J Electr Eng Technol.2015; 10(2): 518-528
http://dx.doi.org/10.5370/JEET.2015.10.2.518

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

Performance Analysis and Experimental Verification of Buck Converter fed DC Series Motor using Hybrid Intelligent Controller with Stability Analysis and Parameter Variations

I. Thangaraju†, M. Muruganandam* and M. Madheswaran**

Abstract – This article presents a closed loop control of DC series motor fed by DC chopper controlled by an PID controller based intelligent control using ANN (Artificial Neural Network). The PID-ANN controller performances are analyzed in both steady state and dynamic operating condition with various set speed and various load torque. Here two different motor parameters are taken for analysis (220V and 110V motor parameters). The static and dynamic performances are taken for comparison with conventional PID controller and existing work. The steady state stability analysis of the system also made using the transfer function model. The equation model is also done to analysis the performances by set speed change and load torque change. The proposed controller have better control over the conventional PID controller and the reported existing work. This system is initially simulated using MATLAB / Simulink and then experimental setup done using P89V51RD2BN microcontroller.

Keywords: DC series motor, PID controller, Artificial neural network controller, DC Chopper, MATLAB/Simulink, Embedded system.

1. Introduction

DC series motor in industrial environment has increased, due to the high performance and high starting torque as suitable drive system. The intelligent control based on Artificial Neural Network (ANN), has been utilized for various applications including motor control. This controller has made the control of complex nonlinear systems with uncertainty or un-modeled dynamics as simple as possible [1]. The conventional controllers like PI and PID controllers were widely used earlier for chopper control and motor control applications. But it does not give satisfactory results when control parameters, loading conditions and the motor itself are changed. Intelligent control techniques involving ANN were found to be simpler for implementation and powerful in control applications. MATLAB/ Simulink is used to analyze the performance of the proposed controllers [2, 3].

The training patterns were generated using conventional PI controller and the effectiveness of the proposed scheme was illustrated using simulation studies and the designed controller was implemented in a low cost 8051-based embedded system and the results are documented [4]. A comparison was made with PI, fuzzy, and ANN controllers that were implemented in an embedded system for closed-loop speed control of DC drive fed by a buck-type DC-DC power converter. It was found that the PI based ANN controller has a better control [5]. A fuzzy controller for closed loop control of DC drive fed by four-quadrant chopper is designed and the fuzzy controller was implemented in a low-cost 8051 micro-controller based embedded system. The dynamic response of DC motor with fuzzy controller was tested and found to be satisfactory [6]. DC series motor drive fed by a single phase controlled rectifier (AC to DC converter) and controlled by fuzzy logic was presented. It has been concluded that the fuzzy logic controller provides better control [7]. A fuzzy controller for closed loop control of DC series motor drive fed by DC-DC converter was designed. The fuzzy based DC-DC drive can have better control [8-10].

A robust PID-like Neuro-Fuzzy controller has an ability to compensate for parameter variation, was proposed and applied to the speed control of the indirect vector-controlled induction motor. Simulation and experimental results confirm that the system has good dynamic performance [11]. The efficient speed controller for a DC servo motor based on neural non-causal inverse modeling of the motor was developed [12]. The random training for the neural networks was accomplished online, which enables better absorption of system uncertainties into the neural controller [13]. Different hybrid techniques using PID and ANN controller were discussed for DC series

---

† Corresponding Author: Dept. of Electrical and Electronics Engineering, Government college of Engineering Bargur, Krishnagiri Dist. Tamilnadu, India. (thangarajui@yahoo.co.in)

* Dept. of Electrical and Electronics Engi-neering, Muthayammal Engineering College, Rasipuram, Namakkal Dist. Tamilnadu, India. (muruganm1@gmail.com)

** Dept. of Electronics and Communication Engineering, Mahendra Engineering College, Mallasamudram West, Tiruchengode, Namakkal Dist. Tamilnadu, India. (madheswaran.dr@gmail.com)

Received: September 7, 2012; Accepted: August 25, 2014

motor and separately excited motor [14-18]. The stability analysis method based on the higher ordered derivatives of universal learning networks and its application to a DC motor system were described [19-21]. Fuzzy-Neuro control architecture was applied for some special electrical machines like brush less DC motor, permanent magnet DC motor and switched reluctance motor in order to obtain the precise speed control and better performances [22-24].

In this present work the DC series motor with two different parameters are controlled by DC-DC buck converter. The PID controller performance is enhanced by Artificial Neural Network. Initially the equation and transfer function model of the DC series motor with DC-DC converter is developed and simulated using MATLAB/ Simulink. Then the system is implemented with a NXP 80C51 family Microcontroller.

2. Proposed System

The block diagram of the proposed system with Hybrid PID-ANN controller is shown in Fig. 1. The system consists of DC-DC buck converter (DC chopper) to drive the DC series motor. The system has two loops, namely an inner ON/OFF current control loop and an outer PID-ANN speed control loop. The actual current of the motor is sensed by a LEM current sensor and given to the comparator. The comparator compares the actual and reference current and gives the signal to the gate. The gate blocks the PWM signal whenever the motor current exceeds the reference current (I_{Lref}).

The PWM coming from the ANN controller is given as first input to the logical AND gate. The actual current and the reference current are compared with a comparator and the comparator output is given to the second input to the AND gate. The comparator output is logical 1 when the actual current within the limit of the reference current. The comparator output is logical 0 when the actual current exceeds the limit. In such a way that the PWM from ANN controller comes out of the logical AND gate when the actual current within the limit. Otherwise the AND gate blocks the PWM and protect the motor from over current. This controller is called as ON/OFF type current controller. Then the PWM is given to the DC-DC buck converter through the gate and isolator.

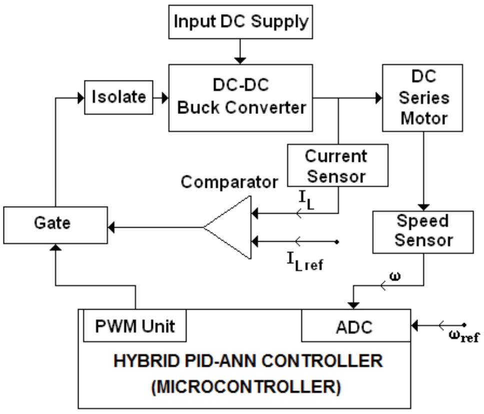

Fig. 1. Block diagram of the proposed system

In outer speed control loop, the actual speed $\omega(k)$ is sensed by pulse type speed sensor and which is given to the f to v converter and this voltage is used for speed feedback to the ADC and then given to the microcontroller. The error signal e(k) is obtained by comparing actual speed $\omega(k)$ with reference speed $\omega_r(k)$. The change in error $\Delta e(k)$ can be calculated from the present error e(k) and pervious error $e_{pervious}(k)$.

In Hybrid PID-ANN controller the error and change in error are given as input. The output of the controller is denoted as duty cycle dc(k). The change in duty cycle $\Delta dc(k)$ can be calculated from the new duty cycle dc(k) and previous duty cycle $dc_{pervious}(k)$. The PWM signal is generated by the Hybrid PID-ANN controller. The PWM signal was generated, by comparing the repeating sequence and the duty cycle from the controller. Then the PWM signal controls the output voltage of DC-DC converter. The output voltage of the DC-DC buck converter is varied from zero to maximum of input voltage applied, so wide range of speed control possible from zero to the rated speed. The input and output gain of the PID-ANN controller can be estimated by simulation [8, 9].

3. Modeling of DC Series Motor with DC Chopper System

Fig. 2 shows the chopper controlled DC series motor circuit. The chopper gain (Duty Cycle) is considered as δ. The transfer function of the system can be obtained from the basic voltage and torque equation

The motor voltage equation can be written as

$$V_a = \delta V_s = i_a R_a + L_a \frac{di_a}{dt} + e_b + e_{res} \tag{1}$$

$$R_a = R_{arm} + R_{se} \quad L_a = L_{arm} + L_{se} + 2M$$

where, i_a is the motor current, R_{arm} and R_{se} are the armature and series field resistance respectively. L_{arm} and L_{se} are the armature and series field inductance respectively and M is the mutual inductance. e_b and e_{res} are the back emf and emf due to residual magnetic flux respectively.

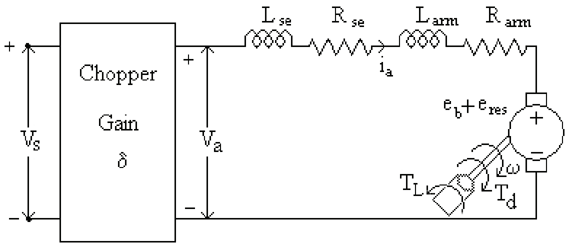

Fig. 2. Chopper Controlled DC Series Motor

The torque equation of DC series motor is

$$T_d = J\frac{d\omega}{dt} + B\omega + T_L \tag{2}$$

where, J is the moment of inertia, B is the friction coefficient, T_L is the load torque and ω is the angular speed.

Considering $I_a = I_{se}$ (I_{se}= Series field current) and ω as the motor speed then the emfs and deflecting torque can be written as

$$e_b = K_{af}\ i_a\omega \tag{3}$$

$$e_{res} = k_{res}\ \omega \tag{4}$$

$$T_d = K_{af}\ i_a^2 \tag{5}$$

where, K_{af} is the armature voltage constant and K_{res} is the residual magnetism voltage constant.

The transfer function for DC series motor could no longer be valid due to its non-linear characteristics. In order to obtain the transfer function, the operating point is considered as armature current I_{a0}, armature voltage $V_{a0,}$ load torque T_{L0}, back emf E_{b0} and residual emf $E_{res0.}$

Considering the small perturbations around the operating points as Δi_a, Δv_a, Δt_d, $\Delta\omega$, Δv_s, Δt_l, Δe_b and Δe_{res}, then the parameters can be written as

$$\begin{aligned}
&i_a = \Delta i_a + I_{a0} \quad ; \quad v_a = \Delta v_a + V_{a0} \\
&t_d = \Delta t_d + T_{d0} \quad ; \quad \omega = \Delta\omega + \omega_0 \\
&v_s = \Delta v_s + V_{s0} \quad ; \quad t_l = \Delta t_l + T_{l0} \\
&e_b = \Delta e_b + E_{b0} \quad ; \quad e_{res} = \Delta e_{res} + E_{res0}
\end{aligned}$$

Since the quantities $(\Delta i_a)^2$ and (Δi_a) $(\Delta\omega)$ are very small the above Eqs. (1) to (5) can be linearized to

$$\begin{aligned}
&\Delta v_a = \Delta\delta\, v_s \\
&\Delta e_b = k_{af}(\omega_0\Delta i_a + I_{a0}\Delta\omega) \\
&\Delta e_{res} = k_{res}\,\Delta\omega \\
&\Delta t_d = 2k_{af}I_{a0}\Delta i_a \\
&\Delta v_a = R_a\Delta i_a + L_a\frac{d\Delta i_a}{dt} + \Delta e_b + \Delta e_{res}
\end{aligned} \tag{6}$$

The linear equations can be transformed by the Laplace transform as

$$\Delta V_a(s) = \Delta\delta\, V_s(s) \tag{7}$$

$$\Delta E_b(s) = k_{af}(\omega_0\Delta I_a(s) + I_{a0}\Delta\omega(s)) \tag{8}$$

$$\Delta E_{res}(s) = k_{res}\,\Delta\omega(s) \tag{9}$$

$$\Delta V_a(s) = R_a\Delta I_a(s) + SL_a\Delta I_a(s) + \Delta E_b(s) + \Delta E_{res}(s) \tag{10}$$

$$\Delta T_d(s) = 2k_{af}I_{a0}\Delta I_a(s) \tag{11}$$

Also from Eq. (2)

$$\Delta T_d(s) = SJ\Delta\omega(s) + B\Delta\omega(s) + \Delta T_L(s) \tag{12}$$

Substituting (8) and (9) in equ (10) can be written as

$$\begin{aligned}
\Delta V_a(s) = {} & R_a\Delta I_a(s) + SL_a\Delta I_a(s) + k_{af}\omega_0\Delta I_a(s) \\
& + k_{af}I_{a0}\Delta\omega(s) + k_{res}\,\Delta\omega(s)
\end{aligned} \tag{13}$$

Solving equ (13), the motor current can be obtained as

$$\Delta I_a(s) = \frac{\Delta V_a(s) - \Delta\omega(s)(k_{af}I_{a0} + k_{res})}{(R_a + SL_a + k_{af}\omega_0)} \tag{14}$$

From equ (11) and (14)

$$\Delta T_d(s) = \frac{2k_{af}I_{a0}[\Delta V_a(s) - \Delta\omega(s)(k_{af}I_{a0} + k_{res})]}{(R_a + SL_a + k_{af}\omega_0)} \tag{15}$$

Equating the Eqs. (15) and (12)

$$\begin{aligned}
&\frac{2k_{af}I_{a0}[\Delta V_a(s) - \Delta\omega(s)(k_{af}I_{a0} + k_{res})]}{(R_a + SL_a + k_{af}\omega_0)} \\
&= \Delta\omega(s)(SJ + B) + \Delta T_L(s)
\end{aligned} \tag{16}$$

Assume that there is no changes in the load torque then $\Delta T_L(s) = 0$, the equ (16) reduced to

$$\frac{\Delta\omega(s)}{\Delta V_a(s)} = \frac{2K_{af}I_{a0}}{\left\{JL_aS^2 + (JR_a + K_{af}\omega_0 J + BL_a)S + [(BR_a + K_{af}\omega_0 B) + (2K_{af}I_{a0})(K_{af}I_{a0} + K_{res})]\right\}} \tag{17}$$

The Eq. (17) is the open loop transfer function of DC series motor. The motor is fed by DC-DC converter, therefore the transfer function of chopper fed DC series motor is become,

$$\frac{\Delta\omega(s)}{\Delta\delta(s)} = \frac{\Delta\omega(s)}{\Delta V_a(s)}\, X\, \frac{\Delta V_a(s)}{\Delta\delta(s)} \tag{18}$$

From Eq. (7) $$\frac{\Delta V_a(s)}{\Delta\delta(s)} = V_s \tag{19}$$

Substituting the Eqs. (17) and (19) in (18)

$$\frac{\Delta\omega(s)}{\Delta\delta(s)} = \frac{V_s 2K_{af}I_{a0}}{\left\{JL_aS^2 + (JR_a + K_{af}\omega_0 J + BL_a)S + [(BR_a + K_{af}\omega_0 B) + (2K_{af}I_{a0})(K_{af}I_{a0} + K_{res})]\right\}} \tag{20}$$

The Eq. (20) is the transfer function for chopper fed DC series motor.

4. Design of PID and PID-ANN Controllers

4.1 PID controller design and stability analysis

The PID controller improves the steady state and transient response. It is the combination of proportional control action, integral control action and derivative control action. The Proportional control action stabilizes the gain but produces a steady state error, the integral action reduces the steady state error and the derivative action reduces the rate of change of error. The transfer function of PID controller is given in Eq. (21)

$$\frac{\Delta\delta(s)}{\Delta E(s)} = K_P[1+\frac{1}{T_i S}+T_d S] \tag{21}$$

where K_p is the proportional gain, T_i is the integral time and T_d is the derivative time.

$$\frac{\Delta\omega(s)}{\Delta E(s)} = \frac{\Delta\omega(s)}{\Delta\delta(s)} X \frac{\Delta\delta(s)}{\Delta E(s)} \tag{22}$$

Substituting the Eqs. (20) and (21) in (22)

$$\frac{\Delta\omega(s)}{\Delta E(s)} = \frac{K_p V_s 2K_{af} I_{a0}(1+T_i S+T_i T_d S^2)}{\left\{T_i S\{JL_a S^2+(JR_a+K_{af}\omega_0 J+BL_a)S+ [(BR_a+K_{af}\omega_0 B)+(2K_{af}I_{a0})(K_{af}I_{a0}+K_{res})]\}\right\}} \tag{23}$$

$$\frac{\Delta\omega(s)}{\Delta E(s)} = \frac{\left(\{K_p V_s 2K_{af} I_{a0} T_i T_d\}S^2+ \{K_p V_s 2K_{af} I_{a0} T_i\}S+\{K_p V_s 2K_{af} I_{a0}\}\right)}{\left\{\{T_i JL_a\}S^3+\{T_i(JR_a+K_{af}\omega_0 J+BL_a)\}S^2+ \{T_i[(BR_a+K_{af}\omega_0 B)+(2K_{af}I_{a0})(K_{af}I_{a0}+K_{res})]\}S\right\}} \tag{24}$$

$$\frac{\Delta\omega(s)}{\Delta E(s)} = \frac{a_2 S^2+a_1 S+a_0}{b_3 S^3+b_2 S^2+b_1 S+b_0} \tag{25}$$

where,

$a_0 = K_p V_s 2k_{af} I_{a0}$

$a_1 = K_p V_s 2k_{af} I_{a0} T_i$

$a_2 = K_p V_s 2k_{af} I_{a0} T_i T_d$

$b_0 = 0$ $b_1 = T_i[(BR_a+K_{af}\omega_0 B)+(2k_{af}I_{a0})(k_{af}I_{a0}+k_{res})]$

$b_2 = T_i(JR_a+k_{af}\omega_0 J+BL_a)$ and $b_3 = T_i JL_a$

The PID controller parameters are determined by Ziegler-Nichols method. In this method, the controller has to run by taking only K_p value, increase the K_p value of the controller until the system, self-oscillating with constant amplitude, then take the controller gain. According to Ziegler-Nichols procedure, the ultimate gain K_u and the ultimate period of oscillation P_u, are used to find the parameters of the PID controller. The values of K_u and P_u are obtained from the system with MATLAB/Simulink. The K_p, T_i and T_d values are determined using Table 1 [3].

Table 1. Ziegler-Nichols method to determine Kp, Ti and Td

Parameters	K_p	T_i	T_d
P	$K_u/2$	-	-
PI	$K_u/2.2$	$P_u/1.2$	-
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

Fig. 3 shows the Frequency response of DC series motor with PID controller. The stability analysis of PID controller based DC series motor is carried out by bode plot method. The plot is obtained using the transfer function, given in Eq. 25. From the Bode plot it can be absorbed that the phase margin is 45° and the gain margin is 10dB, both gain margin and phase margin are positive, hence the system is stable.

The system stability is also checked by Nyquist stability criterion. If G(s)H(s) (loop transfer function) contour in the G(s)H(s) plane corresponding to Nyquist contour in the S plane encircles the point -1+j0 in the anticlockwise direction as many time as the number of right half of S

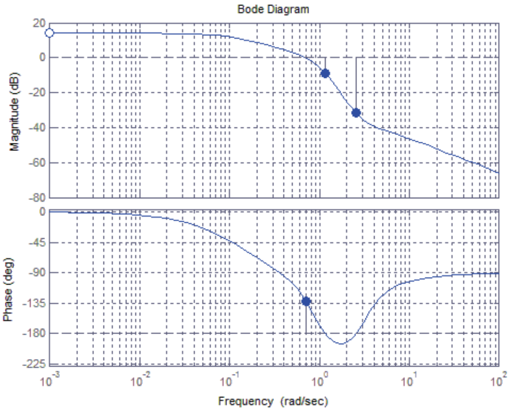

Fig. 3. Frequency response of DC series motor with PID controller

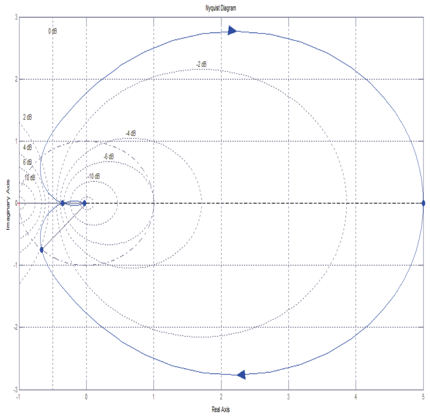

Fig. 4. Nyquist stability Plot for DC series motor with PID controller

plane poles of G(s)H(s), then the closed loop system is stable. From the Nyquist plot shown in Fig. 4, it is examined that the Nyquist contour is not encircles the critical point -1+j0 and there is no poles on right half of the S plane, this implies that the system is stable.

Though the system with PID controller is stable, the performance of time response which is shown in Fig. 5 is not good. In order to achieve the better transient and steady state response of the PID controller, it's performance is enhanced by hybridization with ANN. The error, change in error and duty cycle are the training data for ANN controller and they are obtained from the simulated motor-drive system with PID controller. The Fig. 6 shows the mathematical modeling of DC series motor using MATLAB/Simulink. The complete simulation model of the drive system with PID controller is given in Fig. 7.

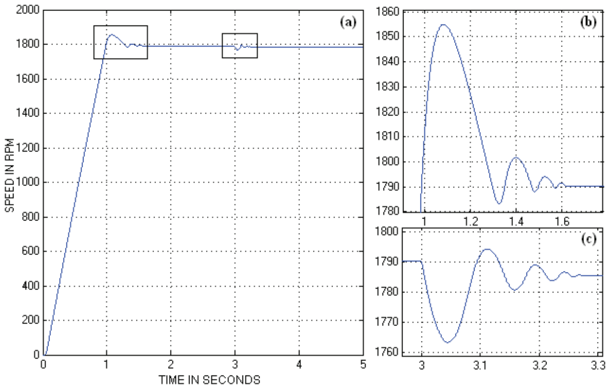

Fig. 5. (a) Speed versus Time response for PID controller (b) Expanded part of overshoot; (c) Expanded part of speed drop with load change

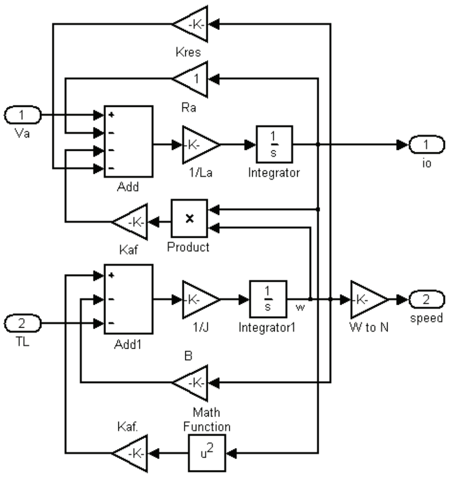

Fig. 6. Simulink model of DC series motor

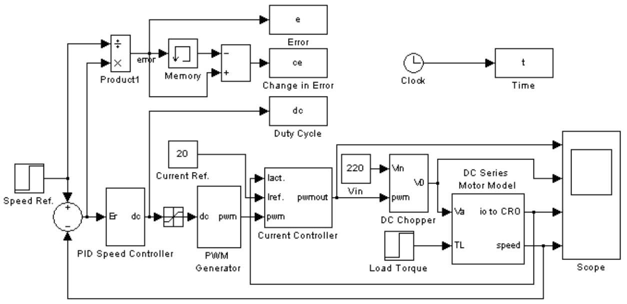

Fig. 7. Simulink Model of the system with PID controller

4.2 Design of PID based artificial neural network controller (Hybrid PID-ANN)

The neural network is based on nonlinear control algorithm that can be worked out because of its mathematical nature [1]. In this section, the solution of implementing PID controller in a neural network is discussed. The ANN controllers designed in most of the work use a complex network structure for the controller. The aim of this work is to design a simple ANN controller with as low neurons as possible while improving the performance of the controller. A two layer feed forward neural network is constructed with two neurons in the input layer and one in the output layer. As the inputs to the neuron controller is the error and change in error. The neurons are biased.

Generally in an Artificial Neural Network, each neuron has an activation function which specifies the output of a neuron to a given input. Neurons are 'switches' that output '1' when they are sufficiently activated and '0' when not activated. The activation functions used for the input neurons are pure linear activation function and for the output neurons are tangent sigmoid activation function. The network is trained for the set of inputs and desired outputs [4]. The training patterns are extracted from the designed PID controller. A Supervised back propagation Neural Network-training algorithm is used with a fixed error goal [5]. The network is trained for an error goal of 0.0005. The error (e) and change in error (ce) are the inputs

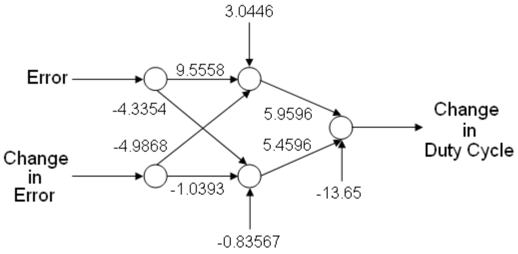

Fig. 8. Structure of Trained Neural Network

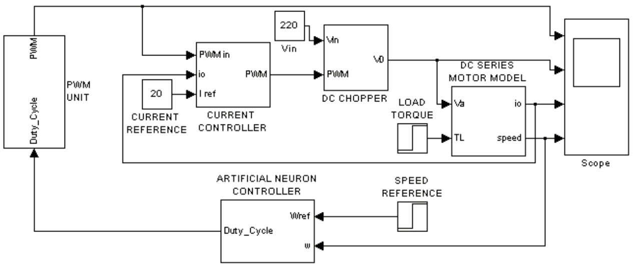

Fig. 9. Simulink model of the proposed system

to the controller. The output corresponds to the change in the duty cycle for the motor control. The detail of the trained network is shown in Fig. 8. The complete simulation model of the drive system with Hybrid PID-ANN controller is given in Fig. 9.

5. Results and Discussion

5.1 Simulation results

The proposed model has current controller and the Hybrid PID-ANN speed controller have been simulated using MATLAB simulink toolbox. The controller was designed and DC-DC converter fed DC series motor was tested with different motor parameter. The specifications of DC series motor for 220V and 110V are given in Table 2.

The speed variations and current variations for the step change in reference speed from 500rpm to 1000rpm at 4 sec and 1000rpm to 1500rpm at 7 sec with 10% load torque for 220V DC series motor with PID and PID-ANN controller are shown in Fig. 10. Due to the inertia in the beginning the motor takes 0.3sec to reach the speed from 0 to 500rpm whereas in the second step it took 0.25sec only to reach the speed from 500 to 1000rpm. The Hybrid PID-ANN controller performance was analyzed by changing the motor parameters as mentioned in the Table 2. Fig. 11 shows the speed variations and current variations for the step change in reference speed from 500rpm to 1000rpm at 4 sec and 1000rpm to 1500rpm at 8 sec with 10% load torque for 110V DC series motor with PID-ANN controller.

It is seen from the Fig. 11 the Hybrid PID-ANN controller regulates the speed at 1500 rpm. Also due to the inertia in the beginning the motor takes 0.21 sec to reach the speed from 0 to 500rpm whereas in the second step it took 0.15 sec only to reach from 500 to 1000rpm. The Hybrid PID-ANN controller provides proper seed regulation for all the step speed changes. The comparative time domain parameters of 220V motor and 110V motor for speed variation of various set speeds are depicted in Table 3. From the comparative analysis in table 3 shows the designed PID-ANN controller performance is fairly

Table 2. DC Series Motor Specifications

DC motor Parameters	220V Motor	110V motor
Motor Rating	5HP	2 HP
Dc supply voltage	220 V	110 V
Motor rated Current	18 A	12 A
Inertia constant J	0.0465 Kg-m^2	0.016 Kg-m^2
Damping constant B	0.005N.m.Sec./rad	0.003N.m.Sec./rad
Arm. resistance R_a	1Ω	0.4 Ω
Arm. inductance L_a	0.032 H	0.0096 H
Motor Speed	1800 rpm	1500 rpm
Arm. voltage const. K_{af}	0.027 H	0.027 H
Residual magnetism voltage const. K_{res}	0.027 V.Sec./rad	0.027 V.Sec./rad

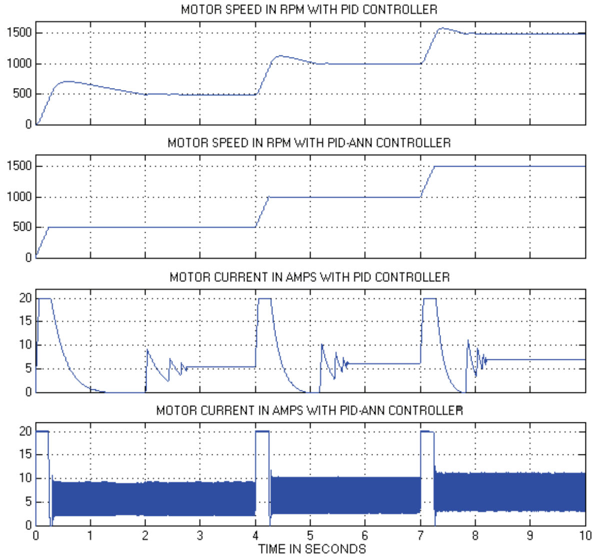

Fig. 10. Performance of controller for speed variation at 4 sec. and at 7sec with 10% load torque for 220V motor

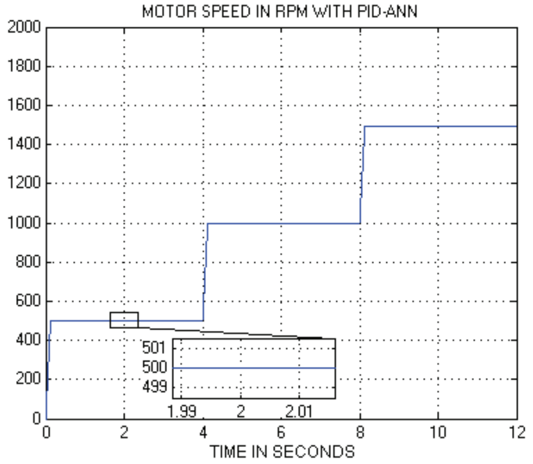

Fig. 11. Performance of controller for speed variation at 4 sec and at 8 sec with 10% load torque for 110V motor

Table 3. Time domain specification of PID and PID-ANN controller for different set speed change with 10% load

Time domain specifications			Max. over Shoot in %	Settling time in Sec.
Set speed change 0 to 500rpm	Conventional PID	220V Motor	7.8	2
		110V Motor	6.6	1.8
	PID-ANN (Proposed system)	220V Motor	0.3	0.3
		110V Motor	Nil	0.21
500 to 1000rpm	Conventional PID	220V Motor	5.2	1.1
		110V Motor	4.2	0.98
	PID-ANN (Proposed system)	220V Motor	0.16	0.25
		110V Motor	Nil	0.15
1000 to 1500rpm	Conventional PID	220V Motor	3.9	0.85
		110V Motor	3.1	0.71
	PID-ANN (Proposed System)	220V Motor	0.13	0.24
		110V Motor	Nil	0.15

good compared with the reported result in [7-9].

The simulated result of motor speed and motor current for various load torque changes from 10% to 25%, 25% to 50% and 50% to 100% applied at 3sec, 5.5sec and 8sec respectively with rated speed with respect to time response with PID controller and PID-ANN controller for 220V motor are shown in Fig. 12. Also the simulated result of motor speed and motor current for various load torque changes from 10% to 25%, 25% to 50% and 50% to 100% applied at 2sec, 4sec and 6sec respectively with rated speed with respect to time response with PID-ANN controller for 110V motor is given in Fig. 13. The comparative time domain specification corresponding to these load changes for 220V and 110V are illustrated in Table 4 for both the controller.

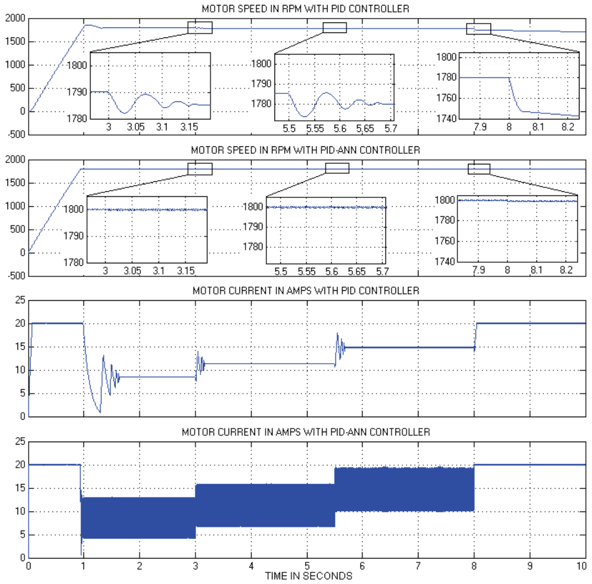

Fig.12. Performance of controller for load variation at 3 sec., 5.5 sec. and 8sec with rated speed for 220V motor

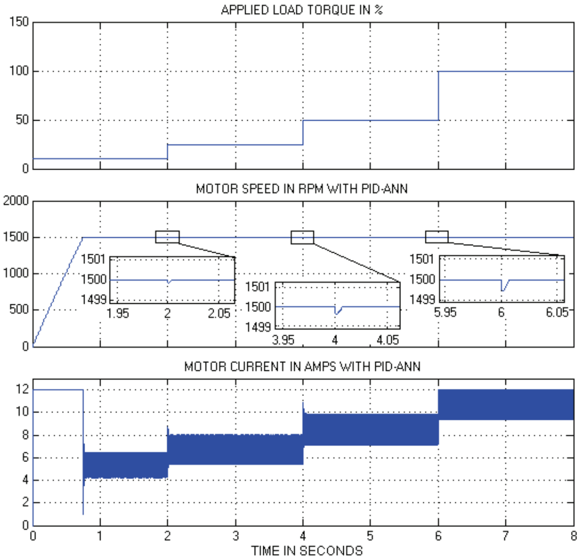

Fig. 13. Performance of controller for load variation at 2 sec, 4 sec and 6 sec with rated speed for 110V motor

Table 4. Time domain specification of ANN and PID controller for different load change with rated speed

Time domain specifications			Max. speed drop in %	Recovery time in sec.	Steady state error in rpm
Load Change 10% to 25%	PID	220V Motor	0.66	0.17	-15
		110V Motor	0.71	0.19	-13
	PID-ANN	220V Motor	Nil	Nil	±0.5
		110V Motor	0.010	0.002	Nil
25% to 50%	PID	220V Motor	1.1	0.68	-20
		110V Motor	1.3	0.72	-17
	PID-ANN	220V Motor	0.02	0.004	±0.4
		110V Motor	0.016	0.005	Nil
50% to 100%	PID	220V Motor	2.8	1.3	-36
		110V Motor	3.1	1.5	-32
	PID-ANN	220V Motor	0.2	0.035	±0.3
		110V Motor	0.033	0.008	Nil

With respect to Table 4 the overall performance of Hybrid PID-ANN controller is evaluated. Up to 25% of load, the maximum speed drop and the recovery time is negligible in PID-ANN controller. If the load increased from 25% to 100% its value increased slightly. The steady state error is also very less in PID-ANN controller than the conventional PID controller. Therefore the PID-ANN controller performance is superior comparing with [7-9] and designed PID controller performance during load changes from 10% to 100%.

The time domain performance of set speed changes and load disturbances are simulated and compared with both the controllers for 220V motor are shown in Fig. 14. The set speed is changed from 1000rpm to 1800rpm at 4sec. The load disturbance is at 7sec. between 10% and 50%. From the simulated result it is inferred that the Hybrid PID-ANN controller gives better performance during speed changes and load disturbances. The performance comparison of proposed Hybrid PID-ANN controller with conventional PID controller is given in Table 5.

The speed regulation for various loaded conditions was compared for both controllers in Fig. 15. From the curve it is observed that in PID controller up to 50% of load the speed is maintaining constant, after 50 % of load the speed is decreases (4% of the rated speed). In Hybrid PID-ANN

Table 5. Performance comparison of proposed system with PID controller for the rated speed and 10% load torque

Controller	PID		PID-ANN	
	220V Motor	110V Motor	220V Motor	110V Motor
Rise time (sec)	0.8	0.71	0.68	0.61
Settling time (sec)	1.55	1.21	0.91	0.7
Max. over shoot (%)	3.06	2.73	0.05	Nil
Steady state error (rpm)	+10	+10	±0.3	Nil

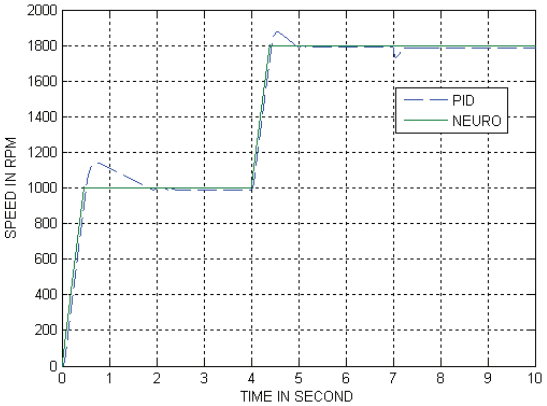

Fig.14. Controllers performance for speed variation at 4 seconds and load disturbance at 7seconds for 220V motor

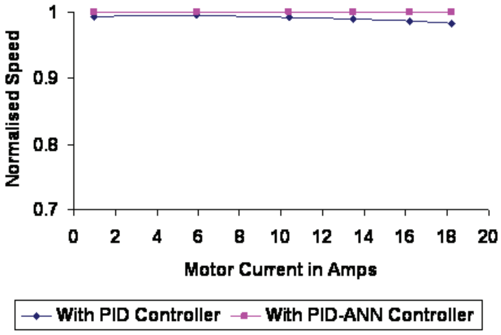

Fig.15. Simulation result of speed regulation of the motor with PID-ANN controller compared with conventional PID controller response for 220V motor

controller up to 100% of load the speed is maintaining constant value. Thus the Hybrid PID-ANN controller gives the better performance than the PID controller. The Hybrid PID-ANN controller provides proper speed regulation to the system for the load changes from 10% to 100%. From the Tables 3, 4 and 5 it is seen that all the performance parameter value is lesser and few parameters are reduces to zero for hybrid PID-ANN controller than the PID controller which shows that the dominance of developed Hybrid PID-ANN controller.

5.2 Experimental results

The designed controllers were implemented with DC-DC converter fed DC series motor by using the NXP 80C51 microcontroller (P89V51RD2BN) based Embedded System. The microcontroller (P89V51RD2BN) has an 80C51 compatible core and it has the features of 80C51 Central Processing Unit, 5V operating voltage from 0 to 40 MHz, 64 kB of on-chip Flash program memory. It also has a PCA (Programmable Counter Array) with PWM and Capture/Compare functions.

In this experimental setup the speed is measured through the compact, high sensing accuracy type optical photo interrupter GP1L53V. This is a device where IR LED and photo-transistor is coupled in to plastic housing. The gap between then allows interrupting signal with opaque material and this way switching the output from ON to OFF. It is a pulse type speed sensor. The pulse frequency then converted in to voltage signal by LM2917 frequency to voltage converter. The actual speed in terms of voltage is given to the 8bit ADC ADC0808CCN. Also the speed is captured as voltage signal using a cathode ray oscilloscope. This speed signal is used for speed feedback from the ADC output to the microcontroller.

The set speed variation is done with the help of potentiometer. The PWM is generated using the microcontroller. The PWM is generated at a frequency of 10 KHz. LEM make current sensor LTSR 25-NP is used to sense the armature current and gives the output to the AND gate. The AND gate is used to allow the PWM when the actual current is less than the set current. Then the PWM is amplified and fed to the DC-DC power converter through an optocoupler isolator CYN 17-1 and driver IC IR2110 chip.

The implementation is done for 1HP DC series motor. The rating of the motor is 1HP, 220V, 3.3A and 1500rpm. The power converter used for controlling the DC series motor is designed with the power MOSFET IRFP450. The rating of IRFP450 is 500V drain source voltage and 14A drain current. To improve the current rating two MOSETs are connected parallel in the power circuit. But actual current rating required for the 1HP motor is 3.3A only. The DC-DC converter output is given to the DC series motor whose speed is to be controlled. Fig. 16 shows the experimental setup of the proposed system.

Figs. 17 and 18 show the experimental results of speed variation from standstill to rated speed using PID controller and Hybrid PID-ANN controller respectively. Fig. 19 shows the experimental responses of a DC series motor for step change in speed. The experimental speed regulation for different load changes with PID-ANN controller for 220V motor is shown in Fig. 20. The controller effectively regulates the speed up to 100% of the load changes. The hardware performance comparison of proposed system with conventional PID controller is given in Table 6.

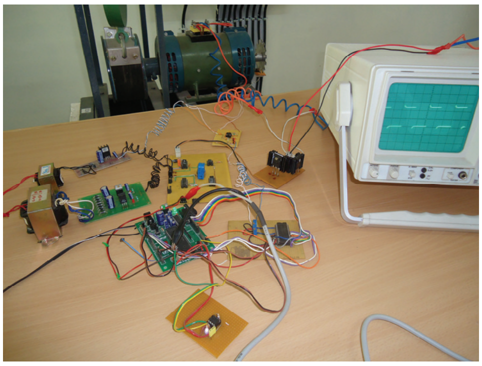

Fig. 16. Experimental setup of the proposed system

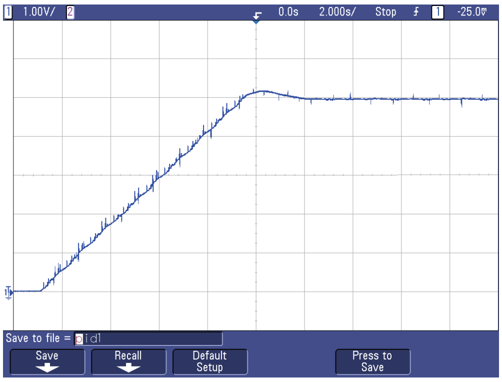

Fig. 17. Experimental result of speed response with PID controller

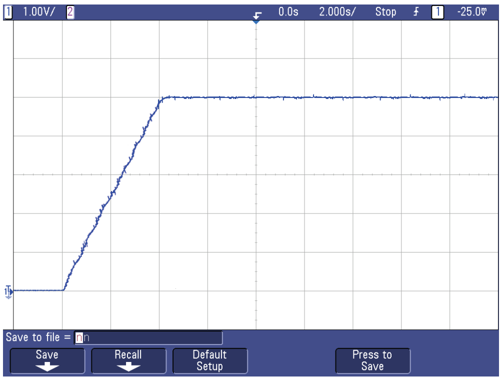

Fig. 18. Experimental result of speed response with PID - ANN controller

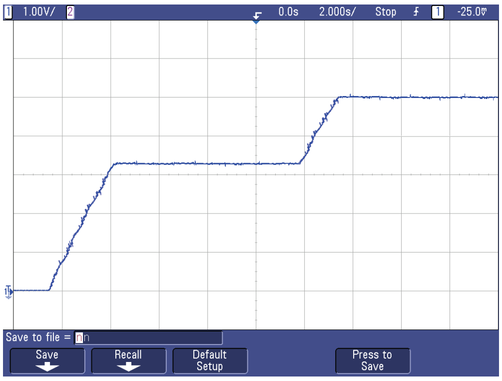

Fig. 19. Experimental result of speed response for step change in speed with PID-ANN controller

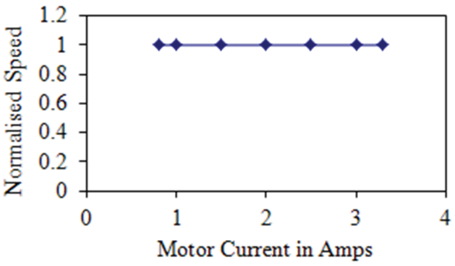

Fig. 20. Experimental result of speed regulation of the motor with PID-ANN controller response for 220V motor

Table 6. Hardware performance comparison of proposed system with PID controller for the speed ω_r=1800 rpm and ΔT_L=10%

Controller		Settling time in sec	Max. over shoot in %	Steady state error in rpm
PID	Simulation	0.75	4.20	-15
	Hardware	10.25	5	-30
PID-ANN	Simulation	0.5	No overshoot	±0.5
	Hardware	4	No overshoot	Nil

6. Conclusion

The performance of the hybrid PID-ANN controlled DC-DC converter fed DC series motor is presented. The steady state and dynamic speed response of DC series motor with Hybrid PID-ANN controller was estimated for various load torque and various speed and found that the speed can be controlled effectively. Even the motor parameters vary the controller works effectively and give the proper speed regulation. This advantage arises from the fact that the Artificial Neural Network has the property of generalization and the neural controller can have a smooth control surface. Also, the architecture of the designed neural network controller is simple and uses only two layers with three biased neurons. The hybrid PID-ANN controller is easy to implement and reduces the computation burden in embedded systems. Finally the hardware also implemented and verified the hardware results with the simulated results, which almost follow the simulation results. Here the Hybrid PID-ANN controller is reduced the computational time. Also the memory required for the program is reduced. The cost of the microcontroller is also less; therefore it can be implemented with economic in real world applications. Hence it can be recommended for all modern industrial drive applications using DC series motor. The analysis provides the various useful parameters and the information for effective use of proposed system.

References

[1] Zurada, J. M., Introduction to Artificial Neural Systems, Mumbai: Jaico Publishing House, 1992.

[2] MATLAB, Neural Network Tool Box User's Guide, Version 3, Massachusetts: The Mathworks Inc.

[3] S. N. Biswas, 'Industrial Electronics', Dhanpat Rai Publishing Company (P) Ltd., 1996.

[4] N. Senthil Kumar, V. Sadasivam, H.M. Asan Sukriya, S. Balakrishnan, "Design of low cost universal artificial neuron controller for chopper fed embedded DC drives", Science Direct, Elsevier B.V., Applied Soft Computing 8 (2008), Page(s): 1637-1642.

[5] Kumar, N. Senthil, Sadasivam, V. and Asan Sukriya, H.M, "A Comparative Study of PI, Fuzzy, and ANN Controllers for Chopper-fed DC Drive with Embedded

Systems Approach”, Electric Power Components and Systems, 36:7, 2008, Page(s): 680-695

[6] M. Muruganandam, N. Senthil Kumar, V. Sadasivam, “A Low-cost Four-quadrant Chopper-fed Embedded DC Drive Using Fuzzy Controller”, Inter National Journal of Electric Power Components and Systems, Volume 35, Issue 8 August 2007, Page(s): 907-920.

[7] H.A.Yousef,H.M.Khalil“A fuzzy logic-based control of series DC motor drives”, Proceedings of the IEEE International Symposium on Volume 2, Issue, 10-14 Jul1995 Page(s):517-522.

[8] M. Muruganandam and M. Madheswaran, “Performance Analysis of Fuzzy Logic Controller Based DC-DC Converter fed DC Series Motor” IEEE international conference, Chinese Control and Decision Conference (CCDC 2009), Page(s): 1635-1640.

[9] M. Muruganandam and M. Madheswaran, Modeling and Simulation of Modified Fuzzy Logic Controller for Various types of DC motor Drives” IEEE international conference on Control, Automation, Communication and Energy Conservation -2009, 4th-6th June 2009.

[10] K. B. Naik and S. D. Pandey, “Analysis and Performance of a Chopper Fed DC Series Motor during Steady-State and Dynamic Operating Conditions”, Science Direct, Science Direct, Elsevier, Electric Power Systems Research, Volume 17, Issue 2, September 1989, Page(s): 139-147.

[11] Sang-Min Kim, Woo-Yong Han, “Induction motor servos drive using robust PID-like Neuro-Ffuzzy controller”, Science Direct, Elsevier, Control Engineering Practice, Volume 14, Issue 5, May 2006, Page(s): 481-487.

[12] H. Rıza ozçalık, “An Efficient DC Servo Motor Control Based on Neural Noncausal Inverse Modeling of the Plant”, Springer-Verlag Berlin Heidelberg 2006, Page(s): 1075-1083.

[13] Ahmed Rubaai, Raj Kotaru, “Online Identification and Control of a DC Motor Using Learning Adaptation of Neural Networks”, IEEE Transaction on Industry applications, Vol. 36, No. 3 May/June 2000 Page(s); 935-942.

[14] Jun Ye, “Adaptive control of nonlinear PID-based analog Neural Networks for a nonholonomic mobile robot”, Science Direct, Elsevier, Neuro computing, Volume 71, Issues 7-9, March 2008, Page(s): 1561-1565.

[15] Tu Diep Cong Thanh and Duong Chi Thien, “Hybrid Neuro - PID Controller of Pneumatic Artificial Muscle Manipulator for Knee Rehabilitation”, Inter-national Symposium on Electrical & Electronics Engineering 2007-Oct 24, 25 2007-HCM City, Vietnam, Page(s): 20-29

[16] Andrei Cozma, Dan Pitica, “Artificial Neural Network and PID Based Control System for DC Motor Drives”, IEEE, 11th International Conference on Optimization of Electrical and Electronic Equipment, OPTIM.2008, 22-24 May 2008, Page(s): 161-166.

[17] Michael J. Burridge, Zhihua Qu, “An improved nonlinear control design for series DC motors”, Science Direct, Elsevier, Computers & Electrical Engineering, Volume 29, Issue 2, March 2003, Page(s): 273-288.

[18] Wiem Jebri Jemai, Houssem Jerbi, and Mohamed Naceur Abdelkrim, “Nonlinear State Feedback Design for Continuous Polynomial Systems”, International Journal of Control, Automation, and Systems, ICROS, KIEE and Springer 2011, Volume 9, Number 3, Page(s): 566-573.

[19] Nobuyuki Matsui, Tomihiko Sugimoto and Hiromi Maenaka, “Stability of chopper-controlled DC series motor under regenerative braking”, Wiley, Electrical Engineering in Japan 1978, Volume 98, Issue 5, Page(s): 40-47.

[20] Ahmed Hussein, Kotaro Hirasawa and Jinglu Hu, “Stability Analysis of a DC Motor System Using Universal Learning Networks”, IEEE International Joint Conference on Neural Networks 2004, vol. 2 Page(s): 1285-1290.

[21] Gou-Jen Wang, Chuan-Tzueng Fong, and Kang J. Chang, “Neural-Network-Based Self-Tuning PI Controller for Precise Motion Control of PMAC Motors”, IEEE Transactions on Industrial Electronics, 2001, Vol. 48, Issue: 2, Page(s): 408-415

[22] Cetin Gencer, Ali Saygin, Ismail Coskun, “DSP Based Fuzzy-Neural Speed Tracking Control of Brushless DC Motor”, Springer-Verlag Berlin Heidelberg 2006, Page(s): 107-116.

[23] F. M. EL-Khouly, A.M. Sharaf, A. S. Abdel-Ghaffar, and A.A. Mohammed, “An Adaptive Neural Network Speed Controller for Permanent Magnet DC Motor Drives”, Proceedings of the 26th Southeastern Symposium on System Theory, 1994, Page(s): 416-420

[24] Brwene Salah Ali, Hany M. Hasanien, and Yasser Galal, “Speed Control of Switched Reluctance Motor Using Artificial Neural Network Controller”, Springer-Verlag Berlin Heidelberg 2011, Volume 250, Part 1, Page(s): 6-14

I. Thangaraju received his B.E degree in Electrical and Electronics Engineering from University of Madras, India in 2000 and his M.E degree in Power Electronics and Drives from Anna University-Chennai, India, in 2005. He obtained his Ph.D. degree in Electrical Engineering from Anna University-Chennai, India, in 2013. He started his career as Lecturer and later was promoted as Assistant Professor in Electrical and Electronics Engineering department at Muthayammal Engineering College, Rasipuram, India. Then he was working as Assistant Engineer in Hydro Electric Power Station, TANGEDCO / Tamil Nadu Electricity Board, Mettur Dam, India for 5½ years. At present he is working as Assistant Professor in the department of Electrical and Electronics Engineering at Government College of Engineering, Bargur, Tamilnadu, India. He has published more than ten research papers in International Journals and conferences. His research interests include Intelligent controllers and drives for electrical applications. He is a member of IEEE and life member of ISTE.

M. Muruganandam received his B.E degree in Electrical and Electronics Engineering from the Periyar University Salem, India, in 2003, and his M.E degree Power Electronics and Drives from the Anna University of Chennai, India, in 2005. He obtained his Ph.D. degree at the Anna University Chennai, India in 2014. At present he is the Head of Electrical and Electronics Engineering Department (PG) of Muthayammal Engineering College, Rasipuram, Tamilnadu, India. He has been a member of the faculty at Centre for Advanced Research, Muthayammal Engineering College, Rasipuram, Tamilnadu, India since 2005. His research interests include fuzzy logic and neural network applications to power electronics and drives, machine modeling and Embedded Systems. He is a life member of ISTE.

M. Madheswaran received his BE Degree from Madurai Kamaraj University in 1990, an ME Degree from Birla Institute of Technology, Mesra, Ranchi, India in 1992, both in Electronics and Communication Engineering. He obtained his Ph.D. degree in Electronics Engineering from the Institute of Technology, Banaras Hindu University, Varanasi, India, in 1999. At present he is a Principal of Mahendra Engineering College, Mallasamudram West, Tiruchengode, Namakkal Dist. Tamilnadu, India. He has authored over hundred and forty five research publications in international and national journals and conferences. His areas of interest are theoretical modeling and simulation of high-speed semiconductor devices for integrated optoelectronics application, Biooptics and Bio-signal Processing. He was awarded the Young Scientist Fellowship (YSF) by the State Council for Science and Technology, Tamilnadu, in 1994 and Senior Research Fellowship (SRF) by the Council of Scientific and Industrial Research (CSIR), Government of India in 1996. Also he has received YSF from SERC, Department of Science and Technology, Govt. of India. He is named in Marquis Who’s Who in Science and engineering in the year 2006. He is a life member of IETE, ISTE and IE (India) and also a senior member of IEEE.