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Implementation of Pid Trained Artificial Neural Network Controller for Different DC Motor Drive

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Abstract: The Speed of the DC motors is controlled by Hybrid PID-ANN controller. The Hybrid PID-ANN (Artificial Neural Network) controller is designed and tested for different types of DC motors like DC separately excited motor and DC series motor. The motor is fed by DC chopper (DC-DC buck converter). It has two loops of inner current controller loop and outer PID-ANN based speed controller loop. The speed controller gives the duty cycle to generate the PWM signal for the control of chopper. There by the DC chopper controls the speed of the DC motor to the set value. The Hybrid PID-ANN controller performances were tested for both DC motors with different load conditions and different set speed variations. Finally it was implemented with a NXP 80C51 family Microcontroller (P89V51RD2BN) based Embedded System. It was found that the hybrid PID-ANN controller with DC Chopper can have better control.

Key words: DC Motors · PID Controller · Artificial Neural Network Controller · DC Chopper · MATLAB Simulink · Embedded System

INTRODUCTION

DC motor drives are engaged with a wide range of applications, such as lifts, cranes, hoist, electric traction, robotic manipulators and battery operated electric vehicles. Such a high performance application requires a motor drive with minimal steady state error, over shoot and under shoot in its speed commands. The application of DC motor in industrial environment has increased due to the high performance and high starting torque (DC series motor) as suitable drive system [1, 2]. Presently the Artificial Neural Network has been widely used for various control applications including motor control. The ANN controller can give robust performance of a nonlinear parameter varying system with load disturbance. This controller has made the control of complex non linear systems with uncertainty or un-modeled dynamics as simple as possible [3, 4]. Earlier the conventional controllers like PI and PID controllers were widely used for chopper control and motor control applications. But it failed to give satisfactory results when control parameters, loading conditions and the motor itself are changed. Hence the tuning and optimization of these controllers are a challenging and difficult task, particularly under varying load conditions and parameter changes. The main disadvantage with the conventional controller is the high computation time. It has been found that the computation burden of conventional controller can be reduced by hybrid PID-ANN controller. Intelligent control techniques involving ANN is found to be simpler for implementation in DC motor control [3].

The DC series motor drive fed by a single phase controlled rectifier (AC to DC converter) and controlled by fuzzy logic [4]. It has been concluded that the fuzzy logic controller provides better control over the classical PI controller. It was also reported that the settling time and maximum overshoot can be reduced. It was reported by H.A.Yousef and H.M.Khalil [5]. Due to the inherent limitations, AC to DC converter fed drive introduces unwanted harmonic ripples in the output and the computation time of fuzzy controller also high. Senthil Kumar *et al.* [6, 7] have been utilized the ANN controller for speed control of DC motor, due to their high computation rate and ability to handle nonlinear

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functions. The training patterns for the neuron controller were obtained from the conventional PI controller and the effectiveness of the proposed neuron controller was studied using simulation studies. The designed controller was implemented in a low cost 8051-based embedded system and the results were documented. Ali Bekir Yildiz and M. Zeki Bilgin [8] have been explained the speed control of a separately excited DC motor driven by DC-DC converter is realized by using Neuro-PID controller. A self-tuning PID neuro-controller was developed for speed control on this model. The PID gains are tuned automatically by the neural network in an on-line way. The controller is developed in this work, based on Neural Network (NN). It offers inherent advantages over conventional PID controller for DC motor drive systems.

Buja *et al*. [9] has explained that the Fuzzy Logic suffers from complex data processing; this problem is reduced by implementing a Fuzzy Logic Controller (FLC) on a neural network (NN). From the FLC design, a NN is trained by supervision to learn the input-output relationship of FLC. This demonstrates that implementing a FLC on a NN is an effective solution to simplify the data processing required by the fuzzy logic while maintaining its human-like approach and control capabilities. A trained neural network is promising, as it requires less computation time and memory. Senthil Kumar *et al.* [10] have demonstrated a low-cost fuzzy controller for closed loop control of DC drive fed by four-quadrant chopper was designed and the fuzzy controller was implemented in a low-cost 8051 micro-controller based embedded system. The simulated closed loop performance of the fuzzy controller in respect of load variation and reference speed change has been reported. Further, the dynamic response of DC motor with fuzzy controller was tested and found to be satisfactory.

M. Muruganandam and M.Madheswaran [11, 12] have enlightened a Fuzzy Controller for closed loop control of DC series motor drive fed by DC-DC converter was designed. The performance in respect of load variation and speed changes has been reported. The performance of the proposed controller was compared with the reported results and found that the fuzzy based DC-DC drive can have better control. But it has the limitation of more computation time due to fuzzy controller. Intelligent control techniques based on ANN has been growing tremendously for industrial applications [13]. ANN for DC drive application is becoming popular due to their high computation rate [14]. Intelligent control techniques involving ANNs are found to be simpler for implementation and powerful in control applications [15-19]. It has been proved that neural controllers are better than fuzzy controllers for microprocessor implementation [20]. Drive behavior under PI, FL and ANN speed controllers was thoroughly compared in this article [21-25].

From the above literature, most of the work focused on separately excited DC motor, which limits the high torque application. Some paper demonstrated with DC series motor with fuzzy controller. In this proposed work two different DC motors were to be taken and which will be controlled by hybrid PID-ANN controller through DC-DC buck converter. The equation model of the DC motors and the DC-DC converter is developed for simulation. Initially a conventional PID controller is designed as a speed controller to extract the training data. Then an ANN controller is designed and it is trained with the training patterns obtained from the PID controller. The designed Hybrid PID-ANN controller is to reduce the steady state error, overshoot and settling time. The closed loop operation is simulated with the trained Hybrid PID-ANN controller to achieve the desired performance of both DC motors. The proposed work is implemented with a P89V51RD2BN Microcontroller and the experiment results are compared with the simulation results. The simulation results concur with the experimental results.

Hybrid Pid-Ann Controller

Based Dc Drive: Figure 1 shows the block diagram of the system with hybrid PID-ANN controller. The system consists of DC-DC buck converter to drive the DC motor. A speed sensor is used to sense the actual speed (ω) and which is used for speed feedback. The PWM signal is generated, by comparing the carrier signal and the duty cycle from the controller output. During the implementation of the proposed system, a micro-controller is used to generate the PWM signal to switch the DC-DC buck converter [9, 10, 11]. This system has two loops, namely an inner ON/OFF current control loop and an outer PID-ANN speed control loop. The current control loop is used to blocks the PWM signal while the motor current exceeds the reference current (I_{Lref}). In outer speed control loop, the actual speed $\omega(k)$ is sensed by speed sensor. 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 $e_{previous}(k)$.

In the proposed system two input Hybrid PID-ANN controller is used. The error and change in error are given as inputs to the controller. The output of the controller is denoted as duty cycle dc(k). The change in duty cycle

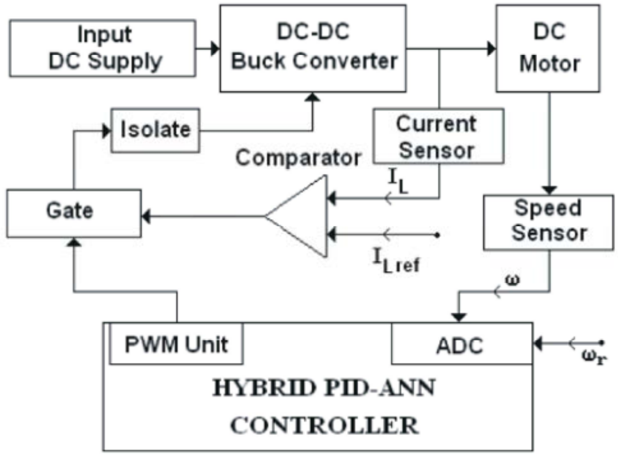

Fig. 1: Block diagram of hybrid PID-ANN controller based DC drive

Δdc(k) can be calculated from the new duty cycle dc(k) and previous duty cycle $dc_{previous}(k)$. The DC-DC converter is used to change the input voltage applied to the DC motor whose speed is to be controlled. The output voltage of the DC-DC buck converter is varied from zero to the input voltage applied, so wide range of speed control possible from zero to the rated speed. The DC motor with different specification may also possible to control the speed by PID-ANN controller through the inner current controller. The input and output gain of the PID-ANN controller can be estimated by simulation. The PID-ANN controller can reduce the error to zero by changing the duty cycle of the switching signal [6].

Mathematical Model of Dc Motors and DC-DC Converter

DC Series Motor Model: The voltage and torque equations of DC series motor are given in equation (1) and (2) respectively.

Consider, $R_a = R_{arm} + R_{se}$; $L_a = L_{arm} + L_{se} + 2M$

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

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

where,

$i_a = i_{se}$ - Motor current
V_0 - Motor terminal voltage
R_{arm} - Armature resistance
R_{se} - Series field resistance
R_a - Total resistance
L_{arm} - Armature inductance
L_{se} - Series field inductance
L_a - Total inductance
M - Mutual inductance
e_b - Back emf
e_{res} - emf due to residual magnetic flex
T - Deflecting torque
J - Moment of inertia
B - Friction coefficient
ω $\frac{d\theta}{dt}$ Angular speed
θ - Angular displacement
φ - Series field flux
T_L - Load torque
K_{af} - Armature voltage constant and
K_{res} - Residual magnetism voltage constant

$e_b \; \alpha \; \varphi \; \omega$ and $\varphi \alpha i_a$ (i.e Before Saturation)

$\therefore e_b \; \alpha \; i_a \omega$

$e_b = K_{af} \; i_a \omega$

$$\omega = \frac{d\theta}{dt} = \text{Angular Speed}$$

Similarly, $e_{res} \; \alpha \; \omega; e_{res} = K_{res} \; \omega \therefore e_{res} = K_{res} \frac{d\theta}{dt}$

By rearranging the equation (1) by replacing e_b and e_{res}

$$V_o = R_a i_a + L_a \frac{di_a}{dt} + K_{af} i_a \frac{d\theta}{dt} + K_{res}\frac{d\theta}{dt} \tag{3}$$

$$\frac{di_a}{dt} = \frac{1}{L_a}\left[V_o - R_a i_a - K_{af} i_a \frac{d\theta}{dt} - K_{res}\frac{d\theta}{dt}\right]$$

$$\frac{di_a}{dt} = \frac{1}{L_a}\left[V_o - R_a i_a - K_{af} i_a \omega - K_{res}\omega\right] \tag{4}$$

Similarly the torque equation also derived as follows,

$$T\,\alpha\,\varphi\, i_a \; and \; \varphi\,\alpha\, i_a \; (Before\,Saturation)$$
$$\therefore T \alpha\, i_a^2$$
$$T = K_{af}\, i_a^2$$
$$\omega = \frac{d\theta}{dt} = AngularSpeed$$

By rearranging the equation (2) by replacing T

$$K_{af} i_a^2 = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + T_L \tag{5}$$

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}\left[K_{af} i_a^2 - B\frac{d\theta}{dt} - T_L\right]$$

(or)

$$\frac{d\omega}{dt} = \frac{1}{J}\left[K_{af} i_a^2 - B\omega - T_L\right] \tag{6}$$

The DC series motor has been modeled with the modeling equations (4) and (6).

DC Separately Excited Motor Model: The voltage and torque equations for DC Separately Excited motor are given in equation (7) and (8) respectively.

$$V_o = i_a R_a + L_a\frac{di_a}{dt} + e \tag{7}$$

$$T = J\frac{d\omega}{dt} + B\omega + T_L \tag{8}$$

By rearranging the equation (7) & (8), the following equations were obtained,

$$\frac{di_a}{dt} = \frac{1}{L_a}\left[V_o - R_a i_a - K_{af}\omega\right] \because e = K_{af}\omega \tag{9}$$

$$\frac{d\omega}{dt} = \frac{1}{J}\left[K_{af} i_a - B\omega - T_L\right] \because T = K_{af} i_a \tag{10}$$

The DC separately excited motor has been modeled with the modeling equations (9) and (10). The equation modeling is more effective than the transfer function model. In transfer function model, it is required to develop separate model for every input and output parameter changes. Where as in equation model used here having, the voltage and load torque are the input parameters, the output parameters are speed, current and deflecting torque etc.

DC-DC Converter: The DC-DC converter switch can be a Power Transistor, SCR, GTO, IGBT, Power MOSFET or similar switching device. In order to get high switching frequency (upto 100 KHz) the Power MOSFET can be taken as a switching device. Normally on state drop in this switch is small and it is neglected [1, 2].

When the gate pulse is applied the device is turned on. During this period the input supply connects with the load. When the gate pulse is removed, the device is turned off and the load disconnected from the input supply. The model equation for DC-DC converter is given in the equation (11).

$$V_o = \delta V^s \tag{11}$$

$$\delta = \frac{T_{ON}}{T}; T = T_{ON} + T_{OFF}$$

where, V_0 - Output Voltage; V_S - Input Voltage
T_{ON} - ON Time; T_{OFF} - OFF Time
T - Total Time; δ - Duty Cycle

Simulation of the System Using Matlab / Simulink

Conventional Controller (PID): In order to train the ANN controller the training data is required. A conventional PID controller is designed and simulated with the drive system for extracting the training data. The PID controller parameters are determined by Ziegler-Nichols method. According to Ziegler-Nichols method, the controller has to run by taking only P value, increase the P value of the controller until itself oscillating with constant amplitude and then take the controller gain. According to Ziegler-Nichols procedure the P, I and D values are determined. The determined values are P = 88, I = 26 and D=0.1. [12 -15].

From the equations (4) and (6) the simulink model of DC series motor was obtained also from equation (9) and (10) the simulink model of DC separately excited motor was obtained and given in Figure 2 & 3 respectively.

The simulink model developed based on the mathematical model of the motor, buck converter and the conventional PID controller is given in Figure 4.

The input and output parameters of PID controller are error and change in duty cycle respectively. The ANN requires error and change in error as input and the change in duty cycle as the output. Therefore the change in error is calculated from the error by simulation which is shown in Figure 4. The above model is simulated for 5 seconds

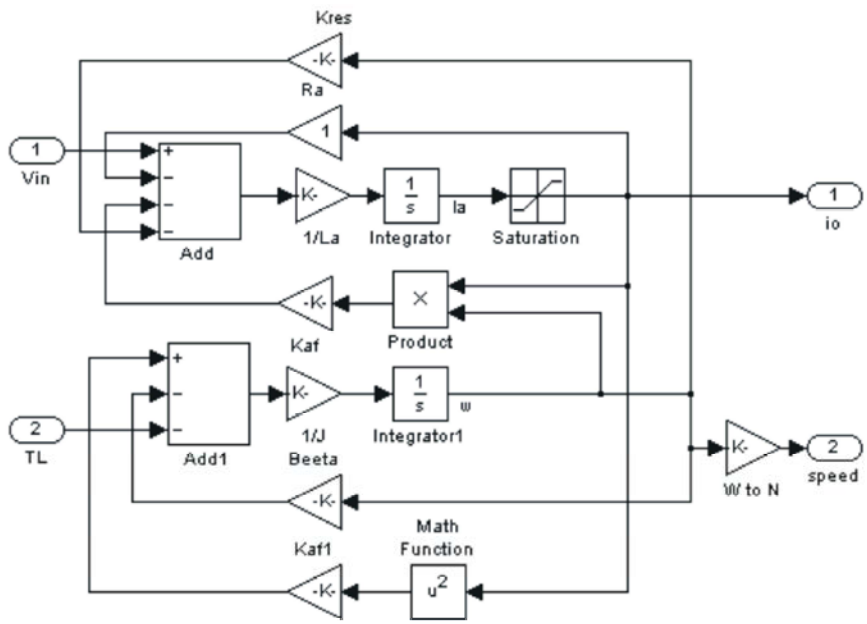

Fig. 2: Simulink model of DC series motor

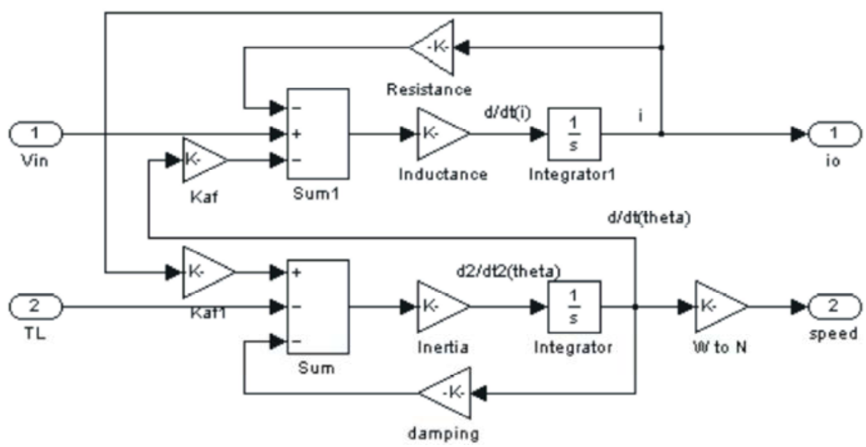

Fig. 3: Simulink model of DC separately excited motor

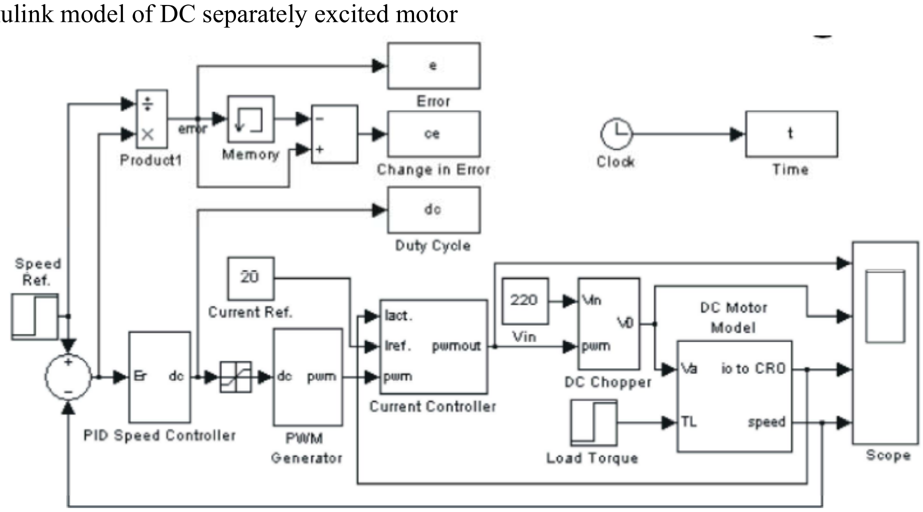

Fig. 4: Simulink Model of the system with conventional PID controller

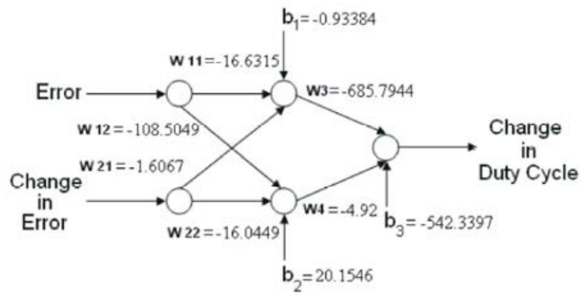

Fig. 5: Structure of Trained Neural network

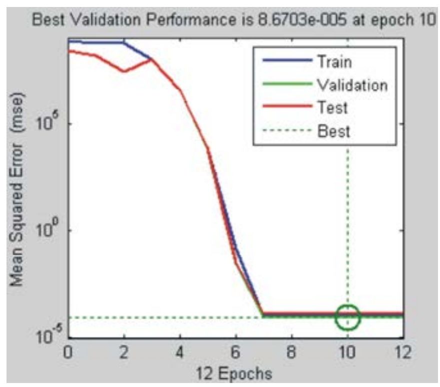

Fig. 6: ANN parameter variation during training

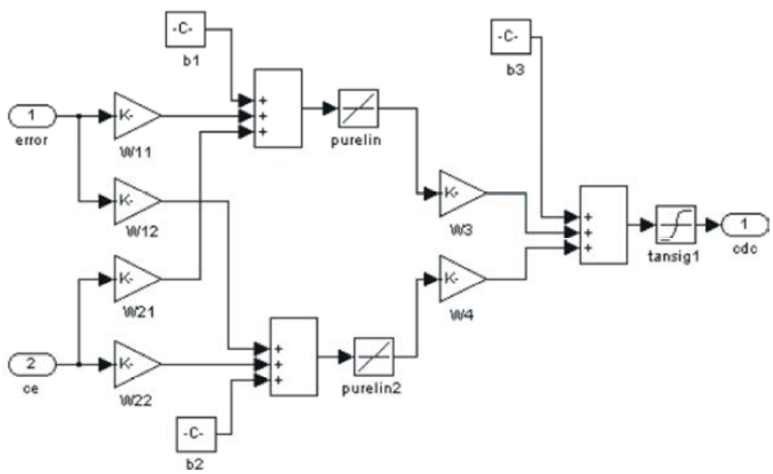

Fig. 7: Structure of the ANN controller using MATLAB

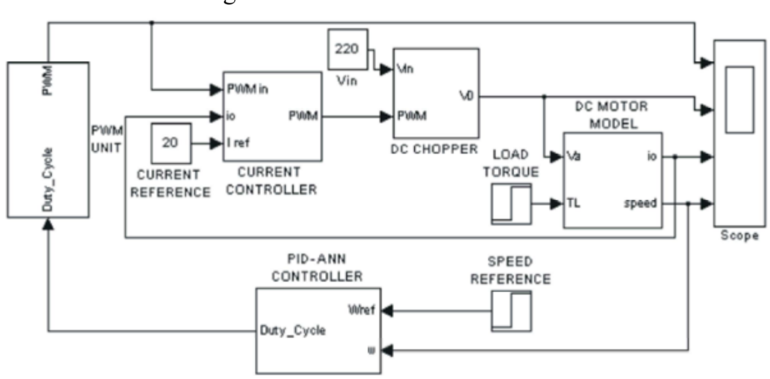

Fig. 8: Simulink Model of the proposed system with Hybrid PID-ANN controller

Table 1: Sample Data from PID controller

Input Data		Target Data
Error	Change in Error	Corresponds to □
1	-0.0005	200020
0.8573	-0.0004	-19160
0.7334	-0.0004	-10409
0.6271	-0.0003	-4932
0.5356	-0.0003	-7337

with the sampling time of 0.0001seconds. Totally 50001 data is obtained from the system with PID controller. Out of 50001 only 1200 data are taken for training the ANN controller by removing the same value of data. The sample data is given in Table 1.

Hybrid PID-ANN Controller: Data processing in PID controller is not more accurate and it will produce error result, means that overshoot, undershoot and steady state error etc. The artificial neural network is based on nonlinear control algorithm that can be worked out because of its mathematical nature [6]. In this section, the solution of implementing conventional PID controller in an Artificial Neural Network is discussed. The ANN controller designed in most of the work use a complex network structure. The aim of this work is to design a simple ANN controller with possible less number of neurons while improving the performance of the controller. In the proposed work a two layer feed forward neural network is created with two neurons in the input layer and one in the output layer.

As the inputs to the ANN controller are the error and change in error, two neurons are used for input layer. The neurons are biased. The activation functions used for the input neurons are pure linear and the tangent sigmoid activation function for output neuron. The network is trained for the set of inputs and desired outputs [6]. The training patterns are extracted from the conventional PID controller. A supervised back propagation neural network-training algorithm was used with a fixed error goal. The network was trained with minimum error goal. The PID-ANN controller output corresponds to the change in the duty cycle for the motor control. The detail of the trained network is shown in Figure 5. [6, 21-25].

The Hybrid PID-ANN is trained with the error goal of 0.000086703 in 10 epochs. The variation of ANN parameter during supervised back propagation training algorithm is graphically shown in Figure 6.

The structure of the ANN controller using MATLAB simulink is shown in Figure 7. The simulation of DC-DC converter fed DC motors is done based on the equation modeling technique, using MATLAB/Simulink toolbox. The complete Simulink model developed is given in Figure 8. The duty cycle is getting from the Hybrid PID-ANN controller and which is given to PWM unit. The PWM unit generates the pulse at 1 KHz of switching frequency. The current controller permits the pulse to the chopper if the motor current is below the reference current. The DC-DC converter regulate the voltage depends on the PWM thereby the motor speed is regulated to the set value.

RESULTS AND DISCUSSION

The proposed model with ON/OFF current controller and the PID-ANN speed controller have been simulated using MATLAB Simulink. The Hybrid PID-ANN controller has been designed and DC-DC converter fed DC motor performance was tested for the motors specified in Table 2. The simulated waves of Gate Pulse, Output Voltage, Motor Current and Motor Speed with respect to time for DC series motor with ω_r = 1800rpm and 30% load is shown in Figure 9. This waveform shows the expanded part of the plot in the time interval 1.495 seconds to 1.52 seconds which shows the precise variations of the above parameters.

The motor set speed change from 1000 RPM to 1500 RPM, with 10% load with respect to time response for PID controller and ANN controller for both DC series motor and DC separately excited motor are given in Figure 10. The comparative time domain specification corresponding to these set speed changes are depicted in Table 3 & 4 for both DC series motor and DC separately excited motor respectively for both the controller.

Table 2: Motor Specifications

	Value	
Parameters	DC Series Motor	DC Separately Excited Motor
P	5HP	3HP
V	220 V	220V
I	18 A	4.3A
J	0.0465 Kg-m^2	0.011 Kg-m^2
B	0.005Nm.Sec./rad	0.004Nm.Sec./rad
R_a	1Ω	0.6Ω
L_a	0.032 H	0.008 H
N	1800 rpm	1800rpm
K_{af}	0.027 H	0.55 H
K_{res}	0.027 V.Sec./rad	-

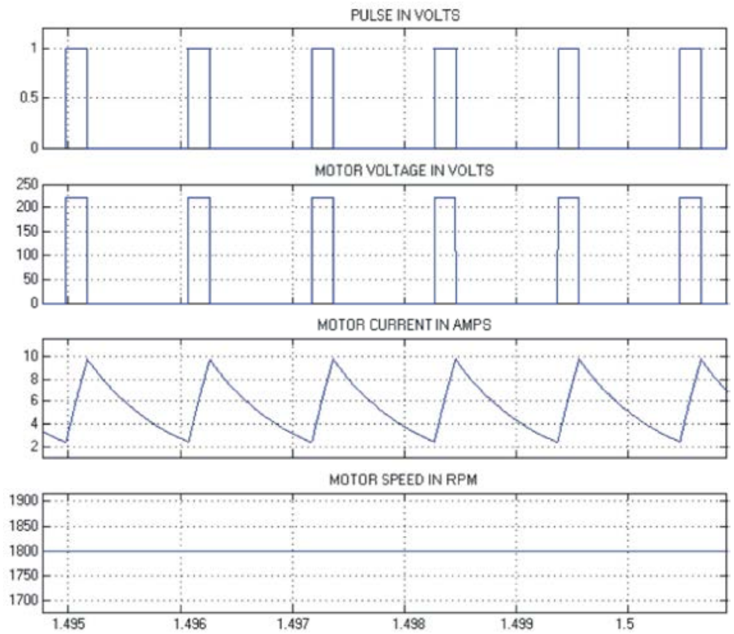

Fig. 9: Pulse, Output Voltage, Motor Current and Speed with respect to Time for DC series motor

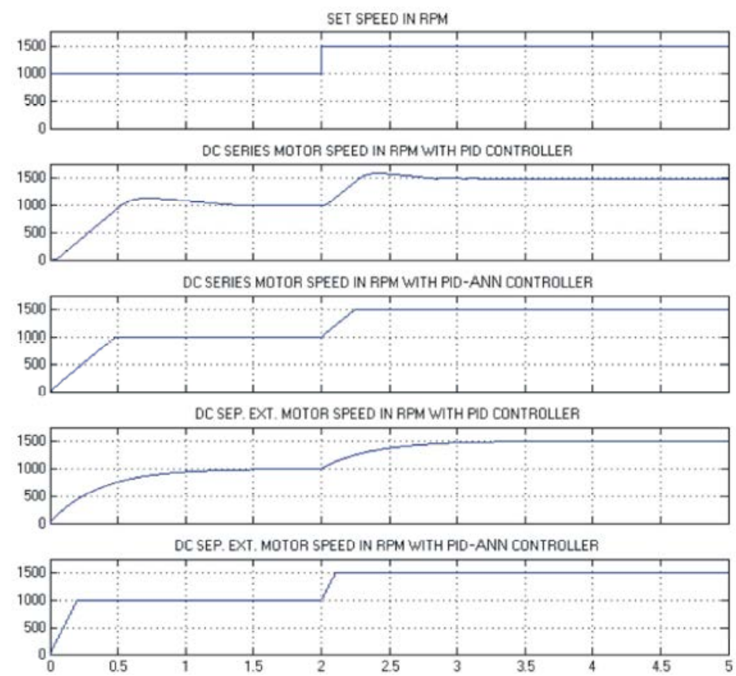

Fig. 10: Performance of controller for set speed variation at 2 sec. from 1000RPM to 1500RPM

With respect to Table 3 & 4 the overall performance of Hybrid PID-ANN controller is superior comparing with designed PID controller performance during set change in the speed. Hence it is recommended for all modern industrial and engineering, DC motor drive applications.

The motor speed, for various load changes at different time interval with speed of 1500rpm with respect to time response for PID controller and Hybrid PID-ANN controller for both DC motors is given in Figure 11. The comparative time domain specification corresponding to these load changes are illustrated in Table 5 & 6 for both DC series motor and DC separately excited motor respectively for both the controllers.

Table 3: Time domain specification of PID and PID-ANN controller for set speed change with 10% load for DC series motor

Time Domain Specifications		Max. over Shoot in %	Settling time in Sec.
Set Speed Change from 0 to 1000rpm	PID	6.8	1.3
	PID-ANN	-	0.5
Set Speed Change from 1000 to 1500rpm	PID	4.4	0.75
	PID-ANN	-	0.3

Table 4: Time domain specification of PID and PID-ANN controller for set speed change with 10% load for DC separately excited motor

Time Domain Specifications		Max. over Shoot in %	Settling time in Sec
Set Speed Change from 0 to 1000rpm	PID	-	1.6
	PID-ANN	-	0.1
Set Speed Change from 1000 to 1500rpm	PID	-	1.1
	PID-ANN	-	0.05

Table 5: Time domain specification of PID and PID-ANN controller for different load change with the speed of 1500 RPM for DC series motor

Time Domain Specifications		Max. Speed Drop in %	Recovery time in Sec	Steady State Error in rpm
Load Change from 10% to 50%	PID	1.66	0.35	15
	PID-ANN	0.1	0.005	±0.75
Load Change from 50% to 100%	PID	2.5	3.5	-25
	PID-ANN	0.5	0.1	±0.3

Table 6: Time domain specification of PID and PID-ANN controller for different load change with the speed of 1500 RPM for DC separately excited motor

Time Domain Specifications		Max. Speed Drop in %	Recovery time in Sec	Steady State Error in rpm
Load Change from 10% to 50%	PID	0.5	NA	10
	PID-ANN	-	-	±3
Load Change from 50% to 100%	PID	1.16	NA	-21
	PID-ANN	0.4	0.025	±0.3

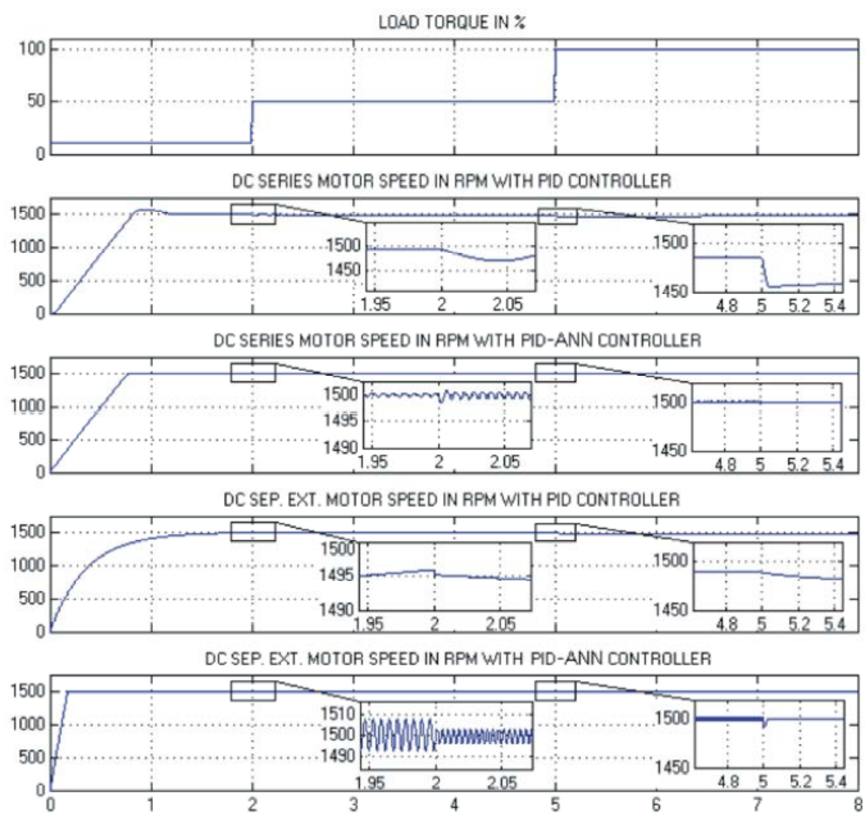

Fig. 11: Performance of controller with 50% load disturbance at 2 Sec. and 100% at 5 Sec.

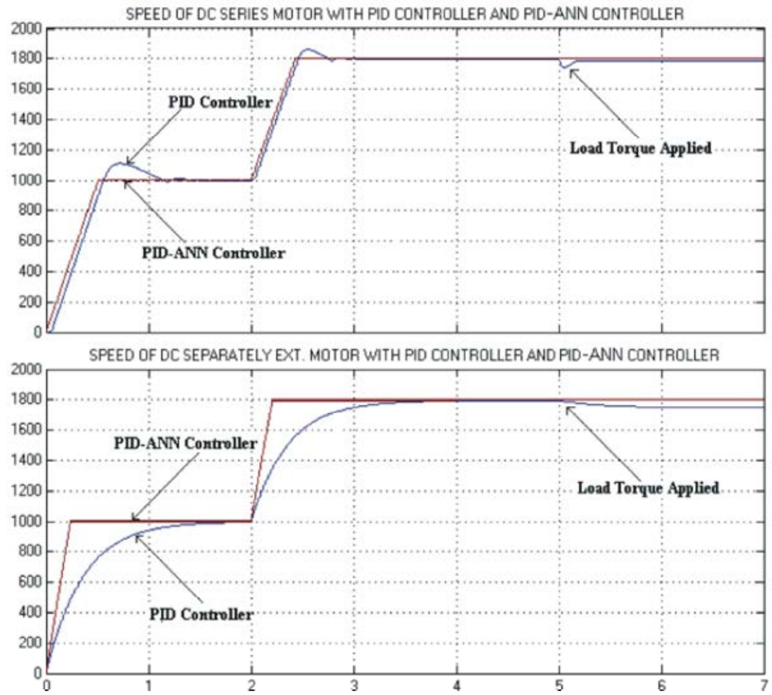

Fig. 12: Controllers performance for speed variation from 1000 RPM to 1800 RPM at 2 seconds and load disturbance 10% to 80% at 5 seconds

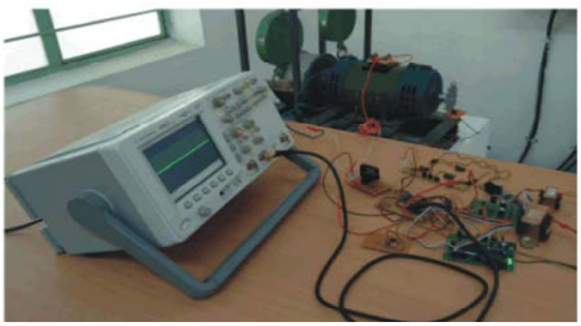

Fig. 13: Hardware setup of the proposed system with DC series motor

With respect to Table 5 & 6 the overall performance of PID-ANN controller is to be evaluated. Up to 50% of load, the maximum speed drop and the recovery time are very less for series motor and it is negligible for separately excited motor with PID-ANN controller. If the load increased from 50% to 100% its value increased to some extent. 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 conventional PID controller during load changes from 10% to 100%. Hence it can be recommended for all modern industrial drive applications using DC motors.

In Table 6 the recovery time for separately excited motor with PID controller for the load torque change from 10% o 50% and 50% to 100% is mentioned as NA (Not Applicable) because the speed is getting dropped during the load change and later the controller unable to recover the original speed again. In the case of PID-ANN controller the speed drop is negligible for the same case and it recovers the original speed immediately.

The time domain performance of set speed change from 1000 rpm to 1800 rpm is simulated and compared for both the controllers are shown in Figure 12 for both the motors. The set speed is changed from 1000rpm to 1800rpm at 2 Seconds. The load disturbance 10% to 80% was given at 5 Seconds. From the simulated result it is inferred that the Hybrid PID-ANN controller gives better performance during speed change and load disturbances.

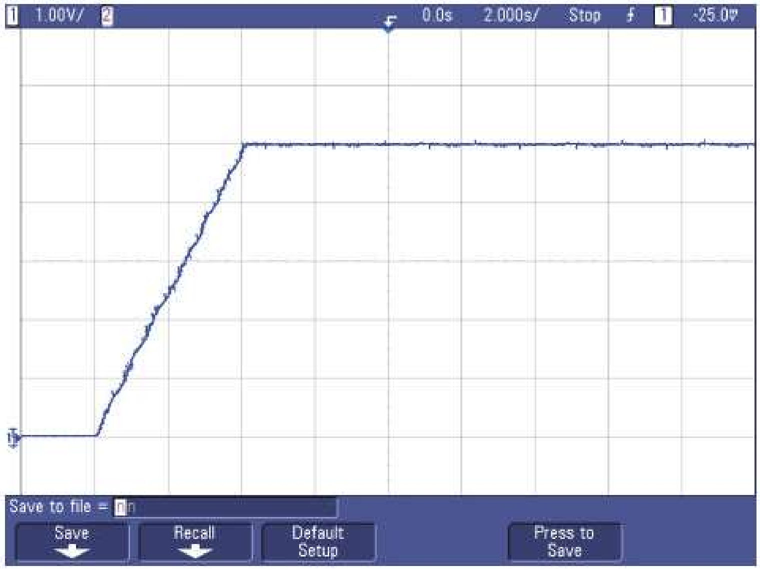

Fig. 14: Experimental graph of speed variation of the step change in reference speed using Hybrid PID-ANN controller for Series motor

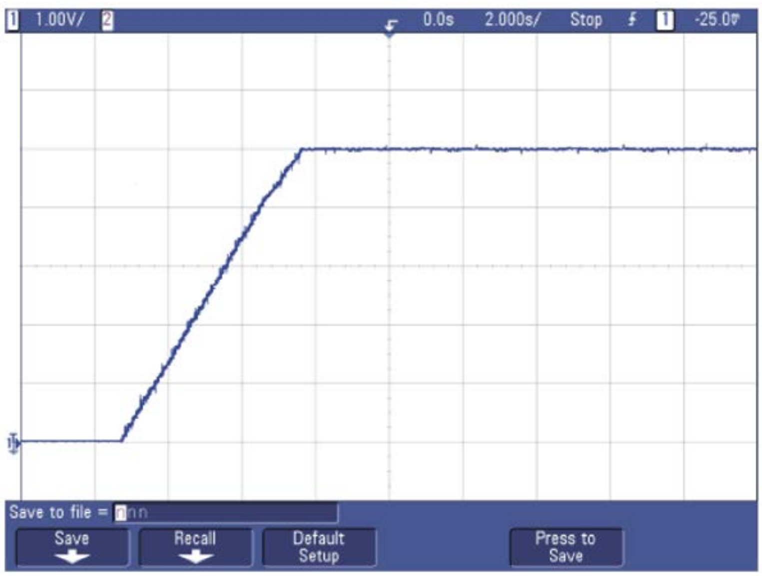

Fig. 15: Experimental graph of speed variation of the step change in reference speed using Hybrid PID-ANN controller for separately excited motor

Experimental Implementation: The designed controller was implemented by using a NXP 80C51 based microcontroller (P89V51RD2BN). The Figure 13 shows the hardware implementation of the proposed system with DC series motor. A buck converter was built with the MOSFET of IRFP450 and the controllers were tested with DC series motor and separately excited motor. A pulse type digital speed sensor was used to sense the speed and to feed back the signal to the controller. The microcontroller (P89V51RD2BN) has an 80C51 compatible core with the following features: 80C51 Central Processing Unit, 5 V Operating voltage, clock frequency from 0 to 40 MHz, 64 kB of on-chip Flash program memory. PCA (Programmable Counter Array) with PWM and Capture/Compare functions. The PWM is generated at a frequency of 10 kHz.

PWM from the microcontroller was then level-amplified with the open collector optocoupler CYN 17-1 and fed to the DC–DC power converter through an isolator and driver chip IR2110. The buck converter output was given to the DC series motor whose speed is to be controlled. The speed sensor connected with motor shaft gives the pulse output which again converted in to voltage using f/v converter and this DC voltage is fed to the ADC available in the microcontroller.

In Figure 14 and 15 the speed response with the rated set speed with Hybrid PID-ANN controller is shown. From the figurer it is observed that there is no overshoot, no steady state error and the settling time also less, which is 4 seconds for series motor and 5 seconds for separately excited motor. These responses show the effectiveness of the Hybrid PID-ANN controller.

CONCLUSION

The performance of the Hybrid PID-ANN controlled DC-DC converter fed DC series motor is presented here. The dynamic speed response of DC series motor with Hybrid PID-ANN controller was estimated for various load disturbance and various speed and found that the speed can be controlled effectively. The Hybrid PID-ANN controller gives the proper speed regulation from 10% to 100% load disturbance. Here the Hybrid PID-ANN controller is reduced the program complications. Also the memory required for the program is reduced. It was implemented with a simple low cost NXP 80C51 family Microcontroller (P89V51RD2BN) based Embedded System. The experimental responses show the effectiveness of the Hybrid PID-ANN controller. The analysis provides the various useful parameters and the information for effective use of proposed system.

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