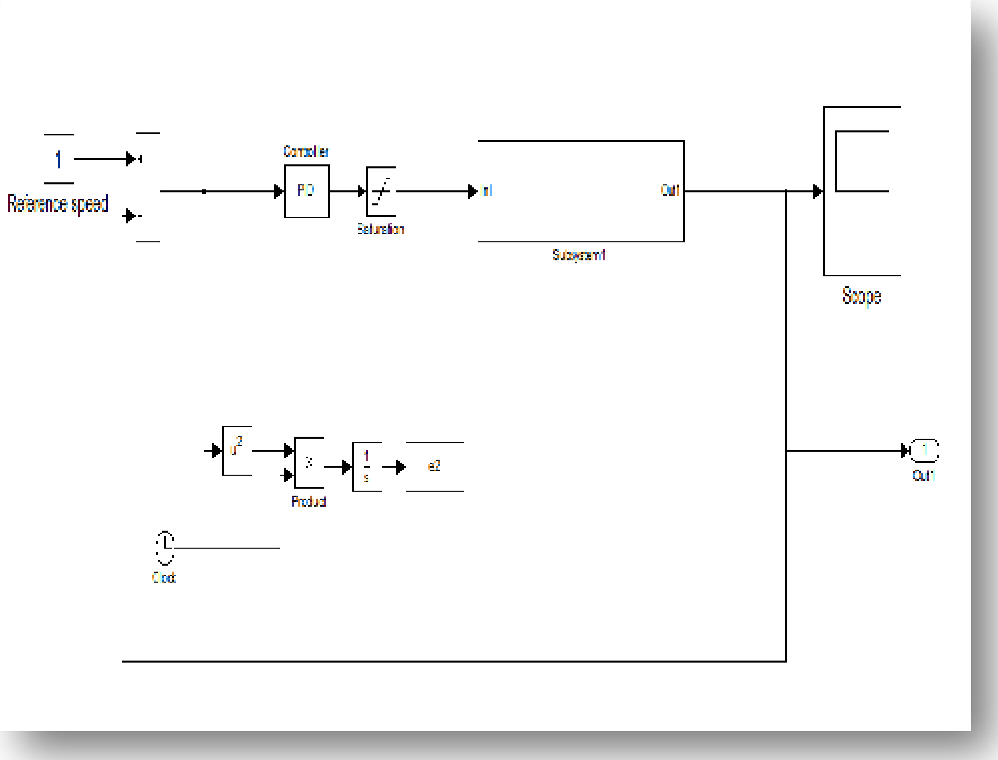

Figure (5) PID controller of separately excited dc motor

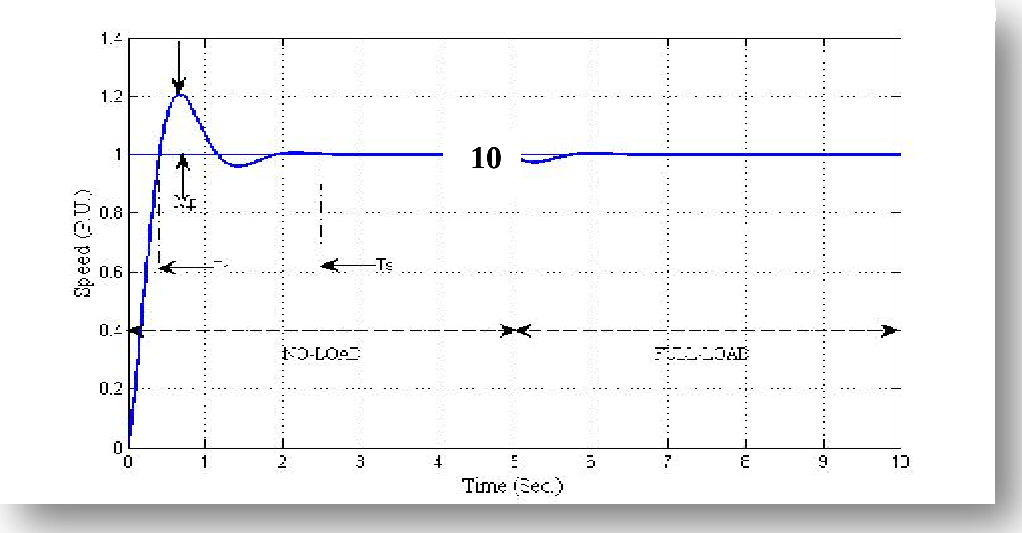

Figure (6) Output speed performance of conventional PID Tuning method.

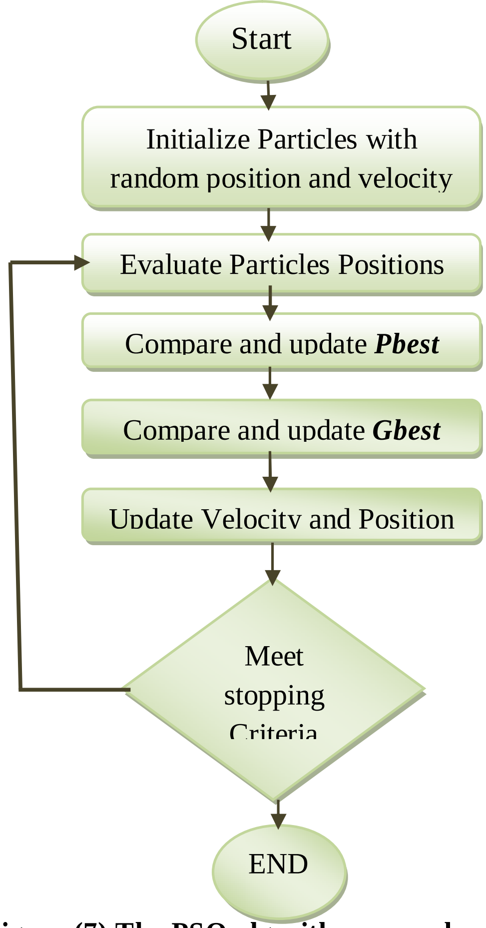

Figure (7) The PSO algorithm procedure.

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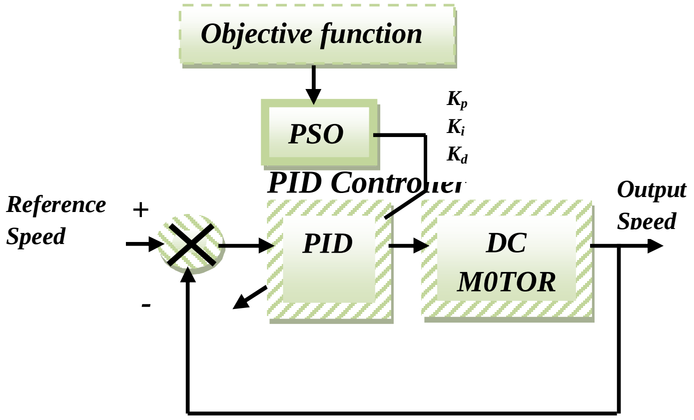

Figure (8) Optimal PID controller with PSO algorithm.

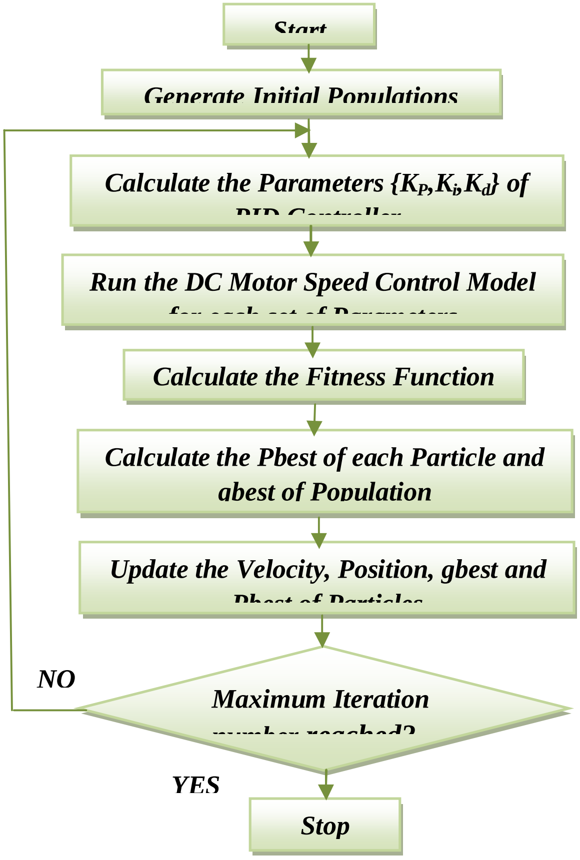

Figure (9) The Flowchart of the PSO-PID Control System

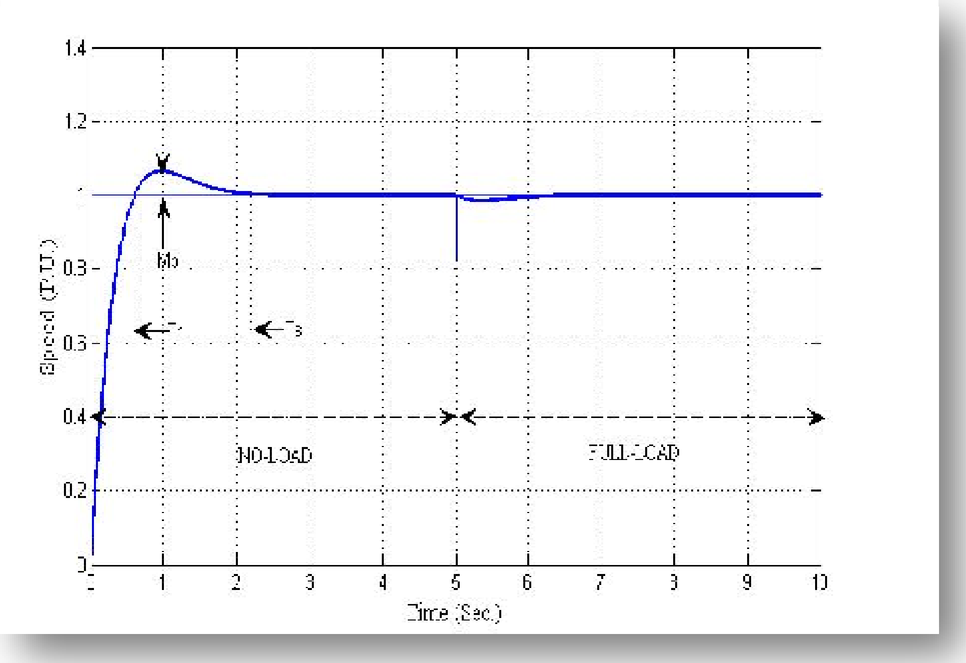

Figure (10) Speed response of PID Controller tuning parameters using PSO Strategy.

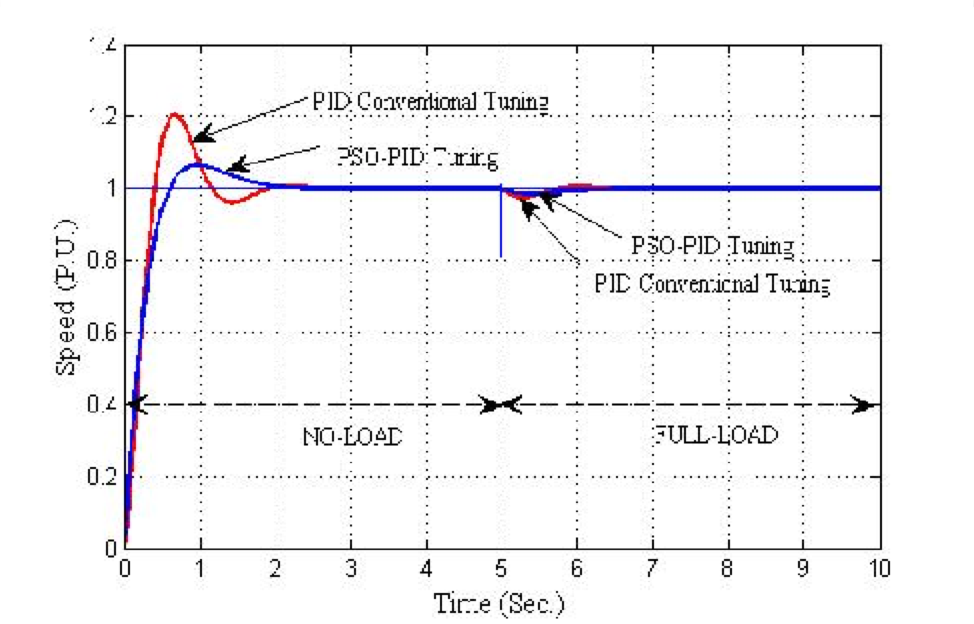

Figure (11) Comparing Performance of PSO-PI Controller and PID Conventional Controller.