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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-Neuro Controller

AHMAD M.EL-FALLAH ISMAIL[1],A.K.BHARADWAJ[2] ,RAJIV RANJAN TEWARI[3]

[1]Research Scholar in the Department of Electrical and Electronic Engineering, Shepherd School of Engineering & Technology, SHIATS-Deemed University (India), and Research Scholar in the Department of Electronic and Communication Engineering, University of Allahabad (India),, E-mail: Ahmad_engineer21@yahoo.com.

[2] Professor in the Shepherd School of Engineering and Technology, Sam Higganbottom Institute of Agriculture, Technology and Sciences-Deemed University (Formerly AAI-DU) Allahabad, India.

[3] Professor in the Department of Electronics and Communication, J.K Institute of Applied Physics and Technology, University of Allahabad, Email: rrt_au@rediffmail.com.

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, Artificial Neural Network (ANN) controller and Hybrid Fuzzy-Neuro Controller. Fuzzy-Neuro Controller is recently getting increasing emphasis in process control applications. The paper describes application of Fuzzy-Neuro 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-Neuro 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-Neuro Controller over the neural network 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. We describe in this paper the use of Hybrid Fuzzy-Neuro Controller of a SEDC Motor. In this case, the obtained results were simulated on Simulink of Matlab.

Keywords: Separately Excited DC Motor (SEDC), Fuzzy Logic Controller (FLC), Artificial Neural Network(ANN) Controller.

I.INTRODUCTION

In spite of the development of power electronics resources, the direct current machine became more and more useful. Nowadays their uses isn't limited in the car applications (electrics vehicle), in applications of weak power using battery system (motor of toy) or for the electric traction in the multi-machine systems too. The speed of SEDC motor can be adjusted to a great extent as to provide controllability easy and high performance [1, 2]. 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, the controllers can be: PID Controller, Fuzzy Logic Controller; or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy- Ants Colony, Fuzzy-Swarm. The Adaptive Neuro-Fuzzy Inference System (ANFIS), developed in the early 90s by Jang [3], combines the concepts of fuzzy logic and neural networks to form a hybrid intelligent system that enhances the ability to automatically learn and adapt. Hybrid systems have been used by researchers for modeling and predictions in various engineering systems. The basic idea behind these neuro-adaptive learning techniques is to provide a

Corresponding Author: Ahmad M. EL-Fallah Ismail, Research Scholar in the Department of Electrical and Electronic Engineering, Shepherd School of Engineering & Technology, SHIATS-Deemed University (India). Research Scholar in the Department of Electronic and Communication Engineering, University of Allahabad (India),, E-mail: Ahmad_engineer21@yahoo.com.

method for the fuzzy modeling procedure to learn information about a data set, in order to automatically compute the membership function parameters that best allow the associated FIS to track the given input/output data. The membership function parameters are tuned using a combination of least squares estimation and back-propagation algorithm for membership function parameter estimation.

These parameters associated with the membership functions will change through the learning process similar to that of a neural network. Their adjustment is facilitated by a gradient vector, which provides a measure of how well the FIS is modeling the input/output data for a given set of parameters. Once the gradient vector is obtained, any of several optimization routines could be applied in order to adjust the parameters so as to reduce error between the actual and desired outputs. This allows the fuzzy system to learn from the data it is modeling. The approach has the advantage over the pure fuzzy paradigm that the need for the human operator to tune the system by adjusting the bounds of the membership functions is removed.

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.

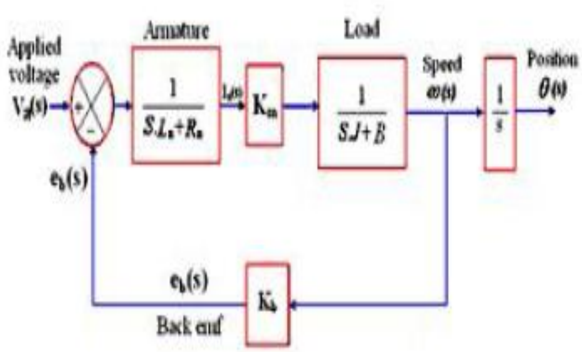

Fig.1 Block diagram of S.E.DC motor without load (Td)

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

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

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

The motor torque equation is

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

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

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

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

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

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

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

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

by substituting it in equation (5) to obtain

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

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

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

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:

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

S.E.DC motor transfer function with load Td(s) is shown in the block diagram in Fig.2 [4-5].

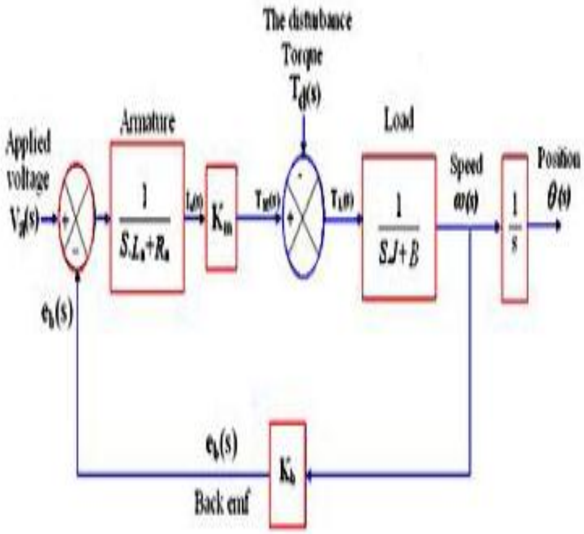

Fig. 2 Block diagram of S.E.DC motor with load (Td)

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 [6-10].

In view to make the controller insensitive to system parameters change, fuzzy logic theory is also implemented by researchers extensively. Indulkar et. al [11] initially designed a controller using fuzzy logic for automatic generation control and responses were compared with classical integral controller. Chang et. al. [12] 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 [13] 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 [14] when implemented not only grid was controlled better but also more economically. Talaq et. al [15] 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 [16] 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 [17], is a two layered fuzzy controller with less overshoot and small settling time as compared with conventional one. Ghoshal [18] 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 [19] 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. NEURAL NETWORK (ANN) CONTROLLER

Artificial Neural Networks are commonly referred as connectionist networks or simply neural networks, have been motivated from the recognition that the brain performs certain tasks much more efficiently in an entirely different way than the conventional digital computers. The neurons are the structural constituents of the brain, which are highly complex non-linear and parallel processing system. ANNs are massively parallel-interconnected networks of simple elements known as artificial neurons and their connectivity is intended to interact with the objects of the real world, in a similar manner as the biological nerves systems do. Neural networks have emerged as a powerful technique for pattern recognition, control, functional mapping and generalization. Neural networks are divided into classes based on network topology, computational element characteristic and training or learning rules.

The basis features of neural networks are (i) High computational rates due to the massive parallelism. (ii) Fault tolerance (damage to a few nodes does not significantly implies over all performance) (iii) Learning or training (the network adopts itself, based on the information received from the environment). (iv) Goal-seeking (the performance to achieve the goal is measured and used to self organize the system, programmed rules are not necessary). (v) Primitive computational elements. The starting point of ANN was the training algorithm proposed by Hebb in 1949, which demonstrated how a network of neurons could exhibit learning behavior.

The main advantages of ANN technology are: (i) It is fast (ii) It possesses learning ability (iii) It adapts to the data (iv) It is robust (v) It is appropriate for non-linear modeling [20-25]. General information on neural network and their applications in power systems have been presented in literature extensively. Beaufays et. al [26] describes an application of layered neural network to nonlinear power systems control which latter applied to control the turbine reference power of a computer-simulated generator unit while Birch et. al [27] investigated the use of neural networks to act as the control intelligence in conjunction with a standard adaptive load frequency control scheme. El-Metwally et. al [28] applied ANN to integrate the automatic voltage regulator and the conventional power system stabilizer into a single controller. Chaturvedi et al [29] have developed an automatic load frequency controller using ANN to regulate the power output and system frequency by controlling the speed of the generator with the help of water or steam flow control. Salem et. al [30] in their paper implemented the experimental verification of a simple neuro-controller as an excitation controller for a physical model of a single machine infinite bus power system.

Another single ANN controller is designed in [31] which controls the input of each area in the power system together. Comparing the results of both conventional and ANN controllers, performance of ANN controller is found better. Demiroren et. al in [32] designed the controller, taking the governor deadband effect and reheater effect, for two area interconnected power system but in [33] a dynamic neural network model for adaptive load frequency control is designed.

V. HYBRID FUZZY NEURAL NETWORK CONTROLLER

In recent years, hybrid fuzzy neural networks have attracted considerable attention for their useful applications in such fields as control, pattern recognition, image processing, forecasting etc. In all these applications, there are different fuzzy neural network architectures proposed for different purposes and fields. Fuzzy control is following what a person says by language (fuzzy sets) on the other hand, ANN control is explained as following what a person does by data. To construct non-linear and intelligent controllers, fuzzy control and ANN control should be combined. Hybrid fuzzy neural network (HFNN) results from fusion of neural networks and fuzzy logic. Thus HFNN is a massively parallel and layered feed forward structure. The fuzzy reasoning method (FRM) has been widely studied and used successfully in a number of control problems.

The FRM controllers can be alleviated by incorporating neural network learning mechanism into the fuzzy controller. A system of this type is referred to as fuzzy neural network. In FRM, the fuzzy relation matrix plays an important role. However, the process of selecting an adaptive fuzzy relation matrix is subjective and most time consuming, generally completed by trial and error. Furthermore, it is often impractical to obtain the fuzzy relation matrix from the process operator, particularly if the system is complex and/or if the fuzzy conditional statements have more than two variables. Since the process operator usually has only a general idea of the fuzzy relation matrix in a given region, the process of making that general idea precise is the most difficult task in the design of a finely tuned fuzzy controller [34-35].

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 and Artificial Neural Network (ANN) Controller 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, Artificial Neural Network (ANN) Controller, FLC+ANN Controller). The actual response of FLC+ANN Controller comparing with the actual response of FLC, and ANN is shown in Fig. 4. Table 2 lists the Comparison of the performances of Fuzzy, ANN and hybrid Fuzzy-ANN controllers, to show the effectiveness of the proposed approach.

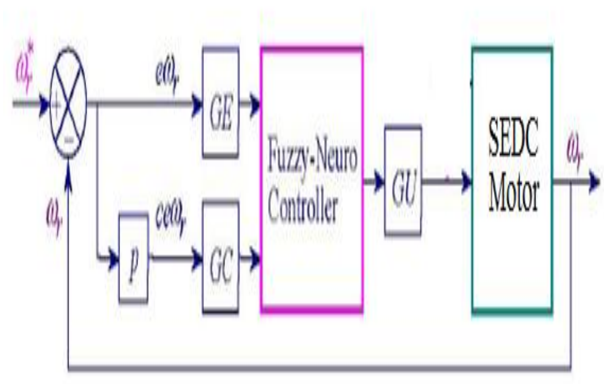

Figure 3 Structure of Fuzzy-Neuro Controller

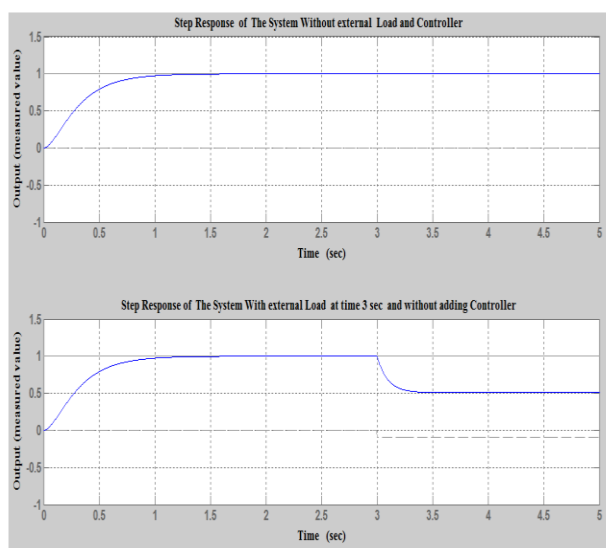

Figure 4 Step response of the system with external load

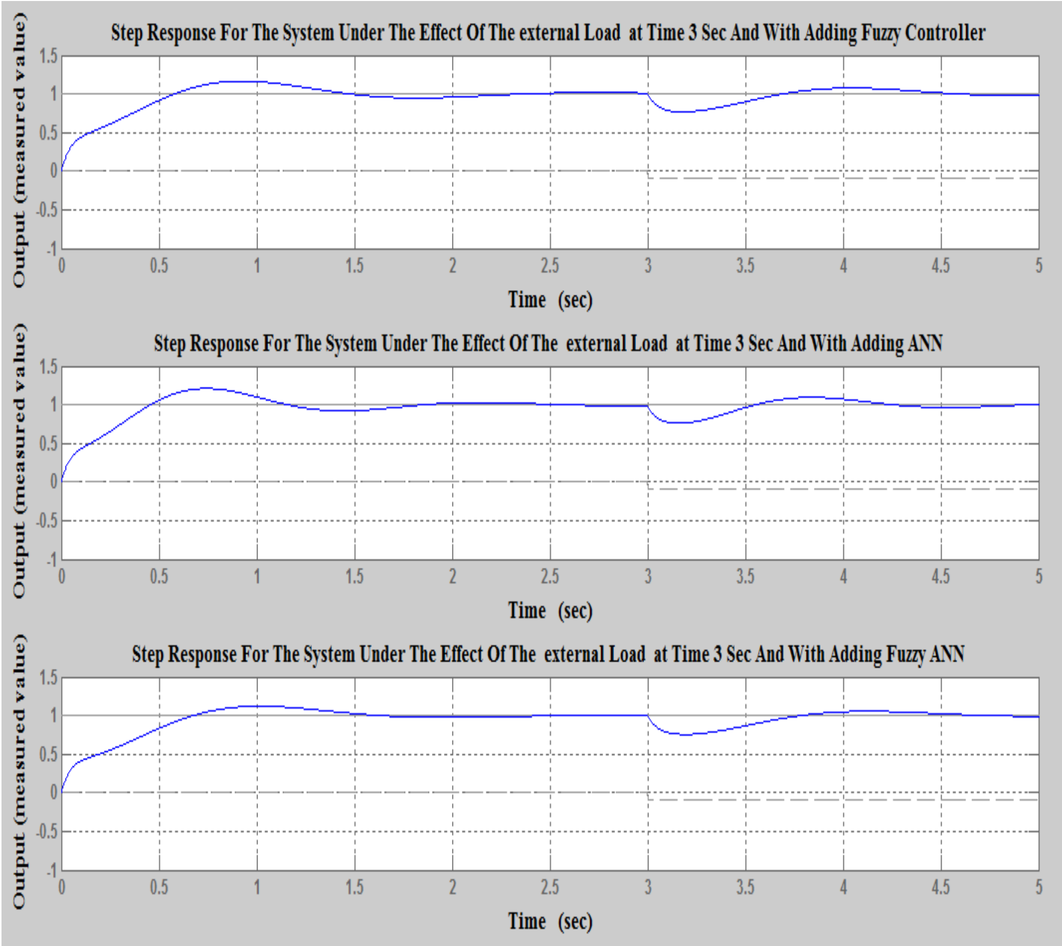

Figure 5 simulation results of the comparison among the Fuzzy, Neuro and hybrid Fuzzy-Neuro controller.

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	**Neural network control method**	**Fuzzy-Neuro control method**
Damping ratio (ξ)	**0.7946**	**0.8072**	**0.8585**
Settling Time (t_s)	**0.383 sec**	**0.418 sec**	**0.509 sec**
Maximum Overshoot (%M_p)	**1.6373 %**	**1.3612 %**	**0.5194 %**
Steady-State Error (e_{ss})	**0**	**0**	**0**
Peak Time (t_p)	**1.2100**	**1.22**	**1.23**
Rise Time (t_r)	**0.56**	**0.57**	**0.58**

Table2 Comparison of Fuzzy, Neuro and hybrid Fuzzy-Neuro controller.

VIII .CONCLUSION

By using Hybrid Fuzzy-Neuro Controller for enhancement of stability and accuracy of the SEDC Motor under the effect of the external disturbances and noise, the following advantages have been realized. 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 Fuzzy-Neuro 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 Fuzzy-Neuro Controller over the neural network 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 Fuzzy-Neuro Controller, we can conclude in this paper, that the use of Fuzzy-Neuro Controller 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.

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AUTHORS BIOGRAPHY

Ahmad M. EL-Fallah Ismail, born on June 5th 1982 at Gharian (Libya), Received his Bachelor of Engineering degree from the Faculty of engineering, Al-Jabal Al-Gharbi University (libya) in (2006), He obtained his Diploma in Electrical and Electronic Engg. (Control System) from Faculty of engineering, Alfatah University (libya) in 2008, He obtained his M.Tech. in Electrical and Electronic Engg. (Control System) from Shepherd School of Engineering & Technology, Sam Higginbottom Institute of Agriculture, Technology & Sciences Deemed-University, Allahabad (India) in 2011, Presently he is Pursuing Ph. D in Electrical and Electronic Engg. In Shepherd School of Engineering & Technology, Sam Higginbottom Institute of Agriculture, Technology & Sciences Deemed-University, Allahabad (India) , and also Pursuing Ph. D in the Department of Electronics and Communication at J.K Institute of Applied Physics and Technology, University of Allahabad, Allahabad (India). His field of interest is Intelligent Hybrid Controllers. E-mail: Ahmad_engineer21@yahoo.com.

A.K. Bhardwaj, Shepherd School of Engineering and Technology, Sam Higganbottom Institute of Agriculture, Technology and Sciences - Deemed University (Formerly AAI-DU) Allahabad, India.

Prof. Rajiv Ranjan Tewari (rrt_au@rediffmail.com), born on May 23rd 1956 at Lucknow (India), is teaching graduate and post-graduate students of Comp. Science/Engineering at the University of Allahabad since 1982. He was awarded K.S. Krishnan Award by IETE in the year 1987 for the best paper on System Design. He is life fellow of IETE. His areas of interest are Real-time System Design, Multimedia, Computer Networks and Robotics.