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SIMULATION AND IMPLEMENTATION OF PID-ANN CONTROLLER FOR CHOPPER FED EMBEDDED PMDC MOTOR

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Abstract
The closed loop control of PMDC drive with an inner current controller and an outer PID-ANN (Proportional Integral Derivative – Artificial Neural Network) based speed controller is designed and presented in this paper. Motor is fed by DC / DC buck converter (DC Chopper). The controller is used to change the duty cycle of the converter and thereby, the voltage fed to the PMDC motor to regulate the speed. The PID-ANN controller designed was evaluated by computer simulation and it was implemented using an 8051 based embedded system. This system will operate in forward motoring with variable speed.

Keywords:
PMDC Motor, ANN Controller, DC Chopper, Embedded System, MATLAB Simulink

1. INTRODUCTION

DC motor drives have occupied a wide spectrum of applications in industries. DC motors are used in machine tools, printing presses, conveyors, fans, pumps, hoists, cranes, paper mills, textile and rolling mills. Small DC motors are used primarily as control devices and servomotors for positioning and tracking. PMDC motor finds many applications in industries. General PI and PID controllers are widely used for chopper control and motor control applications. But it doesn't give satisfactory results [1-3].

ANN becomes very popular in many control applications due to their high computation rate and ability to handle nonlinear actions. The training patterns are generated using conventional PI controller and the effectiveness of the proposed scheme is illustrated using simulation studies and the designed controller was implemented in a low cost 8051-based embedded system and the results are documented [4].

The application of the Feed Forward Neural Network trained by Back Propagation algorithm for intrusion detection has been simulated [5]. The biometric personal identification based on iris recognition using artificial neural networks has been demonstrated [6].

The comparison of PI, fuzzy, and ANN controllers were implemented in an embedded system for closed-loop speed control of DC drive fed by a buck-type DC–DC power converter. It is also found that the ANN controller trained with the training data from a PI controller has a better response compared to the ANN controller trained with data from a fuzzy controller [7-13].

The implementation of PID controller in an Artificial Neural Network (ANN) is presented in this paper. The neural network controller can give robust performance of a nonlinear parameter varying system with load disturbance. This controller has made the control of complex nonlinear systems with uncertainty or un-modeled dynamics as simple as possible The ANN controller is designed to reduce the steady state error, overshoot, settling time.

2. PROPOSED SYSTEM

Fig.1 shows the block diagram of the proposed system. The system consists of DC-DC buck converter to drive the PMDC motor. A micro-controller is used to generate the PWM waveform required to switch the DC-DC converter. A Tacho generator and a LEM current sensor are used to sense the speed and current respectively. The actual speed of the motor is given to the ADC of the microcontroller for feedback.

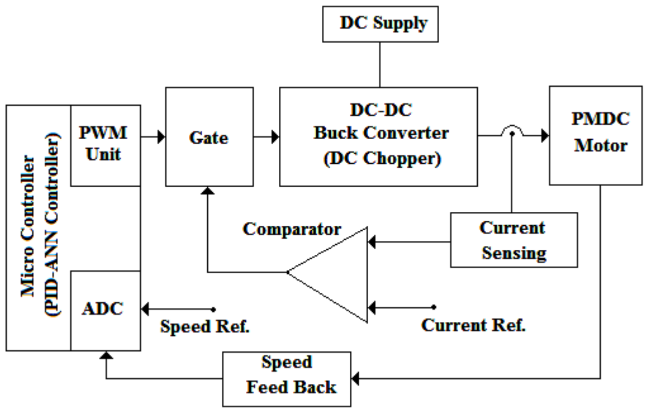

Fig.1. Block diagram of the proposed system

The designed closed loop control has two loops. One is outer PID-ANN based speed control loop and another one is inner current control. In outer speed control loop, the speed is fed back and is compared with set speed. After comparison, error signal and the change in error are calculated and are given as input to the controller. The PID-ANN controller attempts to reduce the error to zero by changing the duty cycle of switching signal.

A two layer feed forward neural network is constructed with two neurons in the input layer and one neuron in the output layer. The inputs to the controller are error and change in error. The output is the change in duty cycle. The new duty cycle for the chopper is calculated from the previous duty cycle and the output of the controller. The output gain in duty cycle calculation is estimated by simulation [4].

Initially, MATLAB/Simulink model of the PMDC motor and the DC-to-DC converter was developed and simulated with conventional PID controller. From the simulation the data like error, change in error and duty cycle were taken. These data were used to train the ANN controller using MATLAB nntool GUI. Then the closed loop operation was simulated with PID-ANN controller to achieve the desired performance. Finally the system was implemented with an Atmel microcontroller (ATmega 16A PU 1028) based Embedded System [5].

3. MATHEMATICAL MODEL OF PMDC MOTOR AND DC-DC CONVETER

3.1 PMDC MOTOR

In PMDC motor the field pole is permanent magnet and the flux produced by the field pole is constant. Therefore the field circuit was neglected for modeling and the armature circuit alone was considered for the motor modeling. The simulation of the entire set up was done using equation models of the motor. The PMDC motor has been modeled with the following modeling equations.

$$\frac{di_o}{dt} = \frac{1}{L}\left[-Ri_o + V_o - K_b\frac{d\theta}{dt}\right] \quad (1)$$

$$\frac{d^2\theta}{dt^2} = \frac{1}{J}\left[K_T i_o - B\frac{d\theta}{dt} + T_L\right] \quad (2)$$

where,

J – Moment of Inertia of the motor
B – Friction coefficient of the motor
K_t – Torque constant of the motor
K_b – Motor back emf constant
T_L – Load torque applied
i_o – Armature current
V_o – Armature voltage applied
R – Armature resistance and
L – Armature inductance

The Eq.(1) and Eq.(2) were derived from voltage and torque equation of PMDC motor respectively. By using the above two equations, the PMDC motor was modeled for simulation and is shown in Fig.2.

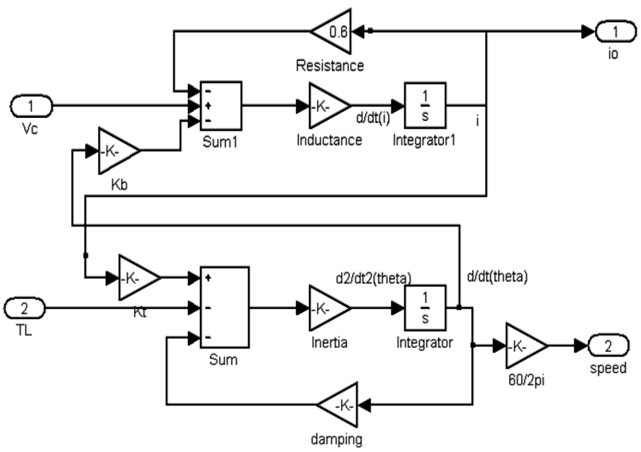

Fig.2. Simulink model for the PMDC motor

3.2 DC-DC CONVERTER

The DC-DC converter switch can be a Power Transistor, SCR, GTO, IGBT, Power MOSFET or similar switching devices. In order to get high switching frequency (upto 100 KHz) the Power MOSFET was taken as a switching device. Normally on state drop in the Power MOSFET switch is small and neglected [11].

When the gate pulse is applied, the device is turned on. During the 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 circuit and waveform of DC-DC converter is shown in Fig.3.

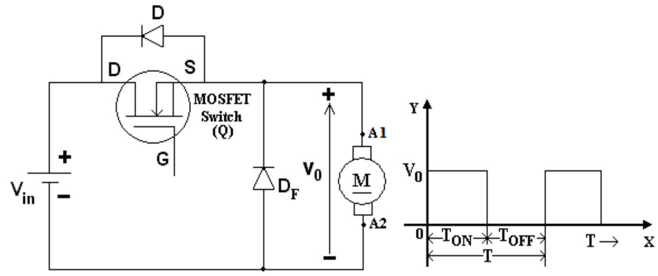

Fig.3. DC-DC converter circuit and waveform

The model equation for DC-DC converter is given by,

$$V_o = \delta V_s \quad (3)$$

$$\delta = \frac{T_{ON}}{T} \quad (4)$$

$$T = T_{ON} + T_{OFF} \quad (5)$$

where,

V_0 – Output Voltage
V_S – Input Voltage
T_{ON} – ON Time
T_{OFF} – OFF Time
T – Total Time
δ – Duty Cycle

The operation of DC-DC converter is given in Table.1.

Table.1. DC-DC Converter Switching operation

Operating mode	Switch Position		Converter Output voltage V_o		Load current i_o
	Motoring (Mode 1)	**Freewheeling (Mode 2)**	**Mode 1**	**Mode 2**	
Forward Motoring	MOSFET (Q) ON	Diode (D_F) ON	V_s	0	+ve

4. DESIGN OF CONTROLLER

4.1 CONVENTIONAL PID CONTROLLER

The PID controller parameters are determined by Ziegler-Nichols method using MATLAB Simulink. According to Ziegler-Nichols method, the controller has to run by taking only P value, increase the P value of the controller until it, self oscillating with constant amplitude, then take the controller gain. According to Ziegler-Nichols procedure the P, I and D values are determined. Fig.4 shows the MATLAB circuit for PID controlled PMDC motor. This circuit is used to take the training data to train the neuron in the artificial neural network controller.

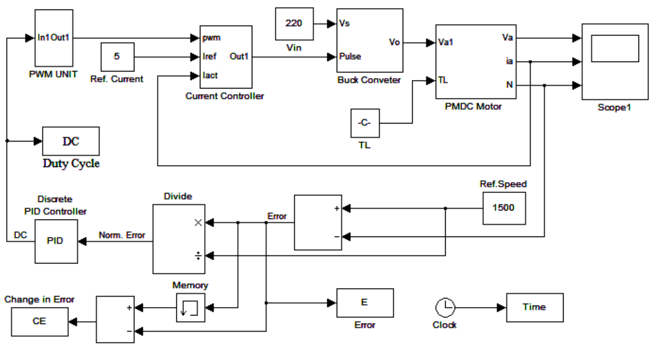

Fig.4. MATLAB circuit for PMDC motor with PID controller

4.2 PID-ANN CONTROLLER

The performance of PID controller is not more accurate and it will produce error result, means that overshoot, undershoot and steady state error etc. The neural network is based on nonlinear control algorithm that can be worked out because of its mathematical nature.

The ANN controllers designed in most of the work uses 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 this work a two layer feed forward neural network is created with two neurons in the input layer and one neuron in the output layer. The activation functions used for the input neurons are pure linear and the tangent sigmoid activation function is used for output neuron [4].

A supervised back propagation neural network-training algorithm is used with a fixed error goal. The PID-ANN is trained with the error goal of 0.000086703 in 10 epochs, since this network is not a perceptron type network. The variation of ANN parameter during supervised back propagation training algorithm is graphically shown in Fig.5.

The error (e) and change in error (ce) are the inputs to the controller. The output corresponds to the change in the duty cycle which is given to the PWM unit. The detail of the trained network is shown in Fig.6.

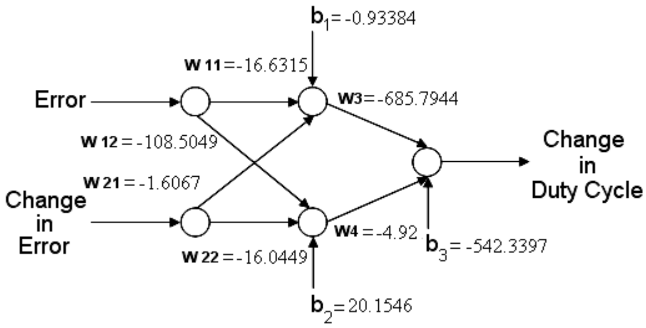

Fig.6. Structure of Trained Neural Network

The complete MATLAB circuit of PID-ANN controlled DC-DC converter fed PMDC motor is given in Fig.7. The duty cycle is getting from the ANN controller and which is given to PWM unit. The PWM unit generates the pulse. The current controller permits the pulse to the chopper if the motor current is below the reference current. Then the chopper gives the required voltage to the PMDC motor to run in the specified speed as given in the reference speed.

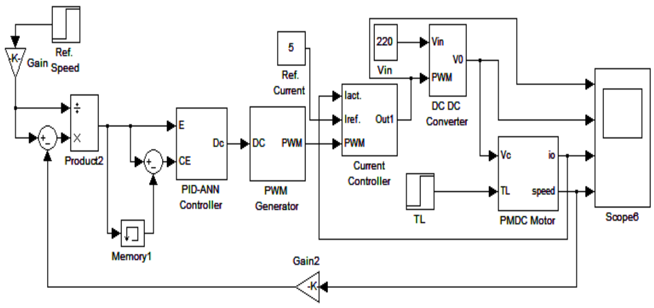

Fig.7. MATLAB circuit for PMDC Motor with PID-ANN controller

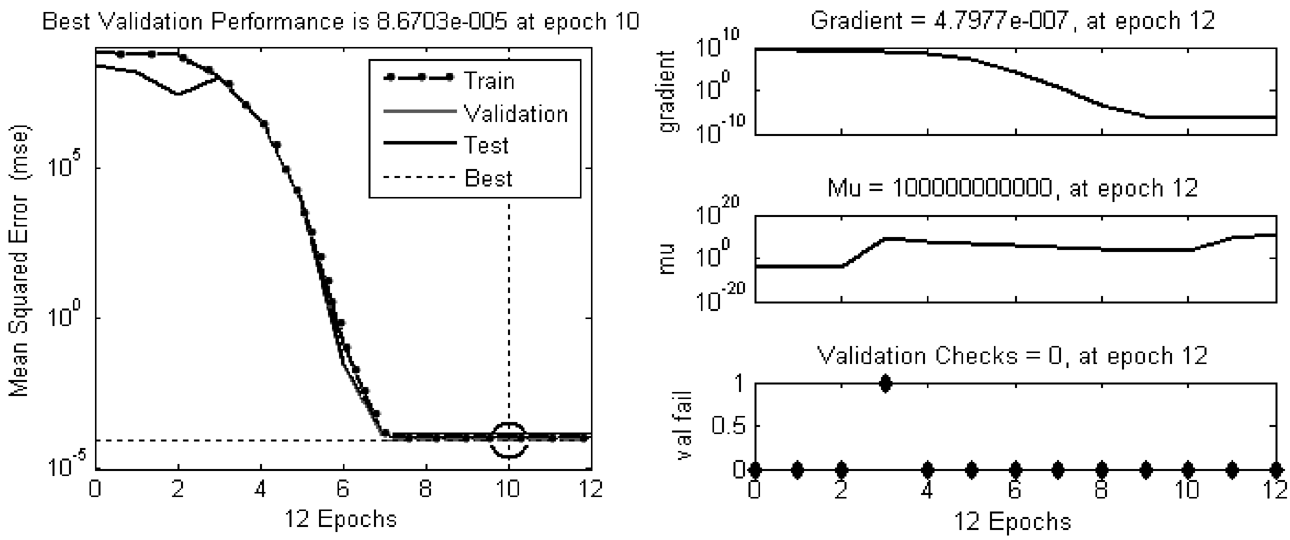

Fig.5. ANN parameter variation during training

5. RESULTS AND DISCUSSION

5.1 SIMULATION RESULT

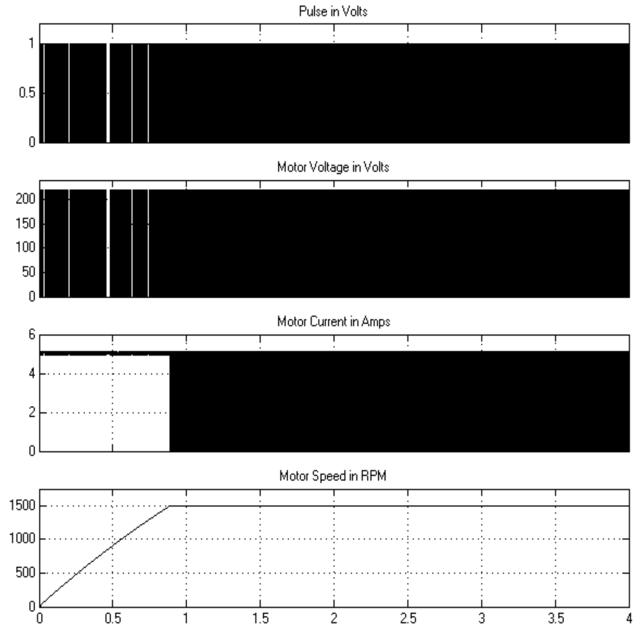

Fig.8. Pulse, Output Voltage, Motor Current and Speed with respect to Time

The simulated waves of gate pulse, output voltage, motor current and motor speed with respect to time with ω_r=1500 rpm and 30% load is shown in Fig.8. At 30% of load the motor is taking almost 0.5 seconds to settle the reference speed. The current is limited to rated value. Fig.9 shows the expanded part of the graph shown in Fig.8.

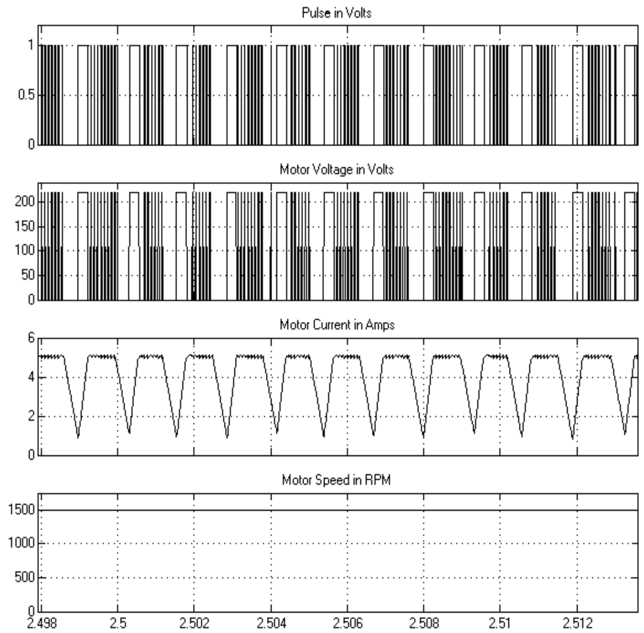

Fig.9. Expanded view of Pulse, Output Voltage, Motor Current and Speed with respect to Time

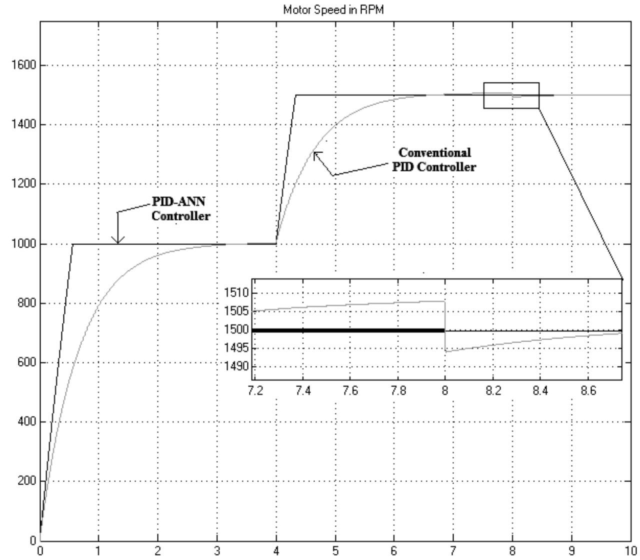

Fig.10. Performance of controllers for speed variation from 1000 RPM to 1500 RPM at 4 sec. and load torque applied from 30% to 80% at 8 sec

The time domain performance of set speed change from 1000 RPM to 1500 RPM at 4 seconds was simulated and compared for both the controllers (Conventional PID and PID-ANN) which were shown in Fig.9. Also in Fig.10 the load torque was applied from 30% to 80% at 8 seconds. The Table.2 depicts the performance comparison of proposed PID-ANN controller with conventional PID controller. From the simulated result it is inferred that the PID-ANN controller gives better performance during speed change and the load torque variation.

Table.2. Performance Comparison of proposed system with conventional PID controller for the speed ωr=1500 RPM and ΔTL=8 N-m applied at t=8secs

Controller	Conventional PID	PID-ANN (Proposed System)
Settling time	3 Sec	0.5 Sec
Steady State Error	5RPM	-
Max. Speed Drop	10 RPM	No Speed Drop
Recovery time	0.8 Sec	-

5.2 EXPERIMENTAL RESULT

The designed controllers were implemented by using an Atmel microcontroller. The ratings of PMDC motor used are 12V, 18 watts, and 1500 rpm. A buck converter was built with the MOSFET of IRF840, and then the conventional PID and PID-ANN controller's performance were tested with the PMDC motor. The experimental setup used is given in Fig.11.

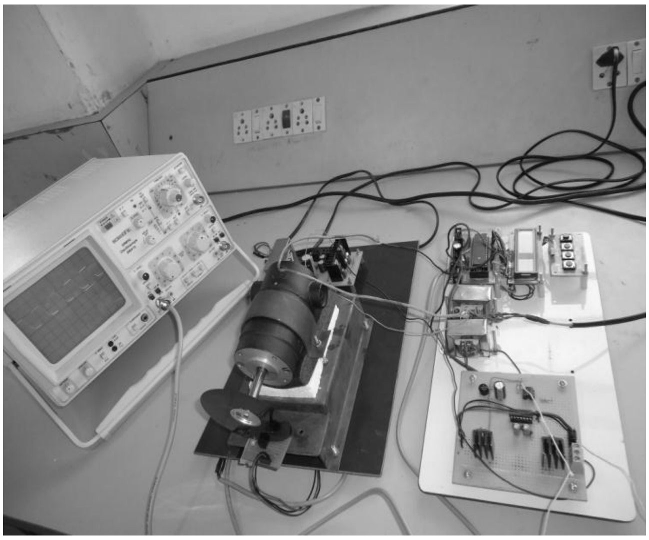

Fig.11. Experimental setup used

The microcontroller Atmel ATmega 16A PU 1028 was used it has the features of High-performance, Low-power 8-bit Microcontroller, Advanced RISC Architecture, Up to 16 MIPS Throughput at 16 MHz, On-chip 2-cycle Multiplier, High Endurance Non-volatile Memory segments, 16K Bytes of In-System Self-programmable Flash program memory, 512 Bytes EEPROM, 1K Byte Internal SRAM, Real Time Counter with Separate Oscillator, Four PWM Channels, 8-channel 10-bit ADC, Operating Voltage 2.7 - 5.5V and speed 0 - 16 MHz.

Fig.12. Experimental output of step change in reference speed from zero to rated speed

PWM waveform from microcontroller is then amplified with open collector optocoupler and fed to the DC chopper through an isolator and driver chip. The DC chopper output is given to the armature of the PMDC motor. The tacho-generator connected to the motor shaft gives a DC voltage proportional to the speed, and this DC voltage is fed to the ADC of the microcontroller. Fig.12 shows the experimental responses of a PMDC motor for a step change in reference speed from zero to rated speed with PID-ANN controller.

6. CONCLUSION

The performance of the PID-ANN controlled DC-DC converter fed PMDC motor is presented here. The dynamic speed response of PMDC motor with PID-ANN controller was estimated for various speed and found that the speed can be controlled effectively. The PID-ANN controller gives the proper speed regulation from 10% to 100% load disturbance than the conventional PID controller. Here the PID-ANN controller is reduced the steady state error, Settling time and the maximum speed drop. Also the memory required for the program is reduced, during the implementation.

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