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Modeling and Analysis of Adaptive Neuro Fuzzy Inference System Based BLDC Motor under Different Operating Conditions

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Abstract— In this paper the performance factors of adaptive neuro fuzzy inference system (ANFIS) based brushless direct current (BLDC) motor for controlling speed and torque under different operating conditions are analyzed. The above scheme has many characteristics like small torque ripple, strong robustness, good anti interference ability and reduction of starting currents. The dynamic characteristics of the brushless DC motor such as speed, torque, current and voltages of the inverter components are observed and analyzed. In order to verify the effectiveness of the controller, the simulation results are compared with PID controller. The simulation result show that the overall performance of ANFIS based BLDC motor is much better when compared to PID controller under different operating conditions.

Index Terms—Brushless DC motor, speed control, torque control, PID controller and ANFIS controller

I. INTRODUCTION

Modern intelligent motion applications demand accurate speed and position control. Many machine and control schemes have been developed to improve the performance of BLDC motor drives. Some simulation models based on state-space equations, Fourier-transforms, d-q axis model and variable sampling have been proposed for the analysis of BLDC motor drives. Limitations of brushed DC motors overcome by BLDC motors include lower efficiency and susceptibility of the commutator assembly to mechanical wear and consequent need for servicing, at the cost of potentially less rugged and more complex and expensive control electronics. BLDC motors offer better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation and higher speed ranges [1]. Due to their favorable electrical and mechanical properties, BLDC motors are widely used in servo applications such as automotive, aerospace, medical, instrumentation, actuation, robotics, machine tools and industrial automation equipment. Many machine design and control schemes have been developed to improve the performance of BLDC motor drives. The model of motor drive has to be known in order to implement an effective control in simulation. Furthermore the fuzzy logic controllers have been used to analyse BLDC motor drive [2].

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A comprehensive model with MATLAB/fuzzy logic toolbox is used to design the FLC, which is integrated into simulations with simulink is analyzed [3]. The mathematical models of brushless DC motors is introduced based on the MATLAB/Simulink with the combination of fuzzy control with traditional PID control. The simulation results show that fuzzy-PID control strategy can be used to make remarkable improvement on the overall performance of brushless DC motors [4]. A fuzzy logic controller for brushless direct current (BLDC) permanent magnet motor drives with the dynamic characteristics such as speed, torque, current and voltage of the inverter components are observed and analyzed using the developed MATLAB model. In order to verify the effectiveness of the controller, the simulation results are compared with TMS320F2808 DSP experimental results. The simulation and experimental results show that the brushless direct current motor (BLDC) is successfully and efficiently controlled by the Fuzzy logic controller [5]. The performance of the fuzzy, PI controller for speed control of BLDC motor and the controller uses three fuzzy logic controllers and three PI controllers. The output of the PI controllers is summed and is given as the input to the current controller. The current controller uses P controller. The BLDC motor is fed from the inverter where the rotor position and current controller are the input. The fuzzy logic control is learned continuously and gradually becomes the main effective control [6]. The detail of BLDC motor with Conventional methods like PI, PID and the performance improvement with fuzzy control with rule table for different values of speed & get accurate answer for the control of speed by using mamdani methods for fuzzy control & centroid method for defuzzification with simulations results [7]. In this paper, the performance of an adaptive neuro fuzzy controller based BLDC motor drive is analyzed. The dynamic characteristics of the brushless DC motor such as speed, torque, current and voltages of the inverter components are observed and analyzed using the developed MATLAB model. In order to verify the effectiveness of the controller, the simulation results are compared with PID controllers. The simulation results show that the performance of brushless direct current motor is better with the ANFIS controller.

II. CONSTRUCTION AND PRINCIPAL OF OPERATION

BLDC motors are a type of synchronous motors and here the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency.

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BLDC motors do not experience the “slip” that is normally seen in induction motors. BLDC motor is constructed with a permanent magnet rotor and wire wound stator poles. Stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut off along the inner periphery as shown in Fig.1. Most of the BLDC motors have three stator windings connected in star fashion. Each of these windings is constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and these are interconnected to make a winding. Each of these windings is distributed over the stator periphery to form an even numbers of poles.

Fig. 1 Stator of BLDC Motor

Rotor of BLDC motor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are used to make permanent magnets as shown in Fig.2. Each commutation sequence has one of the windings energized to positive power, the second winding is negative and the third is in a non-energized condition. Torque is produced due to the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to each other and falls off as the fields move together. In order to keep the motor running, the magnetic field produced by the windings should shift the position, as the rotor moves to catch up with the stator field.

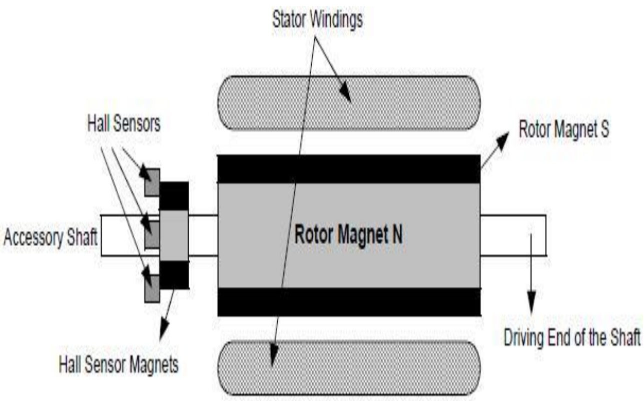

Fig. 2 Rotor of BLDC Motor

III. MATHEMATICAL MODELLING OF BLDC MOTOR

According to the mathematical modeling of BLDC motors, the simulation models can be built through MATLAB/SIMULINK and the Simulation system consists of two closed loop controls namely speed loop and current loop. The inner current loop is adopted based on the basic current equations from mathematical modeling of BLDC motor and the outer speed loop consists of Adaptive neuro fuzzy controller (ANFIS) instead of traditional PID controller. The system structure is Based on modular based structure. Each system structure is divided into several functional blocks namely speed controller, voltage generation, current generation, back emf generation and speed torque blocks and each functional block has its own function. Voltage control block consists of mainly carrier, reference signals and electrical angle ‘θ’ which is generated from the basic equation of BLDC as shown in Fig.3. The Armature winding voltage equations are represented in the equations from 1to 3.

$$V_a = (L-M)\times\frac{di_a}{dt} + i_a \times R + E_a \tag{1}$$

$$V_b = (L-M)\times\frac{di_b}{dt} + i_b \times R + E_b \tag{2}$$

$$V_c = (L-M)\times\frac{di_c}{dt} + i_c \times R + E_c \tag{3}$$

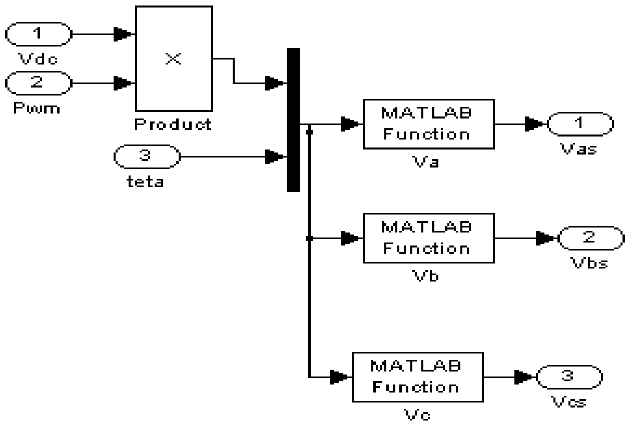

Fig. 3 Voltage Generation Block of BLDC Motor

Back emf generation block consists of angular speed of the rotor ‘ω_r’ back emf constant ‘K_b’ , the back emf of the rotor obtained and by applying ‘θ’ to that block periodic back emf of each phase is obtained. The back emf equations are shown in equations from 4 to 7.

$$E = K_b \times \omega_r \tag{4}$$

$$E_a = \begin{array}{ll} (6E/\pi)\theta & (0<\theta<\pi/6) \\ E & (\pi/6<\theta<5\pi/6) \\ -(6E/\pi)\theta+6E & (5\pi/6<\theta<7\pi/6) \\ -E & (7\pi/6<\theta<11\pi/6) \\ (6E/\pi)\theta-12E & (11\pi/6<\theta<2\pi) \end{array} \tag{5}$$

$$E_b = \begin{array}{ll} -E & (0<\theta<\pi/2) \\ (6E/\pi)\theta-4E & (\pi/2<\theta<5\pi/6) \\ E & (5\pi/6<\theta<9\pi/6) \\ -(6E/\pi)\theta+10E & (9\pi/6<\theta<11\pi/6) \\ -E & (11\pi/6<\theta<2\pi) \end{array} \tag{6}$$

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$$E_c = \begin{cases} E & (0 < \theta < \pi/6) \\ -(6E/\pi)\theta + 2E & (\pi/6 < \theta < \pi/2) \\ E & (\pi/2 < \theta < 7\pi/6) \\ (6E/\pi)\theta - 10E & (7\pi/6 < \theta < 9\pi/6) \\ E & (9\pi/6 < \theta < 2\pi) \end{cases} \quad (7)$$

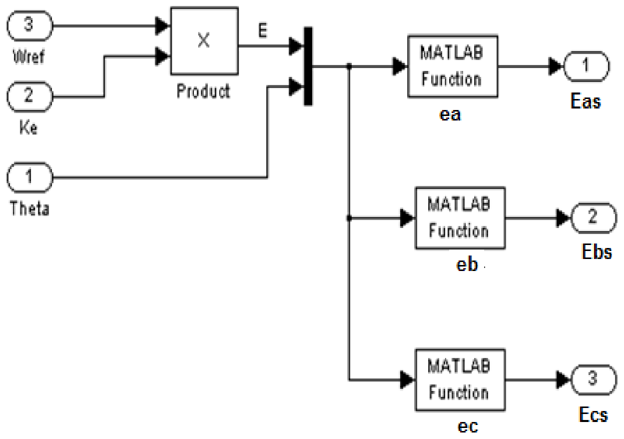

Fig. 4 Back EMF Generation Block of BLDC Motor

Current generation block can be constructed from the voltage block and back emf block by using the basic current equations of BLDC motor as shown in fig.5. The associated equations are mentioned in equations from 8 to 10

$$I_a = \frac{1}{(L-M)}\int (V_a - I_a \times R - E_a)dz \quad (8)$$

$$I_b = \frac{1}{(L-M)}\int (V_b - I_b \times R - E_b)dz \quad (9)$$

$$I_c = \frac{1}{(L-M)}\int (V_c - I_c \times R - E_c)dz \quad (10)$$

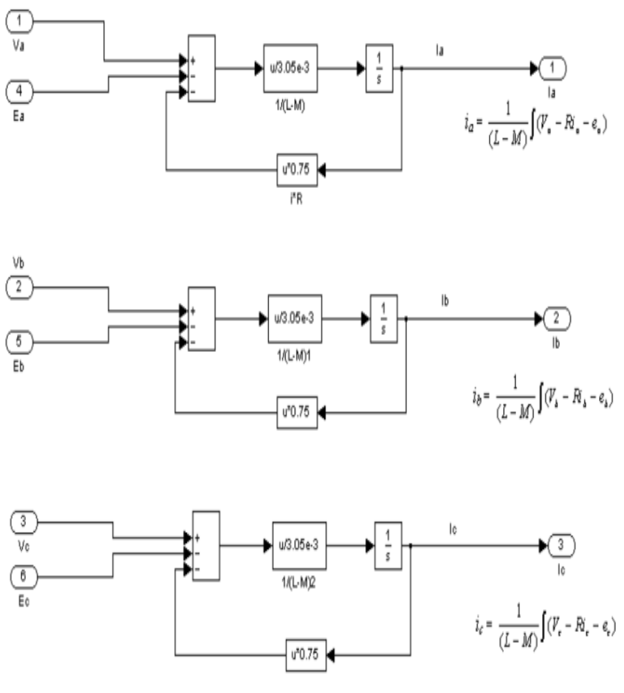

Fig. 5 Current Generation Block of BLDC Motor

The speed and torque control blocks can be constructed by taking inputs from the back emf generation and current generation blocks. Then these blocks are multiplied with each other as shown in fig.6 and associated equations are mentioned in equations from from 11 to 12.

$$T_e = J \times \frac{d\,\omega_r}{dt} + B\,\omega_r + T_l \quad (11)$$

$$T_e = \frac{(E_a \times I_a + E_b \times I_b + E_c \times I_c)}{\omega_r} \quad (12)$$

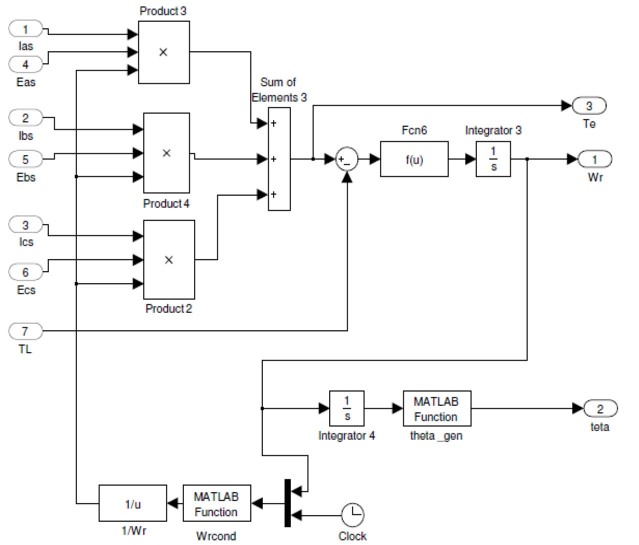

Fig. 6 Speed and Torque Control Blocks of BLDC Motor

IV. FUNCTIONING OF ANFIS CONTROLLER

ANFIS is a based on fuzzy inference system and this system uses the given input and output data to build fuzzy inference system. First a training data set that contains the desired input/output data pairs of target systems to be modeled is required. The design parameters required for any ANFIS controller are number of data pairs, training data sets and checking data sets. For training the number of epochs to be chosen to start the training, learning results to be verified after mentioning the step size. Then the designed ANFIS has two inputs namely, the actual motor speed and reference speed while the output is the torque, which is used to generate current. Structure of ANFIS speed controller is shown in Fig .7 and it is based on the five-layer feed forward fuzzy neural network

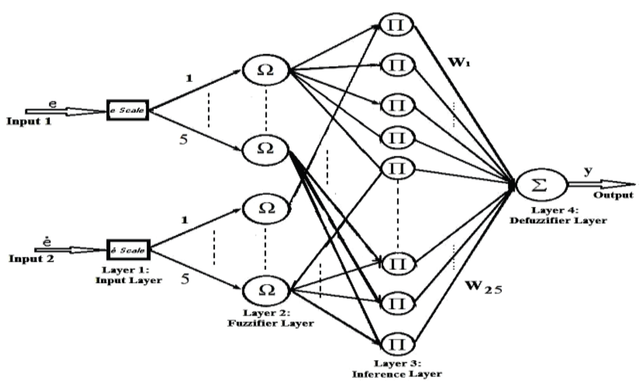

Fig. 7 Structure of ANFIS Controller

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Layer 1 :(Input Layer)
Input layer represents input variables of controller, they are actual speed and reference speed respectively. This layer just supplies the input values x i to the next layer, where i= 1 to n
Layer 2 : (Fuzzification Layer)
This layer receives the input values from the first layer it creates membership function for the respective input variables and these are inputs to the next layer
Layer 3 : (Rule layer)
Each node (each neuron) in this layer performs the pre-condition matching of the fuzzy rules, i.e., they compute the activation level of each rule, the number of layers being equal to the number of fuzzy rules. Each node of these layers calculates the correction which are normalized.
Layer 4 : (Defuzzification Layer)
It provides the output values “y” resulting from the inference of rules. Connections between the layers l 3 & l 4 are weighted by the fuzzy rules that represent another set of parameters for the neuro fuzzy network.
Layer5:(OutputLayer)
In this layer all the inputs coming from the layer 4 sums up and transforms the fuzzy classification results into a crisp values.

V. BLOCK DIAGRAM OF ANFIS BASED BLDC MOTOR

The block diagram of ANFIS based BLDC motor is shown in Fig 8. Here the ANFIS Speed controller is used for controlling the speed. The input to the speed controller is angular reference speed and actual speed. Then the out-put is fuzzy logic controller with rule viewer function parameters ‘*u*’ by which the fuzzy speed controller can be adjusted online in real time application.

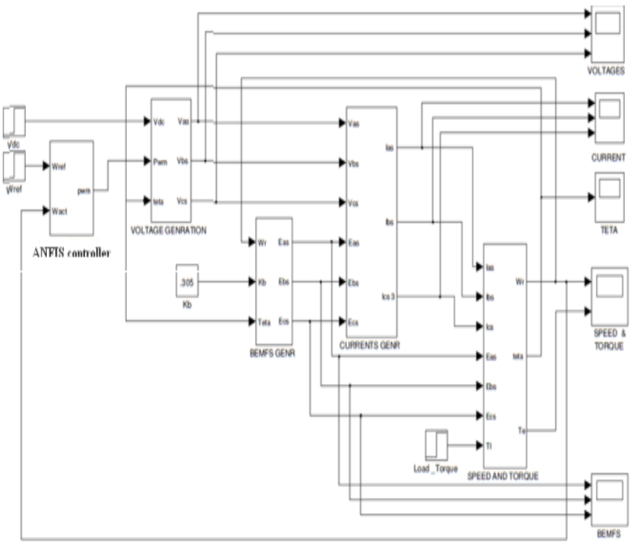

Fig. 8 The Block Diagram of ANFIS based BLDC Motor

This kind of controller is characterized by using fuzzy reasoning and genetic algorithm concepts. Due to two inputs given to the system, the characteristics of the ANFIS controller are similar to PID controller.

VI. SIMULATION RESULTS AND DISCUSSION

To validate the proposed methods, numerical simulation studies have been carried out by using Matlab-Simulink. The parameters of the BLDC motor used in this paper are shown below
Power = 1.2 hp
Poles = 4
Rated current = 2.4 amps
Rated torque = 1.5 N-m
Rated speed = 6000 rpm
Rated voltage = 380 volts
Stator resistance = 5.2 ohms
Stator inductance = 21.5 mH
Rotor inertia J = 1.28e^-4 kgm^2
Torque constant = 0.61 Nm/A
Flux linkage = 0.0769 vs
Bemf const = 0.305V/rad
The simulation results of proposed methods are shown from Fig. 9 – Fig. 14.

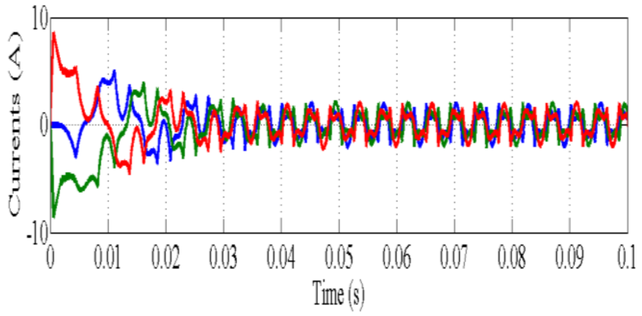

Figure 9 Starting Transients of PID Controller based BLDC Motor

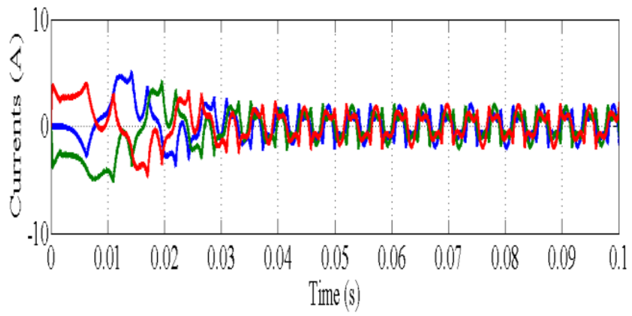

Figure 10 Starting Transients of ANFIS Controller based BLDC Motor

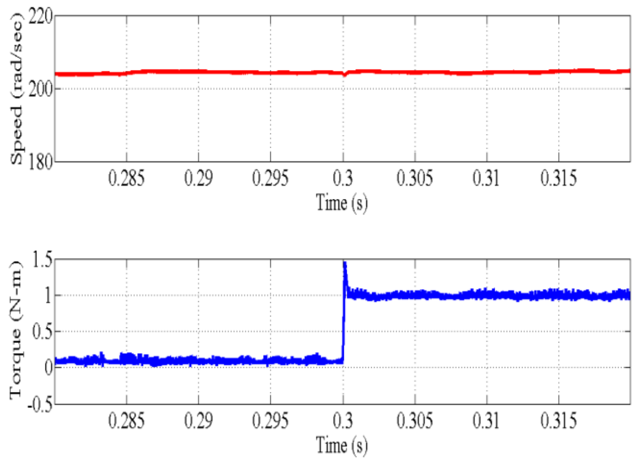

Figure 11 Performance During Step Change in Load Torque with PID Controller based BLDC Motor

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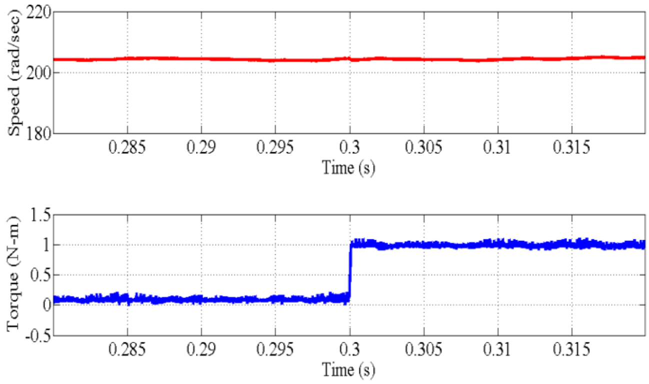

Figure 12 Performance During Step Change in Load Torque with ANFIS Controller based BLDC Motor

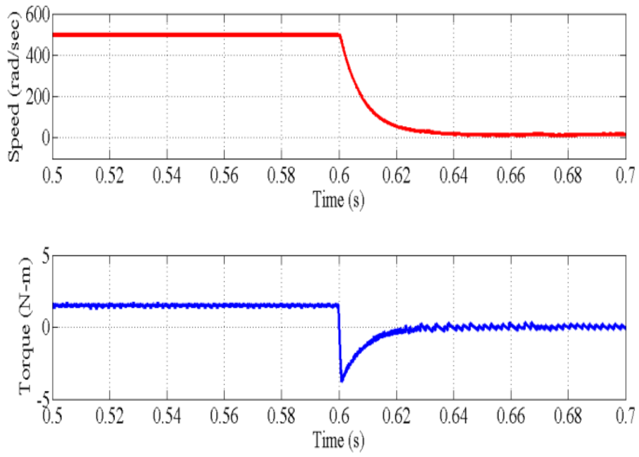

Figure 13 Performance During Speed Change with PID Controller based BLDC Motor

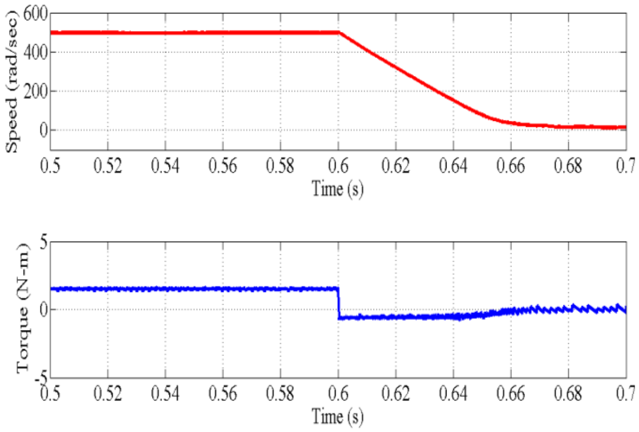

Figure 14 Performance During Speed Change with ANFIS Controller based BLDC Motor

From the simulation results, the following observations are made. The starting transients are up to 10 amps with PID controller where as with ANFIS controller those are reduced between 2 amps. The response during change in load torque command, (load torque of 1 N-m is applied at 0.3 sec) the momentary increase in torque is observed with PID controller when compared to ANFIS controller. It is clear that the speed change (from 500 rpm to zero rpm) is linear and better torque response with ANFIS controller when compared to PID controller.

VII. CONCLUSION

The brushless DC motor drive performance with ANFIS controller under different operating conditions is presented. The dynamic characteristics of the brushless DC motor such as speed, torque, current and voltages of the inverter components are observed and analyzed. It is observed that the performance of the drive is improved with ANFIS controller when compared to PID controller.

REFERENCES

[1] P. Yedamale, Brushless DC (BLDC) Motor Fundamentals. Chandler,AZ: Microchip Technology, Inc., last access; March 15, 2009.

[2] R. Akkaya, A.A. Kulaksız, and O Aydogdu, DSP implementation of a PV system with GA-MLP-NN based MPPT controller supplying BLDC motor drive, *Energy Conv. and Management* **48**, 210-218, 2007.

[3] Tan Chee Siong, Baharuddin; M.Fayzul; M.Faridun N.T, Study of Fuzzy and PI Controller for Permanent-Magnet Brushless DC Motor Drive, *IEEE* International Power Engineering and Optimization Conference.PEOCO 2010

[4] Derong Luo1, Wei Huang1, Shoudao Huang1, Wenqiang Li1, Lei Zheng1Simulation Study of the Fuzzy-PID Control System for Brushless DC Motors 1Department of Electrical Engineering, Hunan University, China

[5] Tan Chee Siong, Baharuddin Ismail, Siti Fatimah Siraj, Mohd Fayzul Mohammed fuzzy logic controller for BLDC pemanenet magnet motor drives

[6] M. V. Ramesh [1], J. Amarnath [2], S. Kamakshaiah [3] and G. S. Rao [3] speed control of brushless dc motor by using fuzzy logic pi controller Department of Electrical and Electronics Engineering, P.V.P. Siddhartha Institute of Technology, Vijayawada, A.P, India

[7] Soni Monika Gordhandas., 2Girish V Jadav Speed Control of BLDC Motor using Fuzzy Logic Controller Parul Institute of Engg. &Technology, Vadodara, India

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