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PSO-FL Controller of Separately Excited DC Motor

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ABSTRACT

This paper presents an application of highbrid controller of a Separately Exited DC Motor (SEDM) using PSO-FL techniques. The controller is designed depending on fuzzy logic rules are such that the systems are fundamentally robust. These rules have capability learning, can learn and tune rapidly, even if the motor parameters are varied. But, adapting fuzzy controller parameters is very complex and depends on operator experience. Therefore a Particle Swarm Optimization technique was adapted for obtaining the centers and the width of triangle inputs membership functions. The FL method is represented too. The complete mathematical model and simulation of a separately excited dc motor is represented using MATLAB10a/SIMULINK. The simulation results demonstrate that the proposed PSO-FL speed controller realizes a good dynamic behavior of the SEDM with very good speed tracking.

Keywords: Particle Swarm Optimization, Fuzzy Logic Controller (FLC), PSO Adapting of Fuzzy Parameters, Speed Control of Separately Excited DC. Motor (SEDM).

أمثلية الحشد الجزئي لتكييف المسيطر الضبابي لمحرك التيار المستمر ذو الإثارة المنفصلة

الخلاصة

يقدم هذا البحث تطبيق للمسيطر الضبابي المنطقي لمحرك التيار المستمر ذو الإثارة المنفصلة بإستخدام خوارزمية تحقيق الامثلية لإسراب الجزيئات. صُمم جهاز السيطرة طبقاً لقواعدِ المنطقِ الضبابيةِ حتى تكون الأنظمةُ متينة. القواعدِ لَها قابليةُ التعلم، يُمْكِنُ أنْ تَتعلّمَ وتتنغّمَ بسرعة، حتى عند إختلاف معاملات المحرّكِ. ولكن عملية تكييف براميترات المسيطر الضبابي معقدة جداً وتعتمد على خبرة المشغل. قُدِّمت في هذا البحث خوارزمية تحقيق الأمثلية لأسراب الجزيئات كتقنية للتكييف الأمثل لمراكز وعرض دوال العضوية المثلثة لمدخلات المسيطر الضبابي، كما وأن طريقة التكييف العادية ممثلة أيضا إنّ النموذج الرياضي الكامل ومحاكاة محرك التيار المستمر ذوالاثارة المنفصلة مُمَثَّلةٌ في هذا البحث بإستخدام الماثلاب/سيمولنك. تُبيّنُ نَتائِجُ المحاكاةَ بأنَّ تحقيقُ أمثلية أسراب الجزيئات المُقْتَرَحة يُحقق سلوكاً ديناميكاً جيداً في السيطرة على سرعة محرك التيار المستمر ذو الاثارة المنفصلة مع تعقب جيد جداً للسرعة.

INTRODUCTION

The DC motor has been popular in the industry control area for a long time, because they have many good characteristics for example: high start torque characteristics, high response performance and easier to be linear control. DC motor has a good speed control respond, wide speed control range. And it is widely used in speed control systems which need high control requirements, such as rolling mill, double- hulled tanker, and high precision digital tools etc. [1]. The speed of DC motor can be adjusted to a great extent as to provide controllability easy and high performance. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types. Fuzzy Logic (FL) was invented in 1970s, which was powerful tool in the field of control applications. The Fuzzy controller gives superior performance over the conventional control methods such as PID controllers even if the accurate mathematical model is not available [2].

Nowadays, several new intelligent optimization techniques have been emerged like: Genetic Algorithm (GA), Ant Colony Optimization (ACO), Simulated Annealing (SA), Bacterial Foraging (BF), and Particle Swarm Optimization (PSO) [3]. Due to its high potential for global optimization, PSO has received great attention in control system such as the search of optimal PID controller and fuzzy controller parameters. PSO is one of the modern heuristics algorithms; it was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-liner optimization problems [4, 5].

In this paper, the proposed Fuzzy-Logic controller (FLC) has some features for the speed control in Separately Excited DC Motor (SEDM), when the speed signal only is required in the control logic, and the transient response is improved. Then Particle Swarm Optimization (PSO) based method for adapting fuzzy controller parameters are proposed as a modern intelligent optimization algorithm. Finally the simulation results are demonstrated.

MATHEMATICAL MODEL OF SEPARATELY EXCITED DC 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 a DC machines have been frequently used in many applications requiring a wide range of motor speeds and a precise output motor control. In this paper, the separated excitation DC motor model is chosen according to its good electrical and mechanical performance more than other DC motor is driven by applied voltage.

In a separately excited dc motor, the field coil is supplied from a different voltage source than that of the armature coil. The field circuit normally incorporates a rheostat through which the field current, and thus the motors characteristics, can be externally controlled. This motor is mainly suitable for two types of loads; those that require constant torque for speed variations up to full-load speed, and those whose power requirements are constant for speed variations above nominal speed. The field current is constant, and then the flux must be constant. The electrical armature and field circuit can model the motor [6, 7]. In this simple model Ra and La indicate the equivalent armature coil resistance and inductance respectively and R_f and L_f indicate the equivalent field resistance and inductance respectively, V_a is the voltage supplied by the power source. The basic motor equations are:

$$T_d = K_f\, i_f\, i_a = K_m\, i_a \qquad \dots (1)$$

$$e_g = K_f\, i_f\, \omega_m = K_m\, \omega_m \qquad \dots (2)$$

$$V_a = e_g + R_a\, i_a + L_a \frac{d\, ia}{dt} \qquad \dots (3)$$

$$T_d = K_m\, i_a = J \frac{d\, Wm}{dt} + B\, \omega_m + T_L$$

$$\therefore \quad T_d - T_L = J \frac{d\, Wm}{dt} + B\, \omega_m \qquad \dots (4)$$

Where ***Km = K$_f$ i$_f$***, is a constant, $\boldsymbol{e_g}$ is the back electromotive force, $\boldsymbol{T_d}$ is the torque of the motor, $\boldsymbol{T_L}$ is the torque of the mechanical load; ***J*** is the inertia of the rotor and ***B*** is the damping coefficient associated with the mechanical rotational system of the motor.

From the previous equations the dynamic model of the separately excited DC motor is simulated as shown in Figure (1).

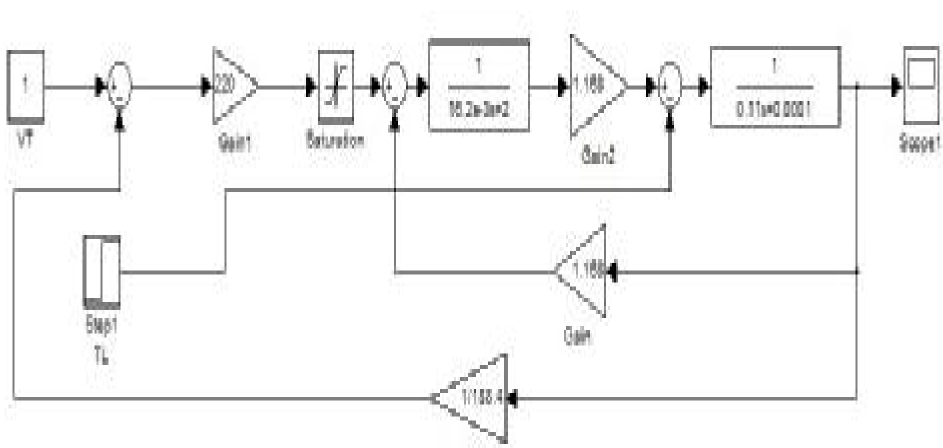

Figure (1) Block Diagram of Separately Excited DC Motor (SEDM).

FUZZY LOGIC CONTROL CONCEPTION

The fuzzy logic control foundation is based on the simulation of people's options and perceptions to control any system. One of the methods to simplify complex systems is to tolerate to imprecision, vagueness and uncertainty up to some extent. Fuzzy logic control is constructed on these logical relationships. Fuzzy Sets Theory is first introduced in 1965 by Zadeh to express and process fuzzy knowledge. There is a strong relationship between fuzzy logic and fuzzy set theory that is similar relationship between Boolean logic and classic set theory.

Fuzzy logic (FL) had many successful applications mostly in control. One of the main advantages of fuzzy logic system is the design on the basis of incomplete and approximate information, thus providing simple and fast approximations of the unknown or too complicated models [8].

The main idea of fuzzy control, which had proved to be a very successful method, is to build a model of human control expert who is capable of controlling the plant without thinking in terms of mathematical model. Usually the Mamdani method is used in adaptive fuzzy logic controller system. For example: if X & Y are the inputs of the fuzzy system, and "*F*" is the output signal:

IF X is A_1 AND Y is B_1 THEN $z=f_1$

IF X is A_2 AND Y is B_2 THEN $z=f_2$

The output "F" can be constructed as:

$$F = \frac{W_1}{W_1+W_2} f_1 + \frac{W_2}{W_1+W_2} f_2 \qquad \dots (5)$$

Where: A_1, A2, B1, B2 are the input membership functions, f_1 and f_2 are the output singleton membership functions, and w_1 and w_2 are the Degree of Fulfillments (DOF) of rule 1 & 2, which can be adaptive to satisfied the input/output data [2].

As mentioned before the selection of Membership Functions (MFs) for the input and output variables and the determination of fuzzy rules are not always easy. There is no formal framework for the choice of the parameters of FLC and hence the means of tuning them and learning models in general have become an important subject of fuzzy control.

LAYOUT OF FUZZY LOGIC CONTROLLER

The function of the fuzzy controller is to observe the pattern of the speed loop error signal and correspondingly updates the control signal so that the actual speed (n_r) matches the command speed (n_r^*). There are two input signals to the fuzzy controller: The error $E = (n_r^*-n_r)$, and the change of error *CE* (also it known as the future of error), which is related to the derivative of error *dE/dt*. A simple fuzzy logic controller of two inputs and one output can be used in this application, for each input three of triangle memberships was used, and five triangle memberships for the output. For such FLC nine (3*3) of *"If"* statement rules was used. Adapting of the input/output memberships positions are very difficult, especially for one don't have experience of the system behavior. Trial and error method can be used in such situations, in this work the final suitable distribution of the input/output memberships after several trial and error iterations can be shown in Figure (2).

The overall system simulation is illustrated in Figure (3). System performance of different command speed, with fuzzy logic controller, under full-load condition is shown in Figure (4). Where the used Separately Excited D.C. Motor (SEDM) which has the following name plate: 220 Volt, L_a= 3.2 mH, R_a= 2 Ω, rotor inertia (J) = 0.11 kg/m^2, B=0.0001N.M. TL=21.4 N.m [9].

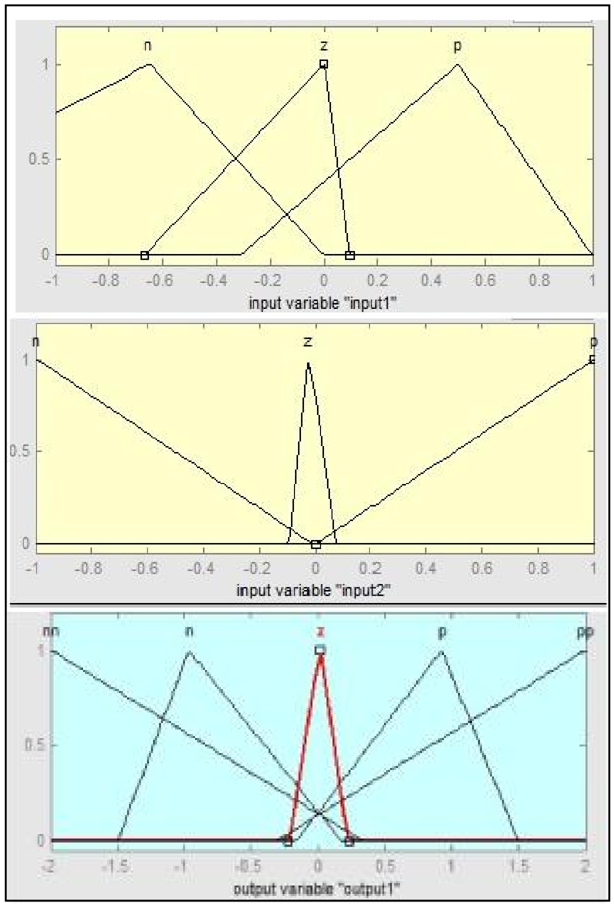

Figure (2) the Conventional Adapting of Input/output MFs.

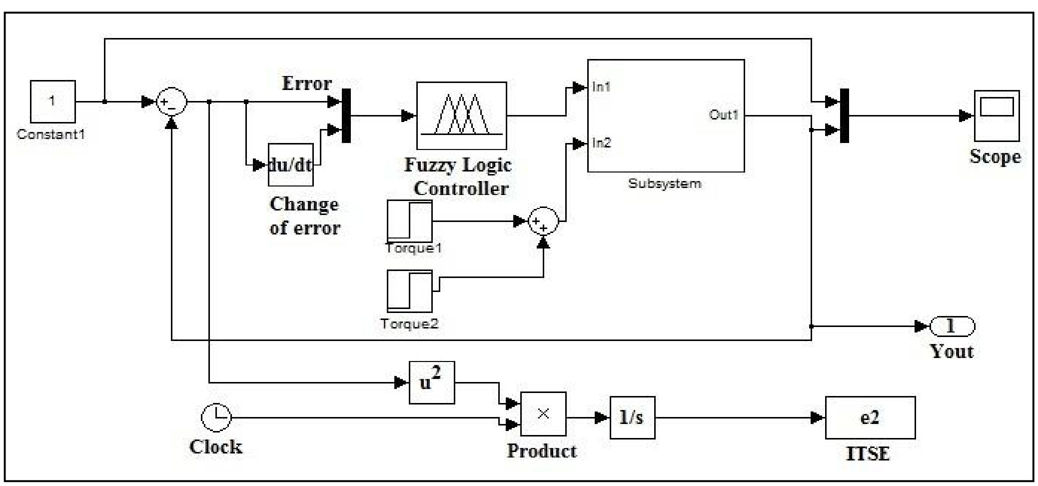

Figure (3) Overall System Simulation.

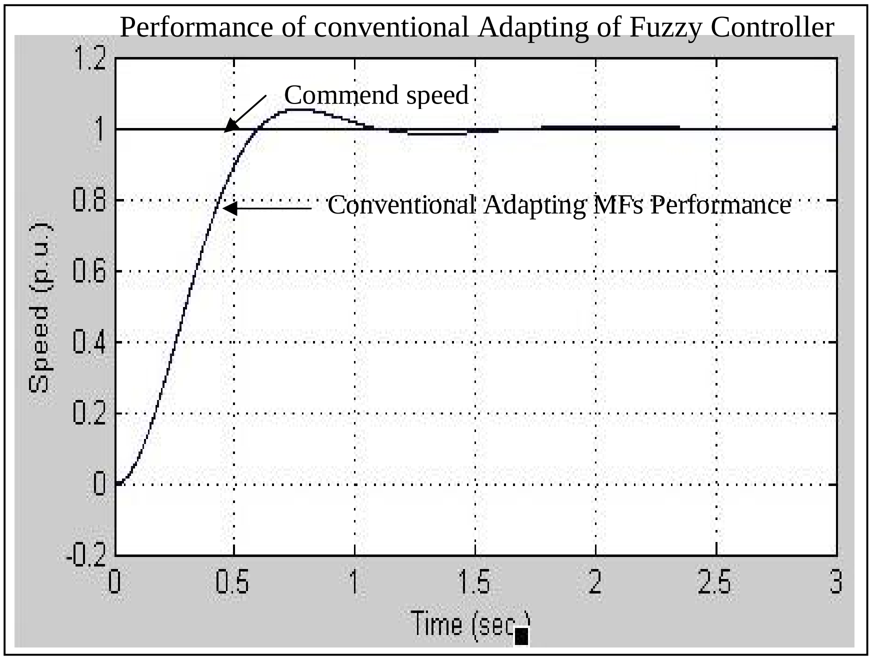

Figure (4) System Performance of FL controller.

PARTICLE SWARM OPTIMIZATION *(PSO)* ALGORITHM

The particle swarm optimization was introduced by James Kennedy and Russ Eberhart in 1995 [4, 10]. Some of the attractive features of PSO include the ease of implementation and the fact that no gradient information is required. It can be used to solve a wide array of different optimization problems. Like evolutionary algorithms, PSO technique conducts search using a population of particles, corresponding to individuals. 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 [2, 4, 10, and 11]. The assumption is a basic concept of PSO. In the PSO algorithm, instead of using evolutionary operators such as mutation and crossover, to manipulate algorithms, for a 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 value so far (P_{best}) and the position 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:

$$x_i=(x_{i1}, x_{i2},\ldots, x_{id}) \qquad \ldots(6)$$

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

$$Pbest_i=(Pbest_{i,1}, Pbest_{i,2},\ldots\ldots, Pbest_{i,d}) \qquad \ldots(7)$$

The index of best particle among all of particles in the group is *gbest.* The velocity for particle I is represented as: $v_i=(v_{i1}, v_{i2},\ldots., v_{id})$. The modified velocity and position of each particle can be calculated using the current velocity and distance from ($Pbest_{i,d}$)to ($gbest_d$) as shown in the following formulas [10 ,12,13]:

$$v_{i,m}^{t+1} = w.v_{i,m}^{(t)} + c_1 * rand * \left(Pbest_{i,m} - x_{i,m}^{(t)}\right) + c_2 * rand * \left(gbest_m - x_{i,m}^{(t)}\right) \ldots\ldots.(8)$$

$$i = 1,2, \ldots\ldots.n;$$

$$m = 1,2, \ldots.d$$

$$x_{i,m}^{(t+1)} = x_{i,m}^{(t)} + v_{i,m}^{(t+1)} \qquad \ldots (9)$$

Where:
n=Number of particles in the group.
d=Dimension.
t=Pointer of iterations (generation).
$v^{(t)}_{i,m}$*=Velocity of particle I at iteration.*
w=Inertia weight factor.
c_1,c_2*=Acceleration constant.*
rand=Random number between 0-1.

$x^{(t)}_{i,d}$*=current position of particle i at iterations.*
$Pbest_i$*=Best previous position of the i-th particle.*
gbest=Best particle among all the particles in the population.

THE APPLICATION OF THE PROPOSED CONTROLLER

In order to design the optimal fuzzy controller, the particle swarm optimization (PSO) algorithms are applied to search globally optimal parameters of fuzzy logic. In this paper is same what complex, because the performance of the system was examined in each iteration and particles position during the optimization algorithm is applied by using MATLAB m-file program and linked with the system simulation program in MATLAB/SIMULINK. The main problem in this work is to optimize the position of the two inputs (*E, CE*) memberships. Each triangle membership is recognized by three parameters: left corner, right corner, and center. Therefore, for six memberships (of the two inputs) eighteen (6*3) parameters must be adapted. Thus, the particles (birds) have eighteen dimensions, or in other words particles must 'fly' in eighteen dimensional spaces. A random of 15 particles positions is assumed (for each dimension 15 birds), and optimization algorithm of 20 iteration is used to estimate the optimal positions of the two inputs memberships parameters. In most intelligent optimization algorithms, there are commonly performance criteria such as: Integrated Absolute Error (IAE), the Integrated of Square Error (ISE), and Integrated of Time weight Square Error (ITSE). That can be evaluated analytically in frequency domain [14]. Each criterion has its 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 disadvantageof ISE criterion. The IAE, ISE, and ITSE performance criterion formulas are as follows:

$$IAE = \int_0^t |r(t) - y(t)|dt = \int_0^\infty |e(t)|dt \qquad \dots (10)$$

$$ISE = \int_0^t e^2(t)dt \qquad \dots (11)$$

$$ITSE = \int_0^t t * e^2(t)dt \qquad \dots (12)$$

In this paper, the integrated of time weight square error ITSE is used for evaluating the accuracy performance of the fuzzy controller. A set of good control parameters can yield a good step response that will result in performance criteria minimization in the time domain, this performance criterion is called Fitness Function (FF) which can be formulated as follows [14,15]:

$$FF = (M_P + E_{ss}) * \beta + ITSE \qquad \dots (13)$$

Where:

M_P is maximum overshot.

E_{ss} is steady state error.

β is the weight factor can set to be larger than 0.7 to reduce the overshot and steady state error, also can be smaller than 0.7 to reduce the rise time and settling time. The parameters of the separately excited DC motor (SEDM) considered in this study are summarized. PSO algorithm process can be summarized in the flowchart shown in Figure (5). And the final obtained positions of the membership functions from the particle swarm optimization algorithm are illustrated in Figure (6).

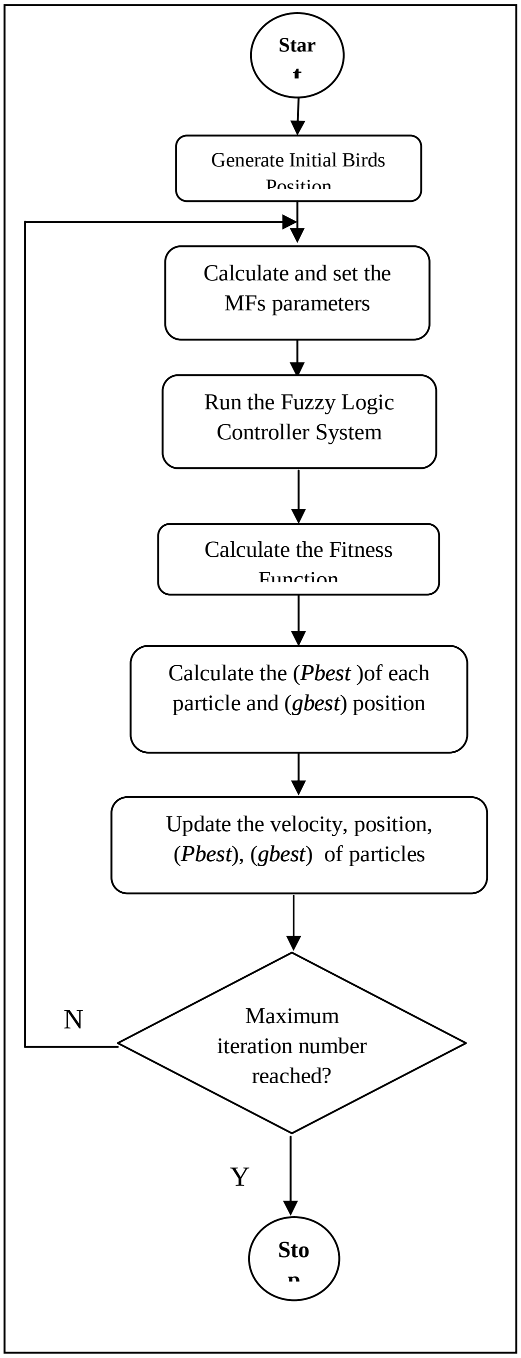

Figure (5) Flowchart of PSO Algorithm

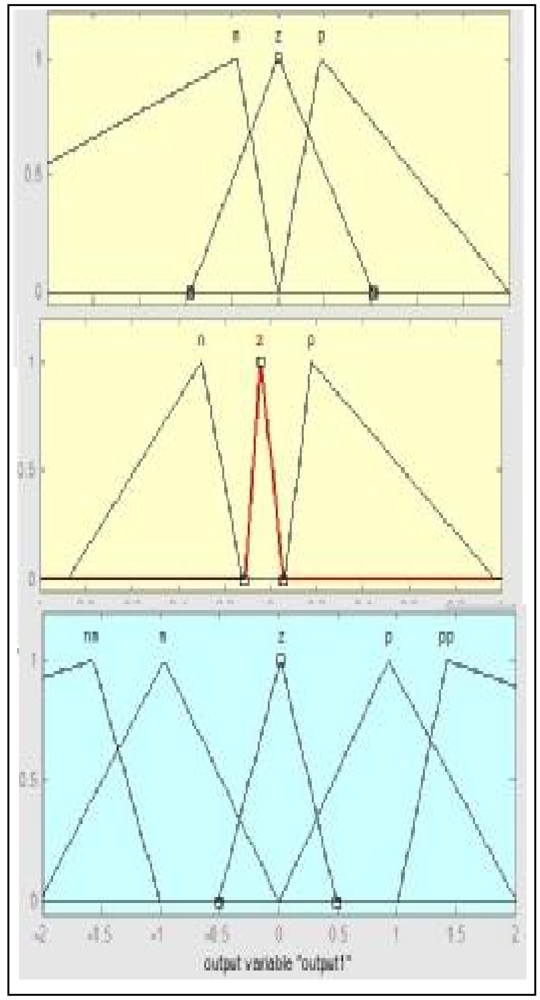

Figure (6) PSO Adapting of Input MFs.

System performance of PSO-based for unit step rated speed is shown in Figure (7).A comparison performance between the proposed PSO method and the conventional adapting method of the fuzzy controller membership functions is illustrated in Figure (8). Output surface of proposed PSO method and the conventional adapting method of fuzzy logic controller is shown in Figure (9).

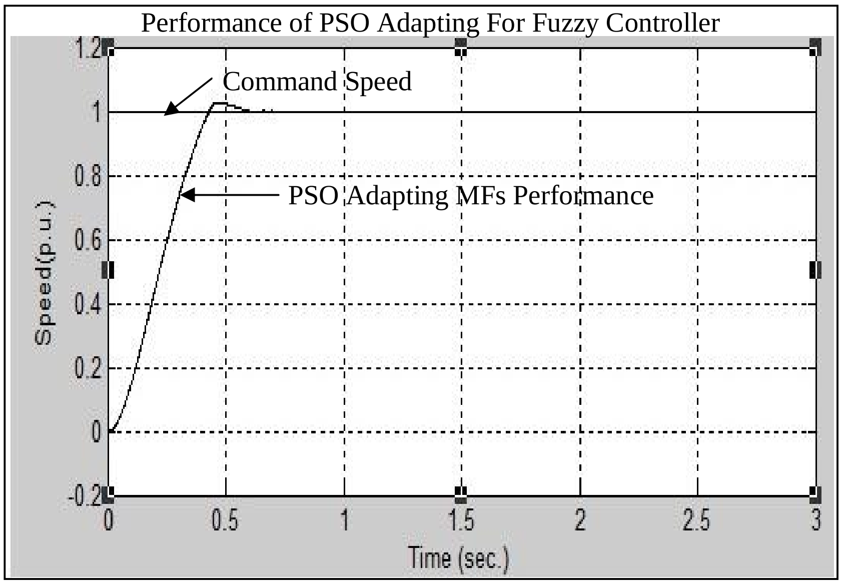

Figure (7) System Performance of PSO Adapting FLC.

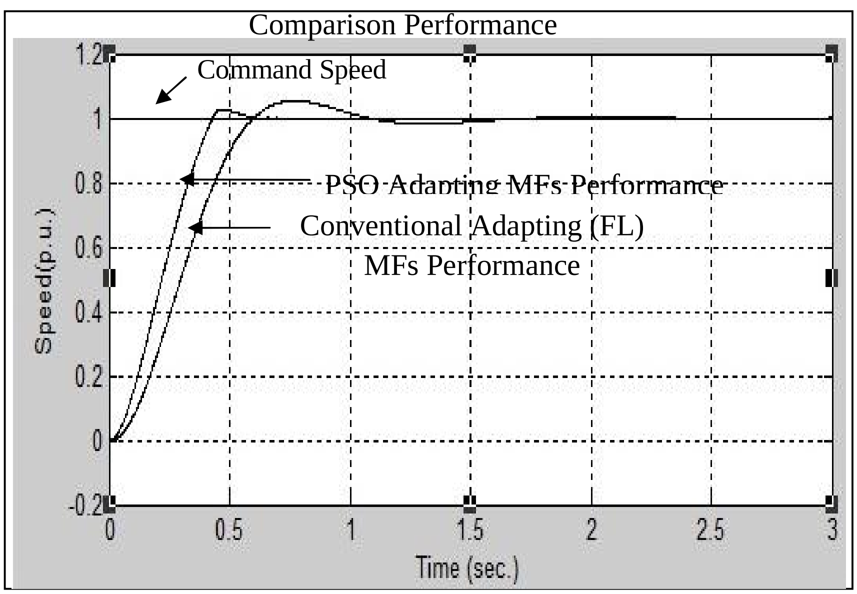

Figure (8) Comparison Performance

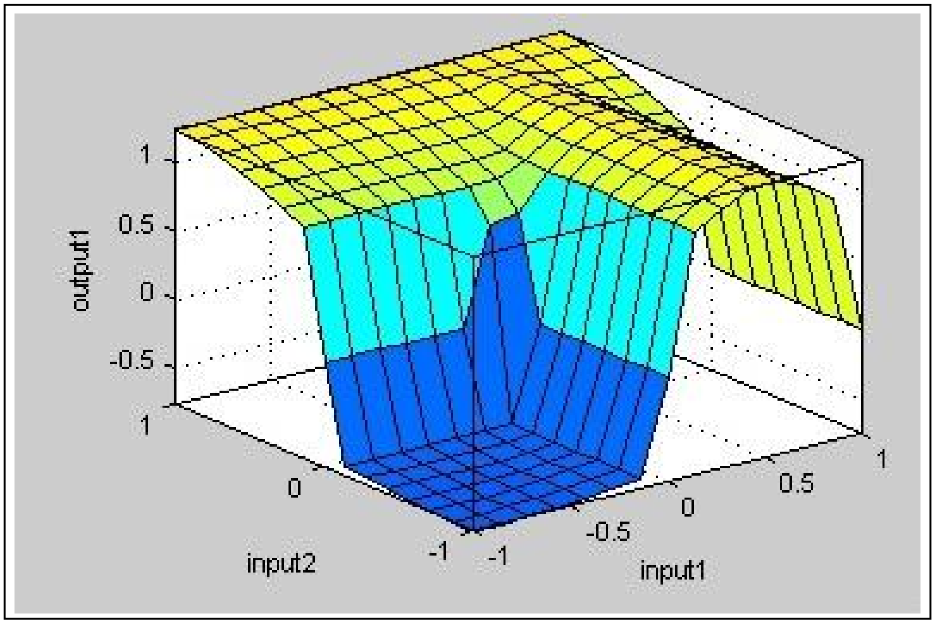

Figure (9) Output Surface of PSO Adapting FLC

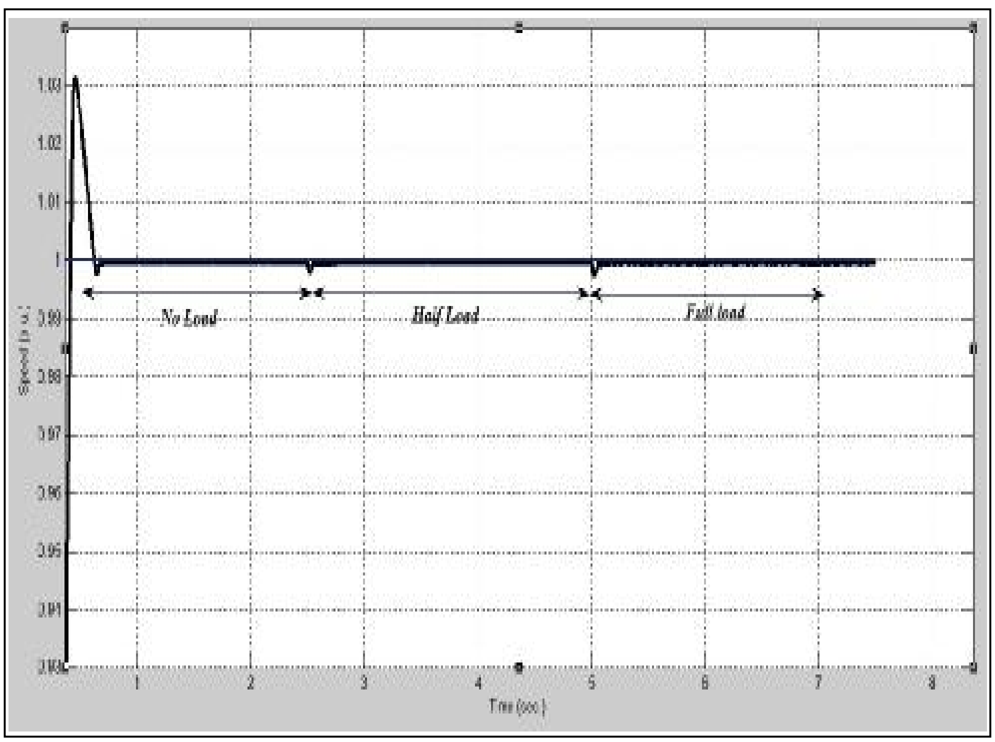

Figure (10) the Speed Response of PSO Adapting FLC under Different Load Conditions.

Conclusion

According to our MATLAB model simulation, we illustrate a comparison performance between the proposal PSO method and the conventional adapting method of the fuzzy logic controller, from which the following tips can be concluded:

1) The proposed PSO adapting method can be obtained a robust and precise speed control for a SEDM. This robust tested under different load conditions .The output speed performance of separately excited dc motor under no-load and half load and full load conditions is shown in fig.(10).
2) It's very c efficient in eliminate computing time, easy to implement, and simple concept. Unlike, the FL which needs long adapting time and complex procedure.
3) The proposed highbrid controller presented satisfactory performances and possesses good robustness
   the overshoot is 3% approximately , the rise time 0.4sec ,steady state error is zero, and settling time is 0.7sec approximately as obtained from simulation results, comparing to the conventional adapting method of the fuzzy logic controller where the overshoot is 7% approximately , the rise time 0.6 sec ,and settling time is 1.5sec approximately.
4) The proposed controller adapting method gives very good speed tracking with non-sluggish performance and high robust controller than those obtained by the conventional adapting of fuzzy logic controllers.

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