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Enhancement of stability and accuracy of the SEDC Motor under the effect of the external disturbances and noise by using Fuzzy-controller Based on PSO

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Abstract: For electrical drives good dynamic performance is mandatory so as to respond to the changes in command speed and torques, so various speed control techniques are being used for real time applications. The speed of a DC motor can be controlled using various controllers like PID Controller, Fuzzy Logic Controller, Particle Swarm Optimization (PSO) and Hybrid Fuzzy-PSO Controller. Fuzzy-PSO Controller is recently getting increasing emphasis in process control applications. The paper describes application of Hybrid Fuzzy-PSO Controller in an enhancement of stability and accuracy of the SEDC Motor under the effect of the external disturbances and noise that uses the Fuzzy-PSO Controller for enhancement of stability and accuracy of the SEDC Motor under the effect of the external disturbances and noise is implemented in MATLAB/SIMULINK. The simulation study indicates the superiority Hybrid Fuzzy-PSO Controller over the Particle Swarm Optimization (PSO) and fuzzy logic controller separately. This control seems to have a lot of promise in the applications of power electronics. The speed of the SEDC motor can be adjusted to a great extent so as to provide easy control and high performance. There are several conventional and numeric types of controllers intended for controlling the SEDC motor speed and executing various tasks: PID Controller, Fuzzy Logic Controller; or the combination between them: Fuzzy-Swarm, Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Particle Swarm Optimization. We describe in this paper the use of Hybrid Fuzzy-PSO Controller for enhancement of stability and accuracy of the SEDC Motor under the effect of the external disturbances and noise We describe in this paper the use of Particle Swarm Optimization (PSO) for designing an optimal fuzzy logic controller of a SEDC Motor. In this case, our approach will optimize the membership functions of a fuzzy logic controller (FLC) using PSO and the obtained results were simulated on Matlab environment.

Keywords: Separately Excited DC Motor (SEDC), Fuzzy Logic Controller (FLC), Particle Swarm Optimization(PSO).

I.INTRODUCTION

We describe in this paper an approach for designing a fuzzy logic controller of a SEDC Motor optimized with PSO.Nowadays, to obtain optimal controllers is a hard task andis complicated to choose the optimal parameters in the control system; therefore, in this case, we design an optimal fuzzy logic controller using an optimization method, in this case PSO [1][2]. The method is called FLC+PSO. Several approaches have been developed in the control area to solve problems of tuning some parameters in some parts of the systems, for example, in [3] it is shown a similar approach using PSO applied to the Preview Control problem, which regularly is obtained using the Algebraic Riccati Equation.

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The solution obtained is good but it is not optimal and has a scope of improvement. Therefore the authors presented a method of design of a Preview Controller using the Particle Swarm Optimization method. The procedure is based on improving the performance by minimizing the objective function i.e. IAE (Integral of Absolute Error). In [4] it is presented a PSO for reactive power and voltage control (volt/VAr control: VVC) considering voltage security assessment (VSA). VVC can be formulated as a mixed-integer nonlinear optimization problem (MINLP). The proposed method expands the original PSO to handle a MINLP and determines an online VVC strategy with continuous and discrete control variables such as automatic voltage regulator (AVR) operating values of generators, tap positions of on-load tap changer (OLTC) of transformers, and the number of reactive power compensation equipment. However our approach is different because we are using a fuzzy system, where the PSO is within the membership functions to find the best parameters of the membership function and to achieve a good control.

II. MODELING WITHOUT & UNDER THE EFFECT OF THE LOAD

The S.E.DC motor transfer function without load is shown in the block diagram in Fig.1.

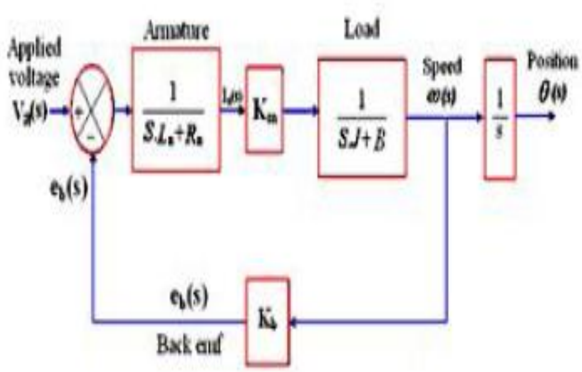

Fig.1 Block diagram of S.E.DC motor without load (Td)

The equations of The SEDC motor in terms of armature control based on Newton's law combined with Kerchief's law are as follows:

$$V_a = L_a \cdot \frac{di_a(t)}{dt} + R_a i_a(t) + e_b \qquad (1)$$

$$L_a \cdot \frac{di_a(t)}{dt} + R_a i_a(t) = V_a - K_b \frac{d\theta}{dt} \qquad (2)$$

The motor torque equation is

$$T_m = J.\frac{d^2\theta}{dt^2} + B.\frac{d\theta}{dt} = K_m i_a(t) \qquad (3)$$

Where

$T_m = T_L + T_d$

At (Td=0) which without disturbance torque (External Disturbance and Noise), $T_m = T_L$. Where TL is the load torque, Td is the disturbance torque &Tm is The motor torque. Using the Laplace transform for equations (1), (2) and (3) assuming initial conditions equal zero can be written as

$$(L_a s + R_a) I_a(s) = V_a(s) - K_b s\theta(s) \qquad (4)$$

$$s(Js + B)\theta(s) = K_m \cdot I_a(s) \qquad (5)$$

$$T_m(s) = T_d(s) + T_L(s)$$

$$s(Js + B)\theta(s) = K_m \cdot \frac{V_a(s) - K_b s\theta(s)}{R_a + L_a s} \qquad (6)$$

Where s denotes the Laplace operator. From equation (4) $I_a(s)$ is given as follow:

$$I_a(s) = \frac{V_a(s) - K_b s\theta(s)}{R_a + L_a s} \qquad (7)$$

by substituting it in equation (5) to obtain

$$\frac{\omega(s)}{V_a(s)} = \frac{K_m}{(Js+B)(L_a s + R_a) + K_m K_b} \qquad (8)$$

The S.E.DC motor transfer function of armature control from the applied armature voltage (input voltage), $V_a(s)$, to speed (the angular velocity) $s\theta(s) = \omega(s)$ without load Which is $(T_d(s)=0)$. The S.E.DC motor transfer function without load is shown in the block diagram in fig. 1. The transfer function given by equation (8) may be written in terms of the time constants of the motor as follows

$$\frac{\omega(s)}{V_a(s)} = \frac{K_m}{R_a B\ (1+s\tau_a)(1+s\tau_m) + K_m K_b} \qquad (9)$$

Where

τ_a L_a/R_a = time constant of armature circuit.

τ_m J/B = mechanical time constant.

S.E.DC motor transfer function of armature control from the Applied armature voltage (input voltage) Va(s) to speed (the angular velocity) $\omega(s)$ with load $T_d(s)$ will become as follows:

$$\omega(s)=\frac{K_m}{(Js+B)(L_a s+R_a)+K_m K_b}V_a(s)-\frac{L_a s+R_a}{(Js+B)(L_a s+R_a)+K_m K_b}T_d(s) \quad (10)$$

S.E.DC motor transfer function with load Td(s) is shown in the block diagram in Fig.2 [5-6].

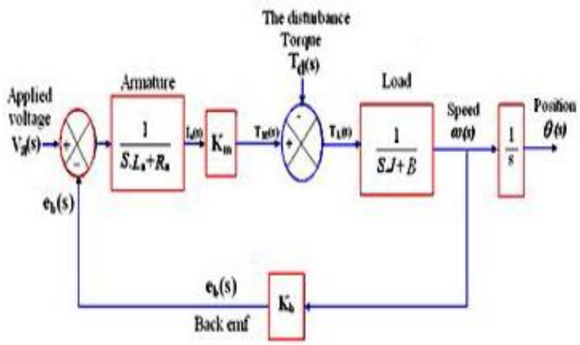

Fig. 2 Block diagram of S.E.DC motor with load (Td)

III. FUZZY LOGIC CONTROLLER

The concept of fuzzy logic was developed by Lotfi Zadeh in 1964 to address uncertainty and imprecision which widely exist in engineering problems. Fuzzy modeling is the method of describing the characteristics of a system using fuzzy inference rules. The method has a distinguishing feature in that it can express linguistically complex nonlinear systems. It is however, very hard to identify the rules and tune the membership functions of the fuzzy reasoning. Fuzzy controllers are normally built with the use of fuzzy rules. These fuzzy rules are obtained either from domain experts or by observing the people who are currently doing the control. The membership functions for the fuzzy sets will be derived from the information available from the domain experts and/or observed control actions.

The building of such rules and membership functions require tuning. That **is,** performance of the controller must be measured and the membership functions and rules adjusted based upon the performance. This process will be time consuming. The basic configuration of Fuzzy Logic Controller (FLC) consists of four main parts (i) Fuzzification where values of input variables are measured and a scale mapping that transforms the range of values of input variables into corresponding universe of discourse is performed then performs the function of fuzzification that converts input into suitable linguistic values, which may be, viewed labels of fuzzy sets. (ii) Knowledge Base consists of data base and linguistic control rule base. The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in an FLC. The rule base characterizes the control goals and control policy of the domain experts by means of set of linguistic control rules. (iii) The Decision Making Logic, it has the capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic. (iv) The Defuzzification a scale mapping which converts the range of values of input variables into corresponding universe of discourse [7-11].

In view to make the controller insensitive to system parameters change, fuzzy logic theory is also implemented by researchers extensively. Indulkar et. al [12] initially designed a controller using fuzzy logic for automatic generation control and responses were compared with classical integral controller. Chang et. al. [13] presented a new approach to study the LFC problem using fuzzy gain scheduling of proportional-integral controllers and proposed scheme has been designed for a four area interconnected power system with control deadbands and generation rate constraints. Ha [14] applied the robust sliding mode technique to LFC problem where, control signal consists of an equivalent control, a switching control and fuzzy control with generation rate constraints and governor's backlash on the other hand the fuzzy controller designed by Chown et. al [15] when implemented not only grid was controlled better but also more economically. Talaq et. al [16] in their research proposed an adaptive controller which requires less training patterns as compared with a neural net based adaptive scheme and performance was observed better than fixed gain controller.

Ha et. al [17] proposed an approach which combines the salient features of both variable structure and fuzzy systems to achieve high performance and robustness. Fuzzy logic controller, designed by El-Sherbiny [18], is a two layered fuzzy controller with less overshoot and small settling time as compared with conventional one. Ghoshal [19] presented a self adjusting, fast acting fuzzy gain scheduling scheme for conventional integral gain automatic generation controller for a radial and ring connected three equal power system areas. Yensil et. Al [20] proposed a self tuning fuzzy PID type controller for LFC problem and satisfactory results are found when compared with fuzzy PID type controller without self tuning.

IV. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Eberhart and Kennedy in 1995, inspired by the social behavior of bird flocking or fish schooling [21]. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA) [22]. The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike the GA, the PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles [23]. Each particle keeps track of its coordinates in the problem space, which are associated with the best solution (fitness) it has achieved so far (The fitness value is also stored). This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbors of the particle. This location is called lbest. When a particle takes all the population as its topological neighbors, the best value is a global best and is called gbest. The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its pbest and lbest locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward pbest and lbest locations [24] [25].

In the past several years, PSO has been successfully applied in many research and application areas. It has been demonstrated that PSO gets better results in a faster, cheaper way compared with other methods [26]. Another reason that PSO is attractive is that there are few parameters to adjust. One version, with slight variations, works well in a wide variety of applications. Particle swarm optimization has been used for approaches that can be used across a wide range of applications, as well as for specific applications focused on a specific requirement. The pseudo code of the PSO is as follows:

For each particle

```
End
Do
   For each particle
      Calculate fitness value
      If the fitness value is better than the best fitness value
(pBest) in history
         set current value as the new pBest
   End
   Choose the particle with the best fitness value of all the
particles as the gBest
   For each particle
      Calculate particle velocity
      Update particle position
   End
While maximum iterations or minimum error criteria is not
attained
```

V. HYBRID FUZZY PSO CONTROLLER

The methodology of this paper involved the Development of a PSO algorithm to optimize the parameters of membership functions of a fuzzy logic controller that controls the velocity of a DC motor. This is possible evaluating the ranges of membership functions within the fuzzy logic controller. After getting the optimal parameter the full model was implemented in Matlab environment where the PSO will create the optimal topologies to achieve a possible solution to this problem, allowing each particle vector containing the potential range of optimal membership for the fuzzy system and to obtain a better result in the simulation. A s the error achieved by the plant is lower, the cost of the particle will be saved as the minimum cost of such a particle to subsequently save the best overall result from all over the swarm.

VI.DESIGN REQUIREMENTS FOR THE SYSTEM

The most basic requirement of S.E.DC motor is that it should be rotated at the desired speed without and under the effect of loads (external disturbances and noise) and intelligent controller is used for reducing the sensitivity of actual response as to load variations (external disturbances and noise), where the actual response variations that have been induced by such external disturbances and noise must be minimized rapidly. The steady-state error of the S.E.DC motor speed should be minimized. The other performance requirement is that motor must accelerate to its steady-state speed as soon as it turns on, The SEDC motor is driven by applied voltage. The reference input (applied voltage) (V) is simulated by unit step input, then an actual response of S.E.DC motor should have the design requirements for the system as follows

(i) Minimize the maximum overshoot

(ii) Minimize the rise time

(iii) Minimize speed tracking error

(iv) Minimize the steady state error

(v) Minimize the settling time

(vi) The system is controllable and observable

(vii)All roots of characteristic equation are lying in the left half of s-plane.

(viii) Damping ratio (ζ) is between (0.4 & 0.86).

The speed of a SEDC motor could be varied from zero to rated speed mainly by varying armature voltage in the constant torque region. Whereas in the constant power region, field flux should be reduced to achieve speed above the rated speed. The motor drives a mechanical load characterized by inertia J, Viscous friction coefficient B, and load torque T_L. The specifications of the SEDC motor are given in table 1.

Armature resistance R_a	2.0 Ohm
Armature inductance L_a	0.5 H
Field resistance R_f	240 Ohm
Field inductance L_f	120 H
Shaft power P	5 hp
The motor torque constant Km	0.1
The back e.m.f constant Kb	0.1
The tachometer constant Kt	1
Viscous friction coefficient B	0.2 Nms
Total inertia J	0.02 kgm^2
Rated voltage V	240 V

Table 1. The specifications of the SEDC motor

VII.SIMULATION RESULTS

Fig.3 shows The structure of the fuzzy controller with PSO algorithms and Fig. 4-5 shows results of simulation (Matlab environment) of a Enhancement of stability and accuracy of the SEDC Motor without and under the effect of the external disturbances and noise by intelligent controller (Fuzzy logic controller, particle swarm optimization (PSO), FLC+PSO). The actual response of FLC+PSO Controller comparing with the actual response of FLC, and PSO algorithms is shown in Fig. 5. Table 2 lists the Comparison of the performances of Fuzzy, PSO and hybrid Fuzzy-PSO controllers, to show the effectiveness of the proposed approach.

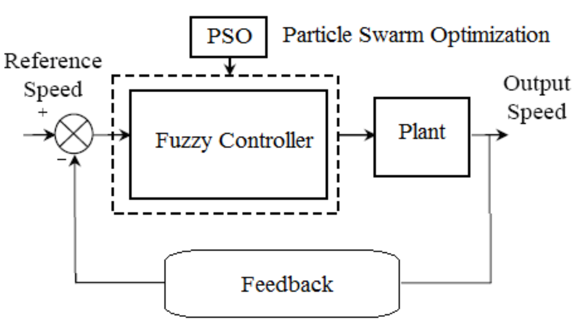

Fig. 3 The structure of the fuzzy controller with PSO algorithms.

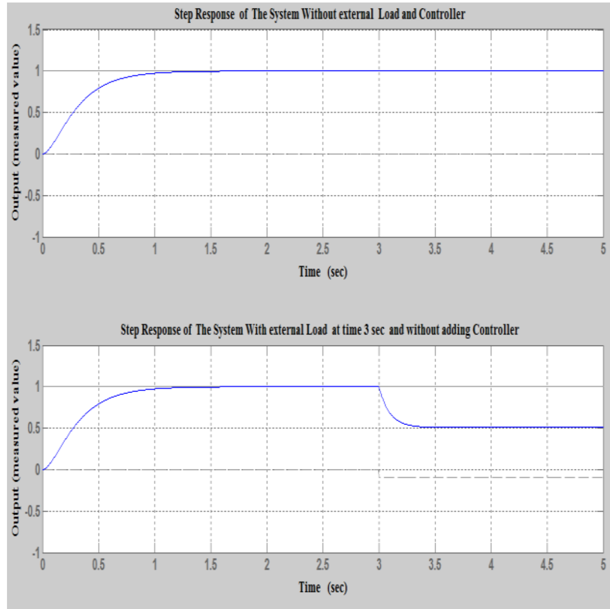

Fig 4 Step response of the system with external load at time 3sec and without adding controller.

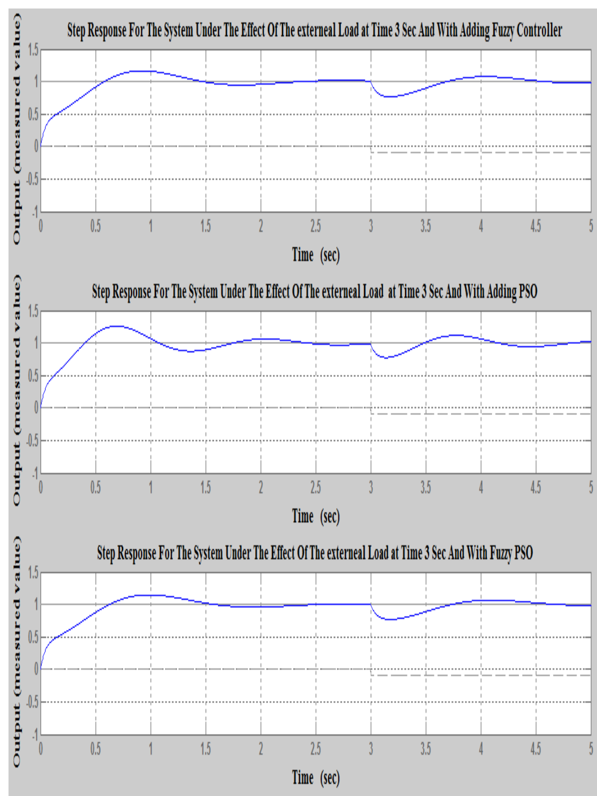

Fig.5 Simulation Results of the comparison among the Fuzzy,PSO and Hybrid Fuzzy-PSO Controller.

SEDC motor under the effect of the load variation, External disturbances and noise at time t = 3 (sec)			
specifications	Strategy of control		
	Fuzzy Logic control method	PSO control method	Fuzzy-PSO control method
Damping ratio (ξ)	0.7946	0.7017	0.7946
Settling Time (t_s)	0.383 sec	0.2130 sec	0.3830
Maximum Overshoot (%M_p)	1.6373 %	4.5326 %	1.6373
Steady-State Error (e_{ss})	0	0	0
Peak Time (t_p)	1.2100	0.1290	0.1210
Rise Time (t_r)	0.56	0.0540	0.0560

Table 2 Comparison of Fuzzy, PSO and hybrid Fuzzy-PSO controller.

VIII .CONCLUSION

By using Hybrid Fuzzy-PSO Controller for enhancement of stability and accuracy of the SEDC Motor under the effect of the external disturbances and noise, . The speed response for constant load torque shows the ability of the drive to instantaneously reject the perturbation. The design of controller is highly simplified by using a cascade structure for independent control of flux and torque. Excellent results added to the simplicity of the drive system, makes the Hybrid Fuzzy-PSO Controller based control strategy suitable for a vast number of industrial, paper mills etc. The sharpness of the speed output with minimum overshoot defines the precision of the proposed drive. Hence the simulation study indicates the superiority of Hybrid Fuzzy-PSO Controller over the Particle Swarm Optimization (PSO) and Fuzzy logic controller separately. . This control seems to have a lot of promise in the applications of power electronics. After having applied the proposed FLC-PSO method we can conclude in this paper, that the use of optimized Fuzzy Logic Controllers is possible to achieve very good results. In particular with this application we are demonstrating statistically that there is significant difference when the controllers are developed manually or automatically. Therefore, with the results presented in the paper we can recommend the use of optimization methods to find some important parameters, in this case, PSO was only used to design the optimal topology of the membership functions. However, Genetic Algorithms, Ant Colony Optimization and other approaches could also be used to achieve this goal. We decided to use PSO, because it is a very good method to implement with this type of applications and is faster that other similar approaches to achieve the goal. Experimental results show better performances that are achieved with the proposed method, optimization with the proposed method FLC-PSO, when it is compared with the controllers without optimization. PSO method optimizes the membership functions, however our proposed method optimizes membership functions and is able to adapt parameters in the PSO in run time, which leads to more robust and better method than the above mentioned approach.

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