An Intelligent Speed Control of Brushless SEDC Motor by using PID, Fuzzy Logic Controller and Neuro- Fuzzy Logic Controller

R.C.Chourasia[1], Dr. A.K. Bhardwaj[2]
[1]Ph.D. Scholar, Electrical Engineering Department from SHIATS Allahabad, India
[2]Associate Professor and HOD in Electrical Engineering Department, SSET, SHIATS Allahabad, India

Abstract:— In modern era, there are not less than six billion motors built in worldwide every year. The Brushless separately excited DC motors are an integral part of industrial plants. In industrial application the demand of BLSEDC motors for low-cost and good quality have increased. The electric appliances, electric aircraft and electric trains have continuous demand growing for automotive industry. The many researchers have proposed different control method for advancing DC motor. Using conventional methods we cannot derive or control multi-variable and non-linear system. In this paper, we proposed BLSEDCM (Brushless Separately Excited DC Motor) using conventional PID controller, Fuzzy Logic controller and Neuro-fuzzy logic controller technique. The proposed methodology gave low-cost excellent flexibility, good robustness, adaptability and also gave high precision to the system. The speed estimator Neuro-fuzzy controller shows that the speed is very closed to desired speed over transient operating conditions and large operating range.

Keywords: BLSEDCM (Brushless Separately Excited Direct Current Motor), PID (Proportional Integral Derivative) Fuzzy Logic Controller and NFLC (Neuro-Fuzzy Logic Controller).

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1. INTRODUCTION

In the industry, there are basically two types of dc motors used. One of them is conventional dc motor in which the flux is produced by the current through the field coil of the stationary pole structure [1, 2]. Second of them is the brushless direct current motor in which the permanent magnet gives the necessary air gap flux on the place of wire-wound field poles. The brushless separately excited direct current motor is conventionally explained as permanent magnet synchronous motor with trapezoidal back EMF waveforms [3, 4]. In BLSEDC motors do not use brushes for commutation; instead, they are commutated electronically. Now days, the BLSEDC motor drives which has high performance are widely used for variable speed drive systems of the electric vehicles and industrial applications.

Practically, the design process of BLSEDC motor drive involves a complex process such as control scheme selection, modeling, parameters tuning and simulation etc. Recently, numbers of modern control solutions are proposed for the speed control design of BLSEDC motor [5]. However, the conventional PID controller algorithm is high reliable, stable, simple and easy to adjustment. Basically, the conventional PID controller used in conventional speed control system [6]. But, in various industrial process with different degree of nonlinear, uncertainty of mathematical model and parameter variability of the system. The control parameter of tuned PID controller is very difficult and poor robustness, due to this it is very difficult to reach the optimal result under field conditions in the actual production. The Fuzzy control method is a better method of controlling, to the complex variable

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parameter and unclear model system [7, 8]. The fuzzy logic control gives simple and good dynamic response, effective control and over strike characteristics.

In fuzzy logic, use membership functions with value varying between 0 and 1[9]. The meaning of that if the authentic expert knowledge is not available or if the processing of controlled system is too complex to derive the desired decision rules. The design of fuzzy logic controller has more time consuming and very tedious or sometimes impossible. The neuro- fuzzy logic control method is much better method of controlling, to the complex variable parameter. The neuro-fuzzy logic control has proven effective for non-linear, complex and imprecisely defined process for which the standard model based control techniques are impossible or impractical [10, 11, 12]. The neuro-fuzzy logic controller is a information process and computation method that mimics the process which found in biological neurons. The main element of NFLC is the neurons. The connection between two neurons is defined as the weight, which process can be tuned or trained on-line, or trained off-line, or combination of both [13, 14].

The main objective of this paper is that it shows the dynamics response of speed with design the PID, Fuzzy logic and Neuro-Fuzzy logic controller to control a speed of BLSEDC motor for keeping the motor speed to be constant when load varies.

II.MATHMATICAL MODEL OF BLSEDC MOTOR

The figure 1. Shows the complete block diagram of speed control of three phase BLSEDC motor. There are two control loops are used to control BLSEDC motor. One of them is synchronizes inner loop the electromotive forces with inverter gate signals. The second of them is outer loop controls the speed of motors by varying the DC bus voltage.

The driving circuitry consists of three phase power supply by voltage source which utilized to energize to BLSEDC motor phases concurrently. By using Hall sensor get the information of current and direction of reference current. The main idea of running motor in opposite direction when it is given opposite current.

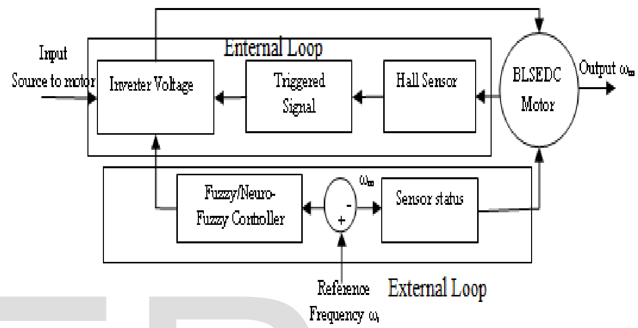

Figure: 1 Block Diagram of BLSEDC Motor for Speed Control

The mathematical model of BLSEDCM drive is given as follows: Assuming that the two-phase conduction, the entire dc voltage is applied to the two-phases having an impedance of:

$$Z = 2\left[R_s + \frac{d}{dt}(L - M)\right] = R_a + \frac{dL_a}{dt} \text{.....(1)}$$

Where

R_a: stator resistance per phase.

L: self inductance per phase.

M: mutual inductance per phase.

$R_a = 2R_s$ and $L_a = 2(L - M)$….(2)

The stator voltage equation is given as:

$$V_s = \left(R_a + \frac{dL_a}{dt}\right) i_a + e_{as} - e_{cs} \text{…(3)}$$

Where the last two terms are back emfs in phases ‘a’ and ‘c’ respectively. During regular operation of the drive system, the back emfs are equal and opposite in direction therefore the back emfs are given as:

$e_{as} = -e_{cs} = \emptyset_p \omega_m \ldots..(4)$

Substitute by Eq.(4) on Eq.(3) the stator voltage become:

$$V_s = \left(R_a + \frac{dL_a}{dt}\right) i_a + 2\emptyset_p \omega_m \ldots..(5)$$

The back emf constant for both phases can be written as:

$$K_b = 2\emptyset_p \ldots..(6)$$

So that, the stator voltage in Eq. (5) become:

$$V_s = \left(R_a + \frac{dL_a}{dt}\right) i_a + K_b \omega_m \ldots.(7)$$

The electromagnetic torque for two-phases is given as:

$$T_e = 2\emptyset_p i_s = K_b i_s \ldots\ldots(8)$$

The electromechanical equation of the BLSEDCM is:

$$T_e - T_L = J\frac{d\omega_m}{dt} + B\omega_m \ldots.(9)$$

The load torque is proportional to the motor speed, so it can be represented as:

$$T_L = K_T \omega_m \ldots..(10)$$

Therefore, Eq.(3.9) can be rewritten as:

$$T_e - K_T \omega_m = J\frac{d\omega_m}{dt} + B\omega_m \ldots\ldots(11)$$

Where:

R_s : stator resistance per phase.
L : self inductance per phase.
M : mutual inductance per phase.
$\emptyset_p$: flux linkage per phase.
ω_m : rotor speed.
V_s : stator voltage.
i_s : staor current.
T_e : electromagnetic torque.
T_L : load torque.
K_T : load torque constant.
K_b : flux constant (volt/rad/sec).
B : motor friction.
J : moment of inertia of BLDCM.

a.Transfer Function for PID controller

The mathematical block diagram of the speed control loop of BLSEDCM drive system is given in Fig. 2. The BLSEDCM contains three inner loops creating a complexity in the development of the model.

Mason's rule is used to reduce the block diagram as follows:

$$G_{Tf} = \frac{\omega_m}{I'_s(s)} = \frac{P}{1+(L_1+L_2+L_3)+L_1L_2} \ldots\ldots(12)$$

where the forward path ,loop gains are respectively given as follows:

$$P = \frac{k_p K_r K_b (1+T_i s)}{T_i s(1+T_r s)(R_a+L_a s)(B+Js)} \ldots\ldots.(13)$$

$$L_1 = -\frac{k_p K_r K_c (1+T_i s)}{T_i s(1+T_r s)(R_a+L_a s)(1+T_c s)} \ldots\ldots(14)$$

$$L_2 = -\frac{K_r}{(B+Js)} \ldots\ldots\ldots.(15)$$

$$L_3 = -\frac{K_b^2}{(R_a+L_a s)(B+Js)} \ldots..(16)$$

The open loop transfer function of the speed control is as follows:

$$G_{speed\ Tf} = \frac{k_{pPID} P K_w (T_{iPID} T_{DPID} s^2 + T_{iPID} s + 1)}{T_{iPID} s(1+(L_1+L_2+L_3)+L_1L_2)(1+T_w s)} \ldots..(17)$$

Where,

K_w: Gain of speed transducer.
T_w: Time constant of speed transducer.
k_{pPID}, T_{iPID}, T_{DPID}: Parameter of the PID controller.

III. CONTROLLED CIRCUIT

A.Design of Brushless SEDC Motor Using PID Controller

Assuming that the characteristics parameters are such as-proportional (p), integral (I) and derivative (D) controller, as applied to the given block diagram below in figure 2.

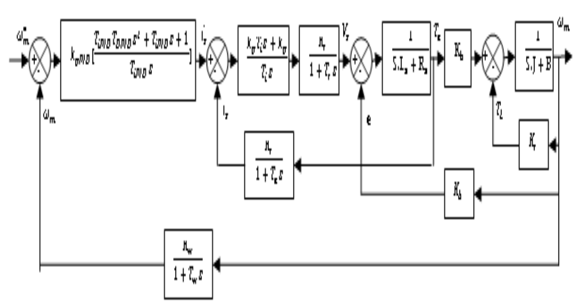

Figure 2: Simulation Model of the speed control loop for BLSEDC Motor using PID controller

From the PID controller to the plant is equal to the K_p (proportional gain) times the magnitude of the error plus the K_i (integral gain) times the integral of the error and plus the K_d (derivative gain) times the derivative of the error. More than 90% PID controller are used in closed loop industrial process. It is simple and excellent but not gives optimal performance in many applications.

There are four important characteristics of the close-loop step response they are such as

i. Rise Time: For the plant output Y the time it takes to rise beyond 90% of the desired level for the first time.
ii. Over soot: Maximum value of the peak level is higher than the steady state, it is normalized against the steady- state .
iii. Settling Time: the time required for the output to reach and stay within the specified range (2% to 5%) of its final value.
iv. Steady state error: The difference between the desired output and steady state output.

There are some important steps for designing a PID controller which are as follows:

a. Determined improved characteristics of the system which is required.
b. Use the Proportional constant K_p to decrease the rise time.
c. Use the Derivative constant K_D which reduces the overshoot and settling time.
d. Use the Integral constant K_i which eliminate the steady- state error.

The value of K_p=1.0, K_i=0.4 and K_D=0.1 values of the PID controller.

Table1. Parameter for BLSEDC motor

Parameters	Values	Parameters	Values
Power	1.2 kW	EMF constant (K_b, $K_{b'}$)	0.358, 2.5 V_s
Voltage	160 Volt	Converter time constant (T_r)	50x10^{-6} s
Current	7.5Amp	Converter gain (K_r)	16 V/V
Torque	3N.m	Current transducer time constant (T_c)	0.000159 s
Phase Resistance(R_a)	1.9 omh	Speed transducer gain (K_w)	1 V_s
Moment of Inertia (J)	0.00035 Kg.m^2	Current transducer gain (K_c)	0.228 V/A
Phase Inductance (L_a)	0.00124H	Speed transducer time constant (T_w)	0.001 s
Motor friction (B)	0.00035N.m/rad/sec	Step input, step input 1	0.001, 0.01

B. Design of Brushless SEDC Motor using fuzzy logic Controller

The Fuzzy controller is use in this paper based on two input FLC structure with combined rule. The whole structure of used controller is given in figure 3.

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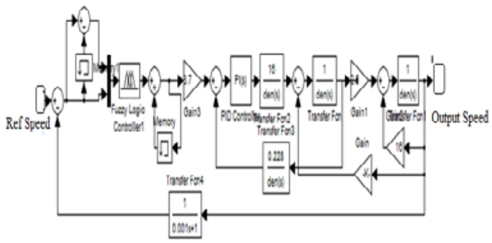

Figure 3 Simulation Model of the speed control loop for BLSEDC Motor using Fuzzy logic controller

The fuzzy controller rules are in the form of: IF $e=E_i$ and $de=dE_j$ THAN $U_{o/p}=U_{o/p}(ij)$. The rule base structure is written in Mamdani Type. These rules are written in table 1, which shows below:

de \ e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table 2 Table for Fuzzy rule

The Fuzzy logic controller has two inputs and output. These are Hall signal (e) error, Actual signal (de) change signal and output (PWM) control signal, respectively. The linguistic variables parameters which uses as inputs and output have been categorized as: NB, NM, NS, Z, PS, PM, PB. All the inputs and output are normalized in the interval of [-1, 1] as shown in figure 4.

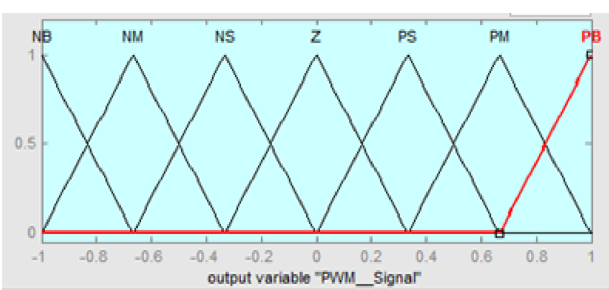

Figure 4 Membership functions for output

These linguistic parameter labels used to explain the Fuzzy sets were negative big '(NB)', negative medium '(NM)', negative small '(NS)', zero '(Z)', positive small '(PS)', positive medium '(PM)', positive big '(PB)'. These Fuzzy set of rules are find out from fundamental knowledge and human experience by the process. The relationship between inputs and output of the rules are defined the control strategy. Every fuzzy control inputs has seven fuzzy sets so that there are maximum 49 fuzzy rules.

C. Design of Brushless SEDC Motor using neuro-fuzzy logic Controller

The neuro-fuzzy logic controller has high robustness, good performance, very high tracking efficiency and high accuracy system.

The neuro-fuzzy logic controller is a cooperative system, it can be considered as a pre processor where in neural network learning algorithm mechanism determines the FIS membership function or fuzzy rules from the training data. When the FIS parameters are determined, the neural network goes to the back ground. Usually the rule based is determined by a self organizing maps or fuzzy clustering approach algorithms. Normally the membership functions are approximated by neural network from the training data. Figure 1 shows the block diagram of the cooperative neuro-fuzzy system.

In this paper the neuro- fuzzy logic controller has been used for speed control of BLSEDC motor. It has four layer based of four part of fuzzy system

First Layer: This layer is called input layer, each input is selected in limited range of input membership functions. Each weight in this layer is equal to one.

Second layer: This layer is called fuzzyfication layer, and it convert crisp input to the fuzzy content. In this layer the Gaussian function is used for nodes.

Third layer: This layer is called decision and inference layer, the product of all input signals is the output of each node. Basically it is based on 49 rules in rule based of fuzzy inference system.

Fourth layer: This is called defuzzifier layer, the summation of all inputs signals from third layer gives a single node computation. The mass of gravity method is used for defuzzification.

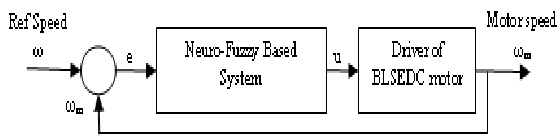

Figure: 5 Block Diagram of neuro-fuzzy logic controller of BLSEDC Motor for Speed Control

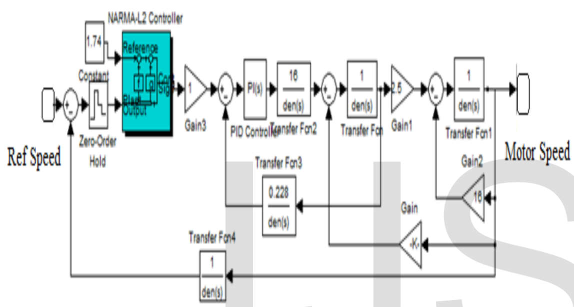

Figure: 6 Implementation of Neuro-Fuzzy logic controllers in SIMULINK for speed control of BLSEDC Motor

For improvement in speed of BLSEDC motor, we improve in learning capacity of neuro- fuzzy logic controller and remind it's the correct and high performance operation. By this work the weights of the network are updated the whole performance is improved. The error between plant output and reference speed and all the derivatives which are used as inputs of BLSEDC motor, shows in figure 6. The figure 5 shows the Block Diagram of neuro-fuzzy logic controller of BLSEDC Motor for Speed Control.

IV. SIMULATION OF PRAPOSED METHODOLOGY AND DISCUSSION

The experimental result is display, the accuracy and the learning capability of the proposed controller,under various operating condition the various simulation were performed in various speed of motor. The work of this paper, different model of BLSEDC motor have been developed by using PID controller, Fuzzy logic controller, Adaptive neural network and Adaptive neuro-fuzzy inference system controller to illustrate the performance of speed control of motor by simulink software. The graph of performances of these controller are shows in following figures:

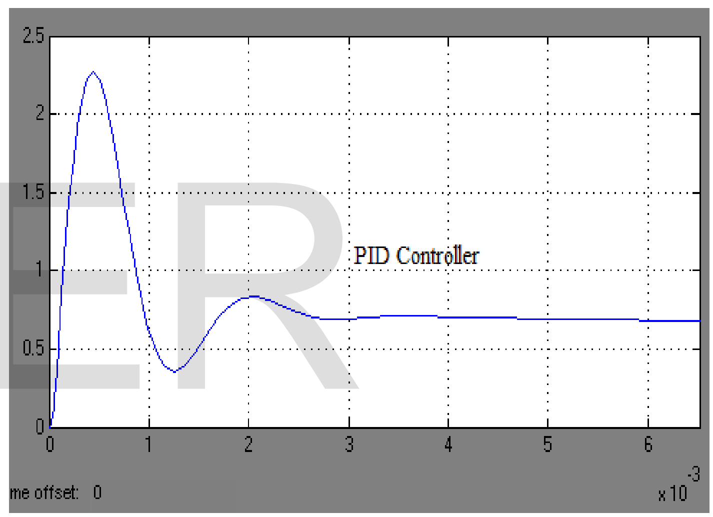

Figure 7 Step response of output (speed in p.u.) of the system BLSECD motor with PID Controller

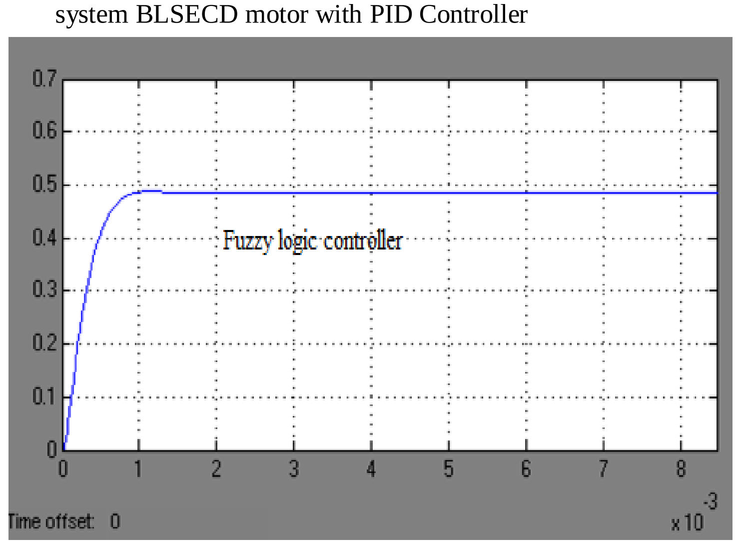

Figure 8 Step response of output (speed in p.u.) of the system BLSECD motor with Fuzzy logic Controller

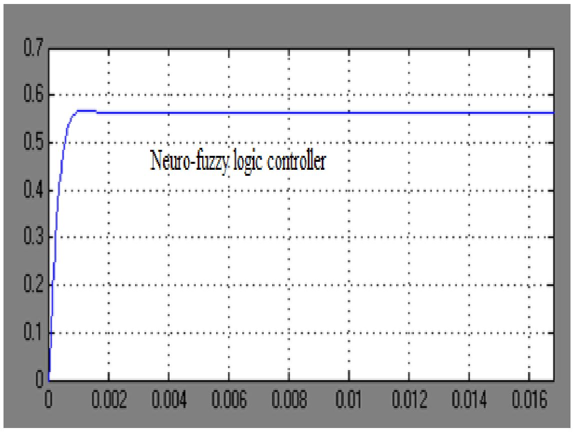

Figure 9 Step response of output (speed in p.u.) of the system BLSECD motor with Neuro-Fuzzy logic Controller

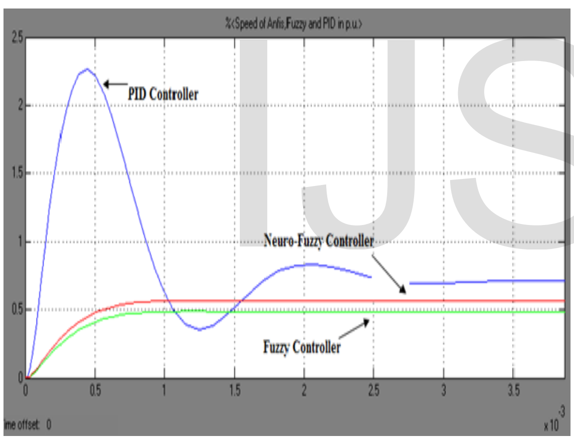

Figure 10 Comparative response of output (speed in p.u.) of the system BLSECD motor with PID, Fuzzy and Neuro-Fuzzy logic Controller

Table 3 Comparative value of response parameter using various controllers

Parameter → / Controller ↓	Steady-State Error (e_{ss})	Peak Time (t_p)	Rise Time (t_r)	Settling time (t_s)
PID controller(1,0.4,0.1)	0	18sec	0.6sec	28sec
Fuzzy controller	0	17sec	0.5sec	24sec
Neuro-Fuzzy controller	0	16.5sec	0.45se	22sec

The Step input of the speed commands is given in various controller used model. This is clear shown in figure 7,8,9,10 and figure 11the speed command optimizing precisely the three control terms rise time (t_r), steady state error (e_{ss}) and settling time (t_s). The proposed system is allows a greater degree of freedom to control and monitor the BLSEDC motor drive system.

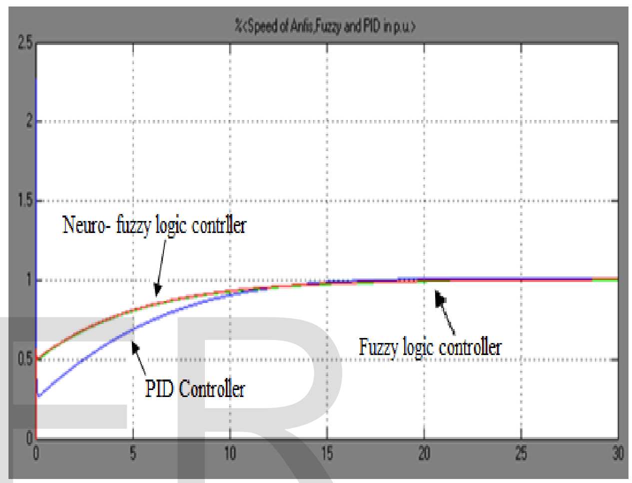

Figure 11 Comparative response of output (speed in p.u.) of the system BLSECD motor with PID, Fuzzy and Neuro-Fuzzy logic Controller

The response of speed of BLSEDC motor is shown in above figure in per unit (p.u.), it is tasted on rated speed at 1500 r.p.m.

Table 4Percentage benefits of controller

Controller → / Parameter ↓	PID to Fuzzy Controller (%	Fuzzy to Neu Fuzzy Controller (%)	PID to Neuro-Fu Controller (%)
Peak Time (t_p)	1	0.5	1.5

Rise Time (t_r)	0.09	0.045	0.135
Settling time (t_s)	0.08	0.04	0.12

V. CONCLUSION

The prototype for control and monitoring BLSEDC motor drive system using various control networks. The BLSEDC motor drive system is given. The speed control of BLSEDC motor PID controller is designed. Again the speed control of BLSEDC motor Fuzzy logic controller and Neuro-fuzzy logic controller are designed. This paper have a well designed controller based on tuned parameters, three control terms have to be optimized; steady state error (e_{ss}), rise time (t_r) and settling time (t_s). The proposed controllers are compared with the conventional controller; the proposed controllers introduce more accurate, faster and well tuned response. The simulation results shows the flexibility of this technique which allows the drive system to be optimized controlled and monitored precisely and remotely.

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AUTHORS

RAMESH CHANDRA CHOURASIA Allahabad received his B.Tech. degree in Electrical Electronics Engineering from Birala Institute of Technology, Mesra, Ranchi. M.Tech in Electrical & Electronics Engineering (Power System) from SHAITS (formally Allahabad Agriculture, Institute, Allahabad India) in 2012. Presently He is pursuing Ph.D. in Electrical Engineering from SHIATS (formally Allahabad Agriculture, Institute, Allahabad - India).E.Mail: ramesh.chourasia@gmail.com

Dr. A.K. BHARDWAJ Allahabad, 16.01.1965,Received his Bachelor of Engineering degree from JMI New Delhi in 1998; He obtained his M.Tech. degree in Energy and Env. Mgt. from IIT New Delhi in 2005. He completed his Ph.D in Electrical Engg. From SHIATS (Formerly Allahabad Agriculture Institute, Allahabad- India) in 2010. He has published several research paper in the field of Electrical Engineering. Presently he is working as Associate Professor and HOD in Electrical Engg. Department, SSET, SHIATS Allahabad- India. E-Mail: dr.akbhardwaj65@rediffmail.com