Speed Control of DC Motor using ANFIS Controller

Akhtar Shabbir Sayyad[1] Umesh G. Bonde[2]
[1]PG Scholar [2]Assistant Professor
[1,2]Shri Sai College of Engineering & Technology, Bhadrawati, India

Abstract— In this paper, DC motor velocity is controlled using PID controller and ANFIS common sense controller. PID controller requires a mathematical model of the controlling system while ANFIS good judgment controller base on experience thru rule-based knowledge. Design of ANFIS perfect controlling controller requires many rule bases decisions, as an instance rule base and fuzzification. The ANFIS has one input which is the speed error. There are six ANFIS rules that are designed for the ANFIS logic controller. The center of maxima approach is used for the defuzzificztion. ANFIS logic controller makes use of mamdani system which employs ANFIS units in consequent part. PID controller chooses its parameters base on trial and error approach or the use of computerized matlab simulink tuning. PID and ANFIS are investigated with the assist of MATLAB / SIMULINK package application simulation. It is based that ANFIS is extra tough in layout comparing with PID controller, but it has an strengthen to be more suitable to meet non-linear traits of DC motor. The results shows that the ANFIS common sense has minimum transient and steady country parameters, which indicates that ANFIS is greater performance and effectiveness than PID controller.

Keywords: ANFIS Controller, DC motor, PID controller

I. Introduction

The development of high performance motor drives is very crucial in industrial as well as different reason applications together with metallic rolling mills, electric powered trains and robotics. Generally, a excessive overall performance motor drive device must have exact dynamic speed command tracking and load regulating reaction to carry out task. DC drives, because of their simplicity, ease of application, excessive reliabilities, flexibilities and favorable value have long been a backbone of industrial programs, robotic manipulators and home equipment wherein speed and position control of motor are required. DC drives are less complex with a single strength conversion from AC to DC. Again the speed torque characteristics of DC cars are much extra advanced to that of AC vehicles. A DC automobiles offer terrific control of speed for acceleration and deceleration. DC drives are typically less high priced for maximum horsepower ratings. DC motors have an extended lifestyle of use as adjustable speed machines and a wide variety of alternatives have advanced for this purpose. In these programs, the motor need to be exactly controlled to give the desired performance. The controllers of the velocity that are conceived for goal to govern the rate of DC motor to execute one kind of tasks, is of several traditional and numeric controller types, the controllers can be: proportional critical (PI), proportional necessary derivative (PID) Fuzzy Logic Controller (FLC) or the aggregate between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Swarm. The proportional– mperative–derivative (PID) controller operates the majority of the manage machine within the world. It has been stated that greater than 95% of the controllers within the industrial manner manage packages are of PID type as no other controller fit the simplicity, clear functionality, applicability and ease of use offered by means of the PID controller. PID controllers offer strong and reliable performance for most systems if the PID parameters are tuned properly.

The major problems in applying a standard control algorithm (PI, PD, PID) during a speed controller are the consequences of non-linearity during a DC motor. The nonlinear characteristics of a DC motor like saturation and fiction could degrade the performance of conventional controllers. Generally, an accurate nonlinear model of an actual DC motor is difficult to seek out and parameter obtained from systems identification could also be only approximated values. The sector of Fuzzy control has been making rapid progress in recent years. symbolic logic control (FLC) is one among the foremost successful applications of fuzzy pure mathematics , introduced by L.A Zadeh in 1973 and applied (Mamdani 1974) in an effort to regulate system that are structurally difficult to model.

Since then, FLC has been a particularly active and fruitful research area with many industrial applications reported. In the last three decades, FLC has evolved as an alternate or complementary to the traditional control strategies in various engineering areas. Fuzzy control theory usually provides non-linear controllers that are capable of performing different complex non-linear control action, even for uncertain nonlinear systems. Unlike conventional control, designing a FLC doesn't require precise knowledge of the system model like the poles and zeroes of the system transfer functions. Imitating the way of human learning, the tracking error and therefore the rate change of the error are two crucial inputs for the planning of such a fuzzy system.

II. Proposed approach

A. PWM and Chopper based PID controlled DC motor

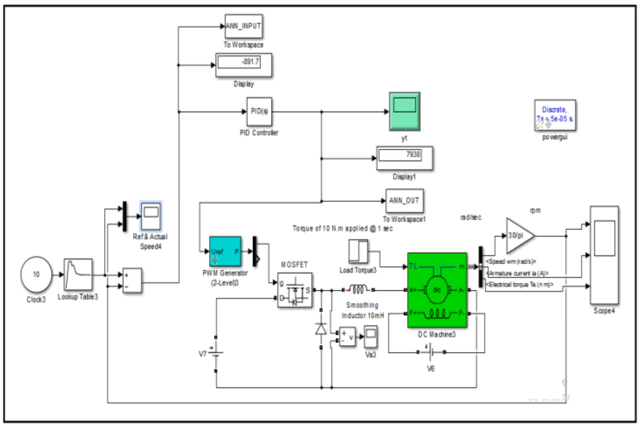

Fig. 1: MATLAB simulink model for speed control of DC motor using PID controller

Figure 1 shows the MATLAB simulink model of PID controller based DC motor speed controlling sing PWM and chopper circuit. In which gain of PWM generator is controlled by PID controller based on actual speed and reference speed error measurement at input of PID controller.

The output pulses of PWM generator is control the chopper circuit or MOSFET switching action so that variable DC supply voltage is supply to the armature winding of DC motor. Hence this method is armature voltage controlling method for speed control of DC shunt motor. After MOSFET switch smoothing reactor is connected for minimization of ripple current from armature supply system. Also freewheeling diode connected across armature winding of DC motor. Freewheeling diode allow to flow of current during OFF period of MOSFET.

Sr No	Name of block	Specification
1	Lookup table	Input time slot values: [0 0.5 1.0 1.1 1.5 2 3 3.5 5] Corresponding speed values: [0 1750 1750 1500 1500 1000 900 900 900]
2	PWM Generator	Generator type: Single phase half bridge; Mode of operation: Un-synchronized; Frequency = 1350Hz; Initial phase angle = 90 Degree; Minimum value = -1; Maximum value = 1
3	MOSFET	FET Resistance Ron = 0.1 Ohm; Internal diode resistance Rd = 0.01 Ohm; Snubber resistance = $5*10^5$ Ohm
4	Diode	Resistance Ron = 0.05 Ohm; Forward voltage Vf = 0.7 V; Snubber capacitance Cs = 0.1Nf
5	Smoothing reactor	Inductance L = 10Mh
6	DC machine	5HP, 240V, 1750RPM, Field voltage 150V Mechanical input = Mecanical torque T_L Armature resistance = 0.78 Ohm; Inductance = 0.0016 H; Field resistance = 160 Ohm; Field inductance = 112.5 H; Field armature mutual Inductance Laf = 1.234 H; Total Inertial = 0.05 J; Viscous friction coefficient Bm = 0.01 N.m.s; Initial speed = 1 rad/sec

Table 1: MATLAB simulink model parameter specification

B. PID Controller tunning

Figure 2 shows the PID controller tuning graphs in which tuning of PID controller with plant or with system is done automatically using MATLAB simulink. The tuning done with reference of reference speed of machine so that to adjust the proportional gain, integral gain and derivative gain of PID controller.

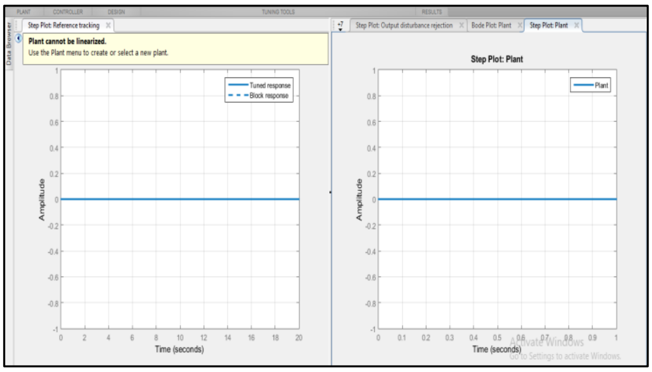

Fig. 2: PID controller tuning window in MATLAB simulink

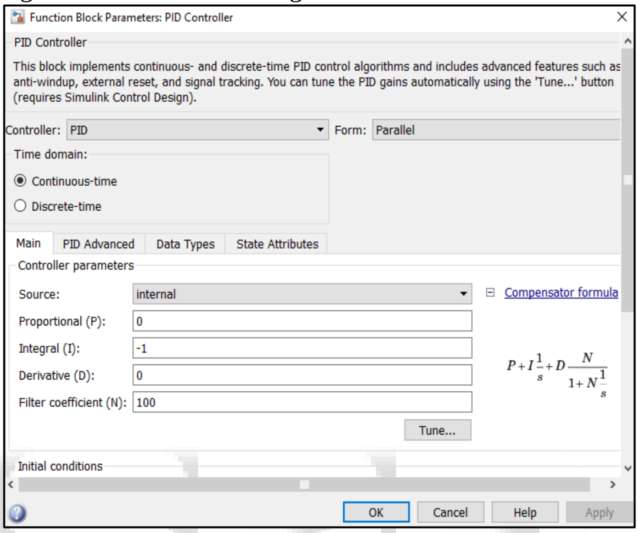

Fig. 3: PID controller parameters and designing window in MATLAB simulink

Figure 3 shows the adjusted PID controller gains after successful tuning of PID controller. In that case Proportional gain, integral gain and derivative gain are respectively 0, -1 and 0.

C. PWM and Chopper based ANFIS controlled DC motor

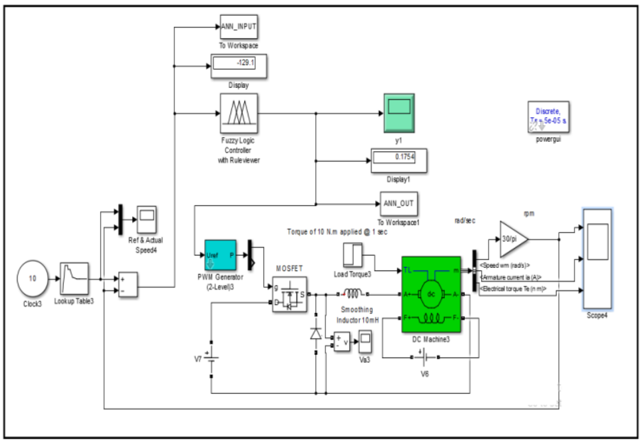

Fig. 4: MATLAB simulink model of pulse width modulation and chopper controlled based DC motor using ANFIS controller

Figure 4 shows the MATLAB simulink model of pulse width modulation and chopper controlled based DC motor using ANFIS controller. The gain of PWM based generator is control by output of ANFIS controller. So that chopper circuit is controlled by ANFIS controller for achieve suitable armature voltage across armature winding. Remaining construction and DC motor same as explain in figure 1.

D. ANFIS Controller design

ANFIS controller is combination of Neural network and Fuzzy logic controller in which training data set for neural network and rule base for fuzzy logic is combines for final controlling action. For getting data base we need to check PWM gain input and corresponding output pulse rate for achieve the proper armature voltage control by chopper MOSFET circuit.

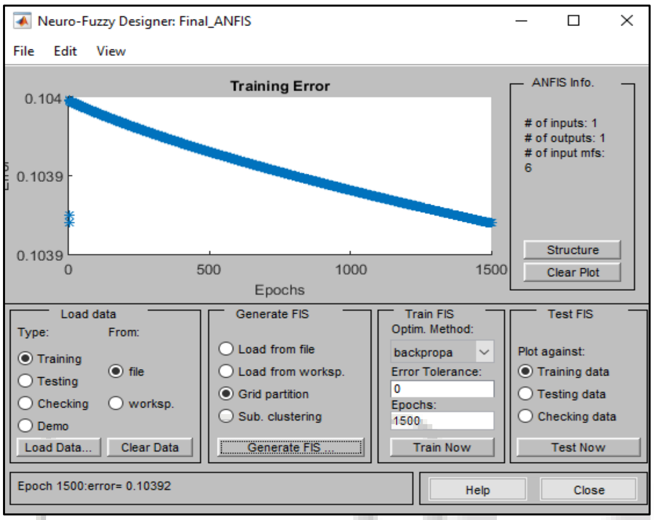

Fig. 5: ANFIS controller training and editor window in MATLAB simulink

In first case training data set are generate from MATLAB simulink model and then from data base Rule base for fuzzy concept is design automatically in MATLAB simulink using ANFIS toolbox shown in figure 5.

Table II shows the training data set for ANFIS controller designing. Te same training data is uploaded in ANFIS controller window for getting fuzzy rule base for controller designing. ANFIS controller is design automatically based on Back-Propagation training algorithm of Neural Network. Then after successful training of ANFIS structure we get the final file which is uploaded in MATLAB simulink ANFIS controller so that to control the speed of DC motor.

Sr No	Input speed error	Output PWM gain from ANFIS
1	-9.5493	-0.08769
2	-166.165	0.093504
3	-180.554	0.102332
4	-199.107	0.113619
5	-205.182	0.117281
6	-214.395	0.122983
7	-3.44822	0.104048
8	-180.503	0.102296
9	-246.258	0.142929
10	-449.862	0.280767
11	-490.18	0.311083
12	-529.632	0.342237
13	-545.764	0.355925
14	-602.584	0.405166
15	-642.401	0.443877
16	-656.042	0.458959
17	-666.894	0.470617
18	-724.723	0.564422
19	-727.478	0.596819
20	-697.316	0.638259
21	-667.819	0.652079
22	-611.982	0.655113
23	-588.444	0.6485
24	-572.351	0.641568
25	-544.913	0.626235
26	-543.584	0.625242
27	-527.698	0.615611
28	-471.732	0.581388
29	-442.283	0.563677
30	-413.929	0.546328
31	-361.681	0.514988
32	-346.669	0.506054
33	-330.832	0.496276
34	-269.123	0.458808
35	-158.607	0.391043
36	646.4065	0.707096
37	218.8546	0.137312
38	130.3063	0.137579
39	113.3761	0.027637
40	92.30065	0.06333
41	54.24467	0.06285
42	46.54938	0.029824
43	46.37436	0.038857
44	46.38316	0.026842

Table 2: Training data set for ANFIS controller

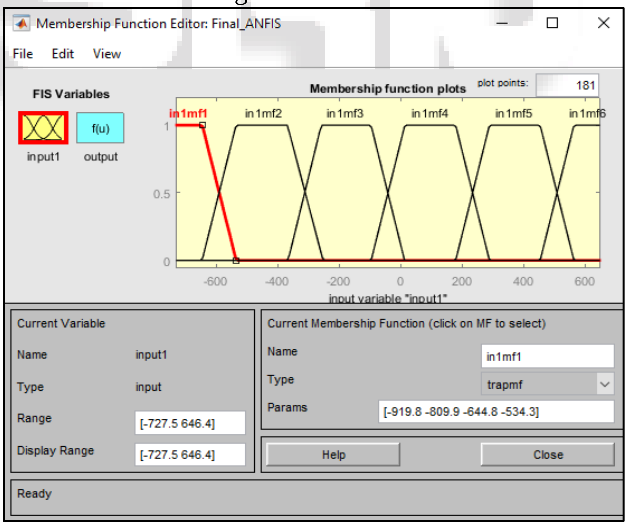

Fig. 6: Membership function for ANFIS input variable i.e. speed error

Name of Input Variable	Range of variable	Type of membership function
In1mf1	-919.8 to -809.9 to -644.8 to -544.3	Trapezoidal
In1mf2	-645.5 to -534.8 to -367.8 to -251.9	Trapezoidal
In1mf3	-365.6 to -257.8 to -95.87 to 13.18	Trapezoidal
In1mf4	-95.6 to 14.04 to	Trapezoidal

	179.3 to 289.2	
In1mf5	179.3 to 289.2 to 454.1 to 564	Trapezoidal
In1mf6	454.1 to 564 to 728.8 to 838.8	Trapezoidal

Table 3: Details of membership function for input variable i.e. speed error

Figure 6 shows the ANFIS input membership function design window after complete training of ANFIS controller using ANFIS training window in matlab simulink. There are total six membership functions are design based on training data set. All six membership functions are trapezoidal membership function and there ranges are also shown in table III.

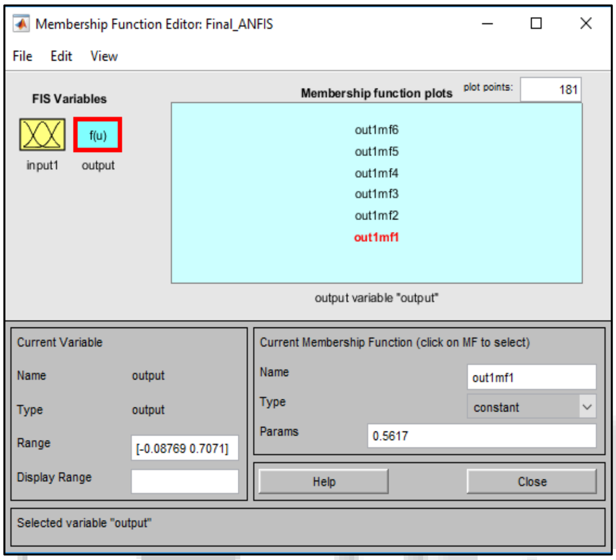

Fig. 7: Membership function for ANFIS output variable i.e. PWM gain adjustment

Figure 7 shows the ANFIS output membership function design window after complete training of ANFIS controller using ANFIS training window in matlab simulink. There are total six membership functions are design based on training data set. All six membership functions are constant value membership function and their value is also shown in table IV.

Name of Input Variable	Range of variable	Type of membership function
Out1mf1	0.5617	Constant
Out1mf2	05102	Constant
Out1mf3	0.1754	Constant
Out1mf4	0.04241	Constant
Out1mf5	0.306	Constant
Out1mf6	0.7071	Constant

Table 4: Details of membership function for output variable i.e. speed error

Figure 8 and 9 shows the ANFIS controller fuzzy rule base and membership function for all rules. The total six rule bases are design for controlling the output that is the gain of PWM generator for speed control of DC motor.

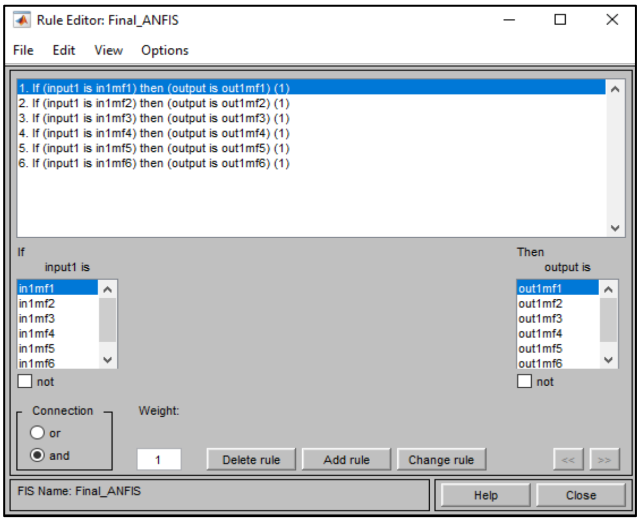

Fig. 8: ANFIS Rule base editor in MATLAB simulink

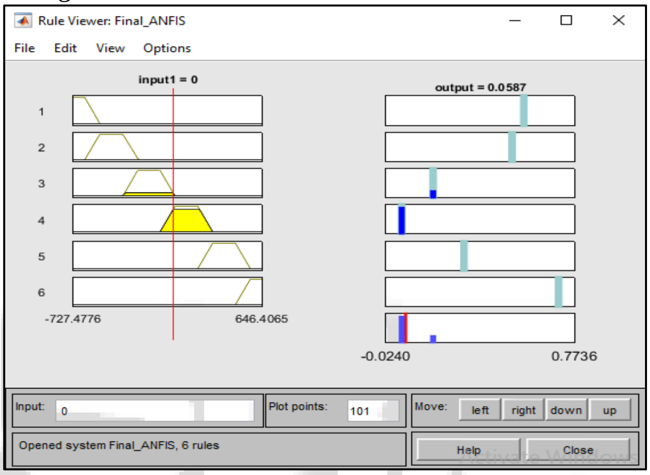

Fig. 9: ANFIS controller rule base with membership function

Figure 10 shows the ANFIS controlling surface in which x-axis represent input of ANFIS controller that is speed error while y axis represent the output of ANFIS that is gain of PWM generator. In that case speed error are ranges from -800 to 800 rpm while gain of ANFIS varies between 0 to 0.8.

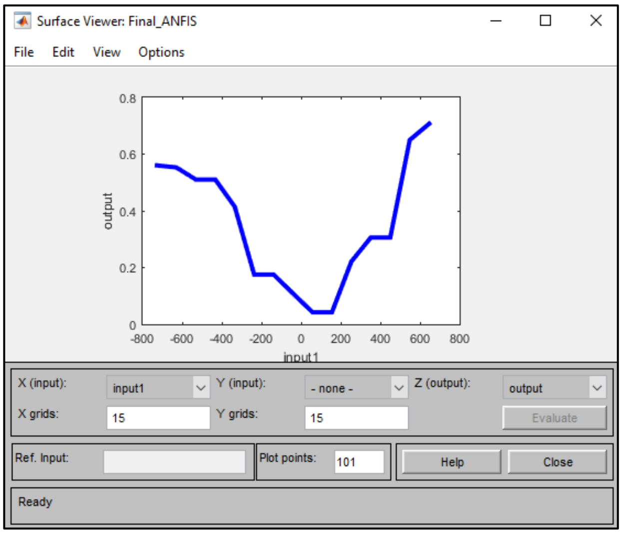

Fig. 10: ANFIS controlling surface for control of gain of PWM generator

III. SIMULATION RESULTS

A. *For PID controller system*

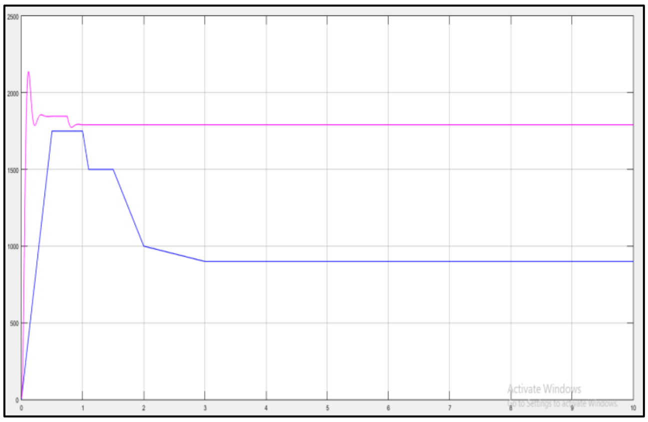

Fig. 11: PID Controlled speed response of DC motor actual speed (pink) and reference speed (blue)

Figure 11 shows the speed controlled by PID controller for DC shunt motor in which x-axis contain time in seconds while y-axis contain speed in rpm. In that case blue line shows the reference or required speed of DC motor while pink line shows the speed controlling of DC motor using PID controller. In that case it is observed that, reference speed and actual speed of motor using PID controller is not match with each other. Hence speed controlling using PID controller is not suitable for PWM and chopper based DC shunt motor.

Figure 12 Shows the response or output of PID controller for controlling the gain of PWM generator in which x-axis contain time in second while y-axis contains gain of PWM generator. The gain of PWM generator is adjusted between 0 to 8000 which is out of range of PWM generator system. As per simulink model property, the gain of PWM generator is ranges between -1 to 1. Hence it is clear that PID controller not provide proper gain as per requirement for the switching action of MOSFET based chopper circuit.

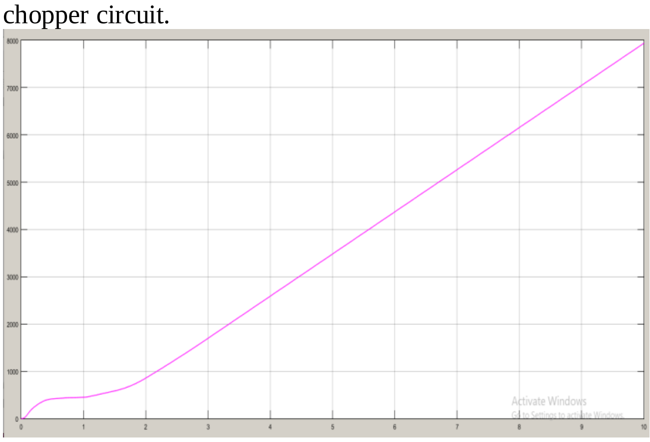

Fig. 12: PID controller response for PWM generator gain controlling for variable speed operation

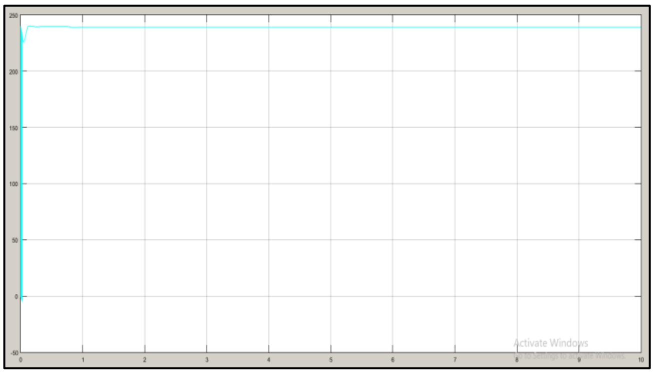

Fig. 13: Armature voltage control by PWM generator using PID controller for variable speed operation

Figure 13 shows the armature voltage generated by PWM generator by controlling the firing pulse of MOSFET based chopper circuit which generate the armature voltage across armature winding. In that case x-axis contain time in second while y-axis contain armature voltage in volts. It is clear that throught the operature armature voltage is 240 Volts throghout the operation. Hence it is clear that PID controller not provide proper voltage as per reference speed variation.

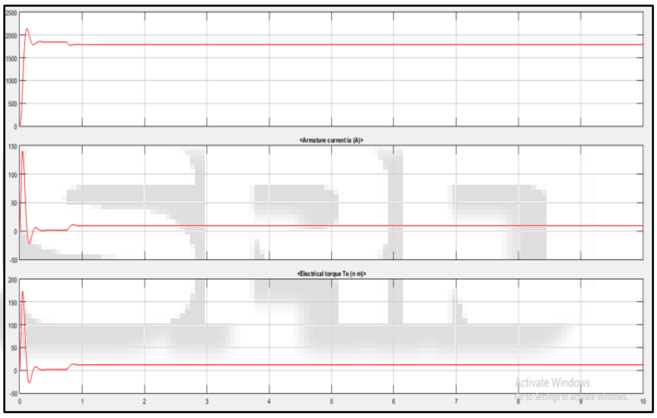

Fig. 14: DC motor actual speed in rpm, armature current in Ampere and Electromagnetic torque in Nm using PID Controller for variable speed operation

B. *ANFIS Controller results*

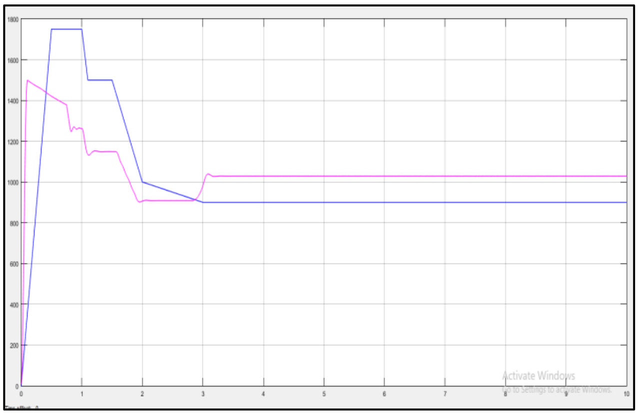

Fig. 15: ANFIS Controlled speed response of DC motor actual speed (pink) and reference speed (blue) for variable speed operation

Figure 15 shows the ANFIS Controlled speed response of DC motor actual speed (pink) and reference speed (blue). In that case x-axis represents the time in second while y-axis represents speed in rpm. As compared with PID controller, the ANFIS controller follows the reference speed. Hence ANFIS controller provides better speed controlling as compared with PID controller (Compare figure 11)

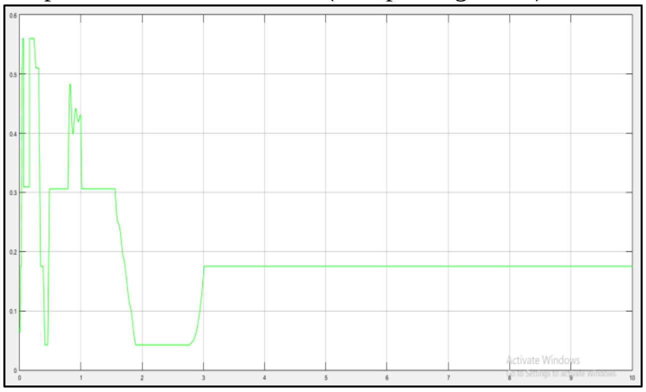

Fig. 16: ANFIS controller response for PWM generator gain controlling for variable speed operation

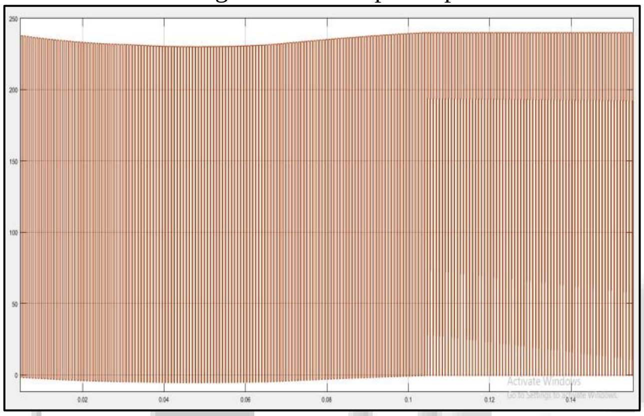

Fig. 17: Armature voltage control by PWM generator using ANFIS controller for variable speed operation

Figure 17 shows that, Armature voltage control by PWM generator using ANFIS controller in which x-axis represent the time in second while y-axis represent the magnitude of voltage in volts. It is clear that the voltage of armature winding continuously changes with respective change in reference speed. As compared with PID controller armature voltage control profile (Fig.13), ANFIS controller provide better voltage control.

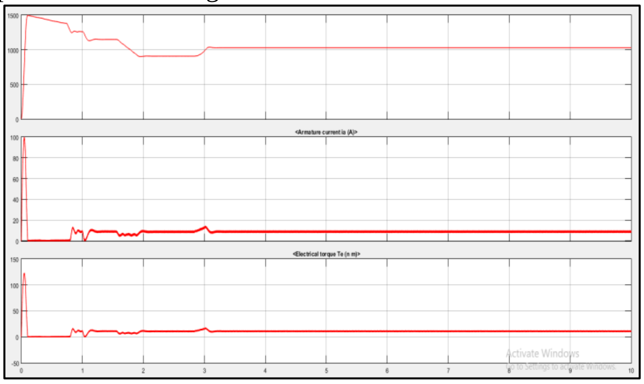

Fig. 18: DC motor actual speed in rpm, armature current in Ampere and Electromagnetic torque in Nm using ANFIS controller

Figure 18 shows the DC motor parameters like speed in RPM, Armature current in Ampere and Electrical torque in N.m. Where, X-axis represent the time in seconds. It is clear that, armature current is changes throughout the operating time with respect to speed changes. Similarly, Electric torque changes with respect to speed of motor.

C. Comparison of PID and ANFIS controller

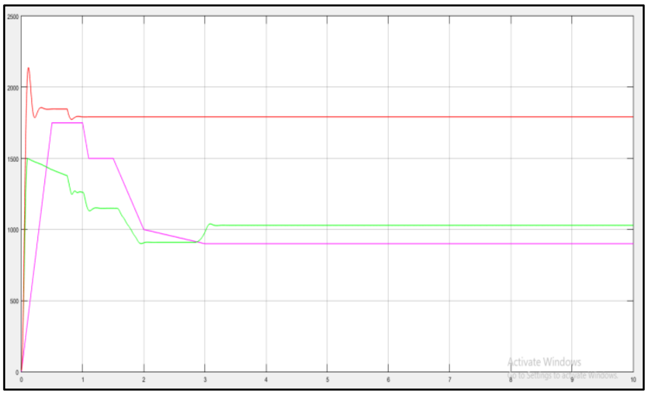

Fig. 19: Speed control of DC motor response by PID and ANFIS controller for variable speed operation

Parameters/Controller types	PID	ANFIS
Rise time (Sec)	0.045	0.055
Settling time (Sec)	0.884	1.3826
Peak overshoot (rpm)	2144	1468
Peak time (Sec)	0.11	0.1
Steady state error (rpm)	830	40

Table 5: Comparison results between PID and fuzzy controller for constant speed operation condition

From table V, it concluded that when compared ANFIS controller with the conventional PID controller, ANFIS controller has better performance in both transient and steady state response, it also has better dynamic response curve, shorter response time, small steady state error (SSE) and high precision compare to the conventional PID controller.

IV. CONCLUSION

Speed Controller system supported ANFIS controller for DC shunt motor has been successfully developed in MATLAB/SIMULINK environment. The performance of the system has been compared with conventional PI controller. Simulation results shown that Adaptive Neuro-Fuzzy controller (ANFIS) has clearly better performance %Mp (peak overshoot), settling time and is in a position to manage the speed.

Focus of this work is to realize better understanding of DC motor Dynamics alongside its control mechanism to develop an ideal simulator platform. The simplified DC motor model dynamics are observed to be very nonlinear. It's therefore integrated with several controller configurations. Among different controller configurations simulated during this paper, ANFIS proven to be more optimized. The developed model is tested through number of simulation run that validate the accuracy of dynamic model and robustness of the proposed controller.

The PID controller and ANFIS controller for separately excited DC motor speed controller are designed using MATLAB software. When applied PID controller and ANFIS controller, the system performance has been improved. It concluded that in comparison ANFIS controller with the traditional PID controller, ANFIS controller has better performance in both transient and steady state response; it also has better dynamic response curve, shorter reaction time, small steady state error (SSE) and high precision compare to the traditional PID controller.

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