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Dynamic Performance Analysis of BLDC Motor with Adaptive Neuro Fuzzy Controller Under Critical Load Condition

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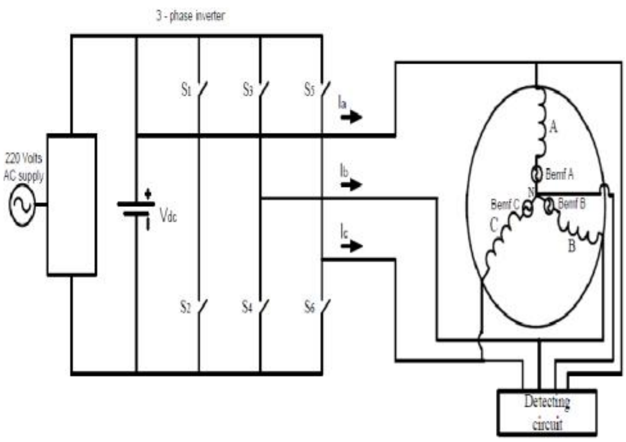
Abstract —. Brushless DC (BLDC) motors have been widely used in many fields of drives for their high power/weight, high torque, high efficiency, long operating life, noiseless operation, high speed ranges and ease of control. In this paper, a Adaptive Neuro-Fuzzy Controller (ANFC) based on supervisory learning is presented for the speed and torque control of BLDC motors to enhance high control performance of the drive under transient and steady state conditions. This controller is combination of Neural Networks (NNs) and Fuzzy Logic (FL), therefore has parallel processing and learning abilities of NNs and inference capacity of FL. For improvement the performance of leaning algorithm and there upon increase efficiency of drive, a fuzzy based back propagation algorithm is employed. The proposed controller has simple structure and also due to its modest fuzzy rule in rule-base is relatively easy for implementation. This controller has high accuracy, suitable performance, high robustness and high tracking efficiency. In order to demonstrate the NFC ability to tracking reference speed and torque and also test of robustness and rejection ability of controller against undesired disturbances or suddenly changes in speed and torque, these designs are simulated with MATLAB/SIMULINK. Results are compared with that of a conventional PID controller and other designs.

1. INTRODUCTION

Brushless DC motors is a new motor, which developed rapidly in recent years with the development of power electronic and the appearance of new permanent magnet materials. Electronic commentators are used to implement the commutation of DC motors, instead of mechanical brushes and commutators. So brushless DC motors are not only having many advantages of AC motors, e.g. simple construction, reliable operation and convenient maintenance, but also those characteristics of AC motors, such as high operation efficiency and excellent speed performance. Furthermore, brushless DC motors overcome the problem that caused by the mechanical contact structures of brushes and commentators of DC motors, for instance, high cost, commutation spark, electromagnetic interference, short life and low reliability [1]. As the development of power electronics technology and the new permanent magnet materials, brushless DC motors become more and more mature, and are increasingly concerned by widespread.

The PID control is advantage to those models with fixed coefficient, such as responding rapidly, high precision. The ANFIS control is independent of system parameters, and with good robustness. In consideration of these advantages, this paper adopts ANFIS control strategy - combines fuzzy control with genetic algorithm Critical load condition is the condition at which both the speed and torque of the system is restricted and violation of the restrictions may cause serious effect on

the system examples of critical load condition are crane lifters and robotic arm in many industrial applications



1.1 ANFIS Controller

ANFIS is a fuzzy inference system and this system uses given input and output data set 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, checking data sets. For the training number of epochs to be chosen to start the training, learning results to be verified after mentioning the step size 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.

1.2 STRUCTURE OF ANFIS CONTROLLER

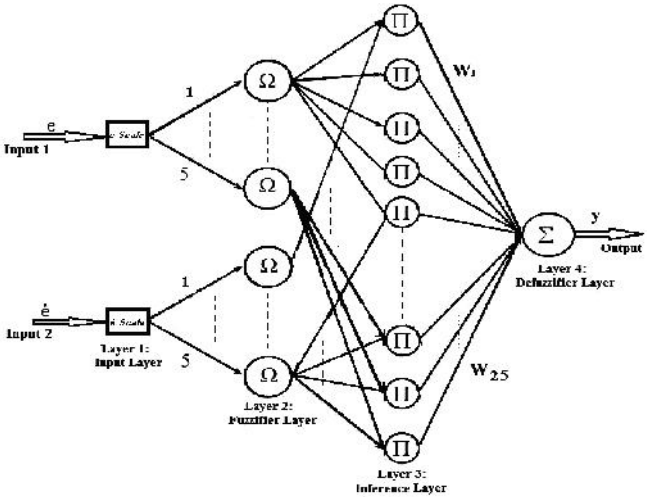
Structure of ANFIS speed controller is based on the five-layer feed forward fuzzy neural network.

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 corrections 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.

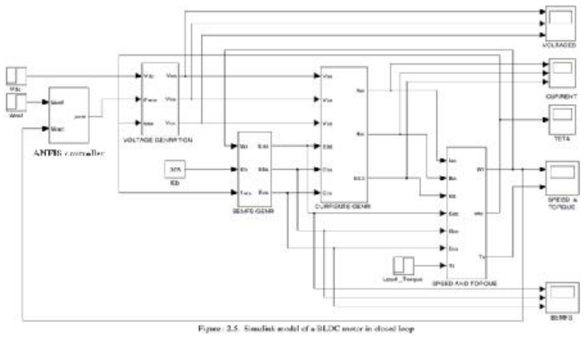
Layer5: (Output Layer)

In this layer all the inputs coming from the layer 4 sums up and transforms the fuzzy classification results into a crisp values.

2. SYSTEM SIMULATION MODEL MODELS

According to the working principal of mathematical modeling of BLDC motors, the simulation models can be built through MATLAB/SIMULINK. Simulation system consists of double closed loop control – speed loop and current loop. The inner loop is current loop which is adopted from the basic current equations from mathematical modeling of BLDC motors. And the outer loop is speed control loop which is consists of Adaptive nuro fuzzy controller (ANFIS) instead of traditional PID controller.

The system structure is presented in Fig 1. Based on modular thinking, the system structure divided into several functional blocks namely speed controller, voltage generation, current generation, back emf generation and speed torque blocks in this each functional block has its own function.



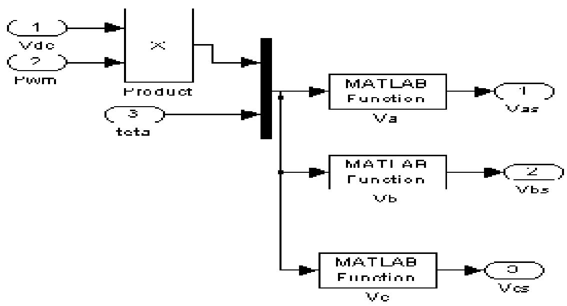
2.1 Voltage generation block:

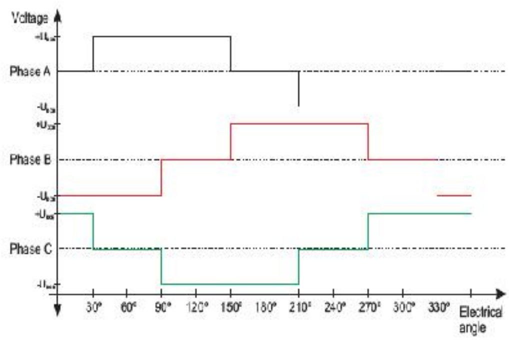
In this voltage control block consists of mainly carrier, reference signals and electrical angle teta is generated from the basic equation of BLDC and applied to the product of voltage signals.The equation of each armature winding can be represented follows

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

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

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

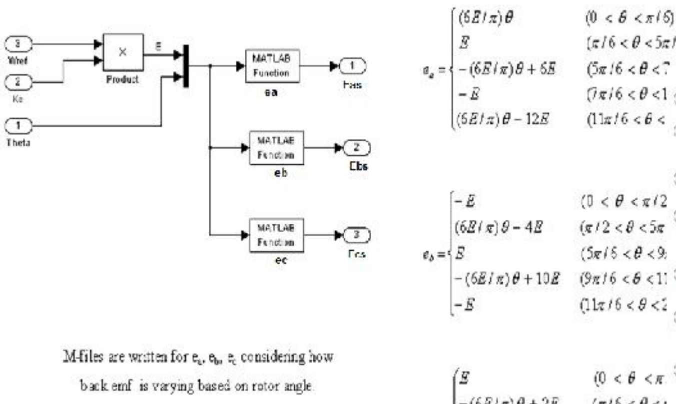




2.2Back emf generation block

In this block from the angular speed of the rotor w $_r$ and back emf constant K_b back emf of the rotor obtained and by applying teta to that block periodic back emf aof each phase is obtained

$$E = K_b * \omega_r$$



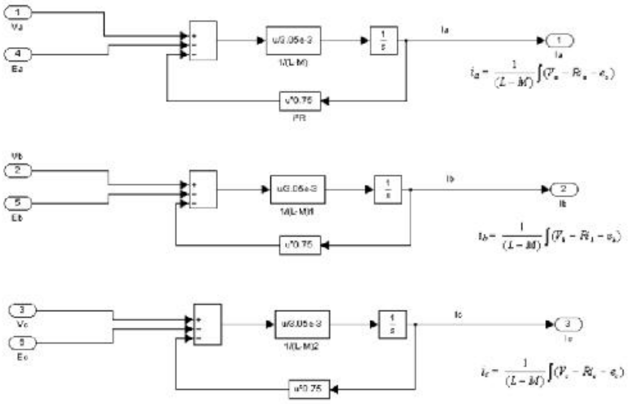
2.3Current generation block

Current generation block obtained from the voltage and back emf blocks by the basic current equations of BLDC motor

$$i_a = \frac{1}{(L-M)}\int (V_a - I_a * R - E_a)dt$$

$$i_b = \frac{1}{(L-M)}\int (V_b - I_b * R - E_b)dt$$

$$i_c = \frac{1}{(L-M)}\int (V_c - I_c * R - E_c)dt$$



2.4Speed and torque control block

In the speed and torque control block takes inputs from the back emf generation and current generation blocks obtained and multiplied each phase current and back emf

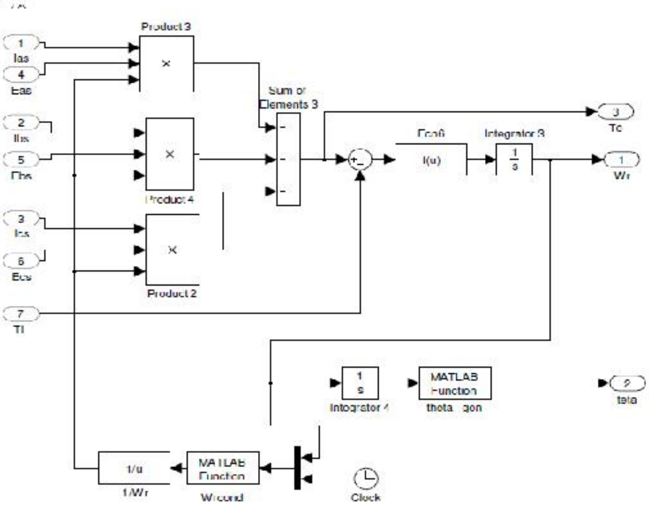
$$T_e = J * \frac{d\omega_r}{dt} + B * \omega_r + T_l$$

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

ii. Fo

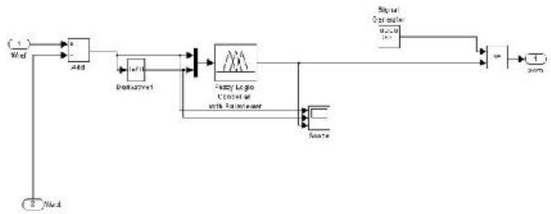
The rotor position θ is a function of % and is expressed as:

$$\frac{d\theta}{dt} = \frac{p}{2}\omega_r$$



2.5Speed control block

Anfis Speed controller is used for speed control. The input to the speed controller is angular reference speed and actual speed . And the out-put is fuzzy logic controller with ruler viewer function parameters *u* by which the fuzzy speed controller can be adjusted online in real time.Due to have only two inputs the characteristics of the Anfis controller is similar with PID controller. Lacking of integral functions, when the motor system come with load disturbance, it is difficult to remove the steady-state error. So this paper uses Anfis controller, in order to improve the disadvantage. This kind of controller is characterized by using fuzzy reasoning and genetic algorithm controller.



3. SIMULATION RESULTS AND ANALYSIS

Start with no load at a given speed and load torque T_L=2Nm is added in the 0.1s. The torque and speed response curve of ANFIS control and traditional PID control are Comparing ANFIS controller with traditional PID control at a given speed, we can concluded that,

1. When there is no load, the wave form response smoothly. Also there is no overshoot, and the torque ripple is small.

2.when sudden load is applied on the motor. Torque ripple is observed and ripple is relatively more in PID and very less in ANFIS. By this the robustness of ANFIS is greatly enhanced.

In acceleration mode of simulation initially speed of the rotor is zero and torque is zero and at 0.1 instant load is applied with 2Nm and rated speed is applied we observe more torque ripples and over shoots are observed more in PID controller than in ANFIS in figures 1,2,3,4.

In deceleration mode of simulation initially speed of the rotor is at rated and torque is 2Nm and at 0.1 instant load is decreased to zero and speed is also decreased to zero we observe negative torque ripples and over shoots are observed more in PID than in ANFIS control from the figures 5,6,7,8.

In step change in speed mode of simulation initially speed of the rotor is increased from a initial value to the rated speed at 0.1 instant and torque 2 Nm is applied at 0.1 instant we observe more distortion in speed curve of PID controller than in ANFIS controller and torque ripples are also high in PID.

Speed Vs Time (Acceleration)

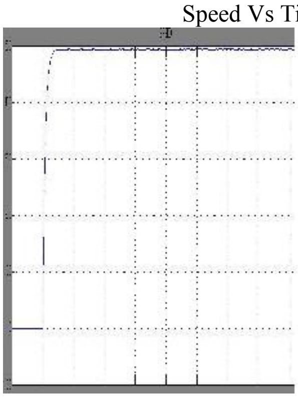


Fig.1 PID speed control Fig.2 ANFIS speed control

Torque Vs Time (Acceleration)

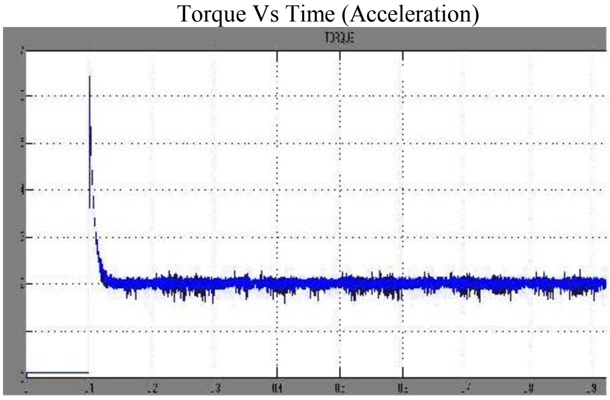


Fig.3 PID torque control

Torque Vs Time (Acceleration)

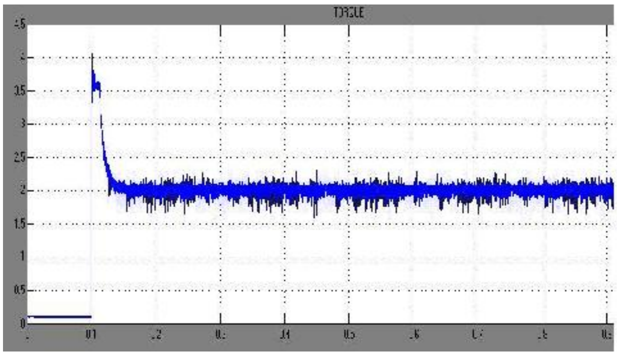
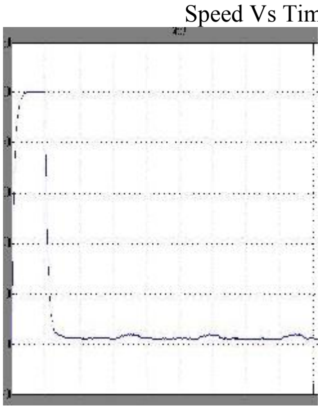


Fig.4 ANFS torque control

Speed Vs Time (deceleration)



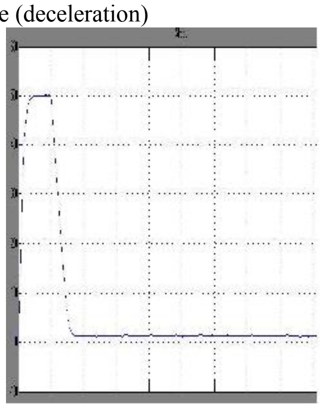


Fig.5 PID speed control Fig.6 ANFIS speed control

Torque Vs speed (deceleration)

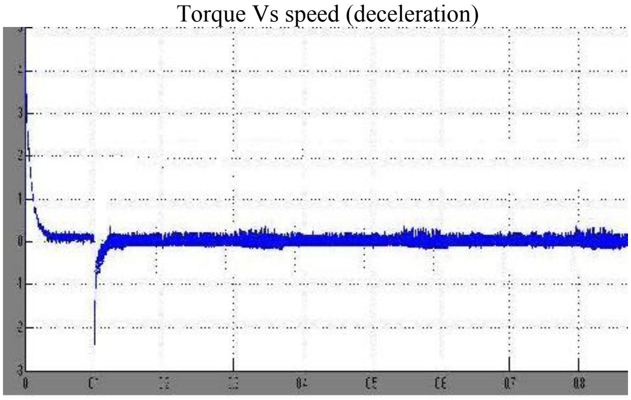


Fig.7 PID torque control

Torque Vs speed (deceleration)

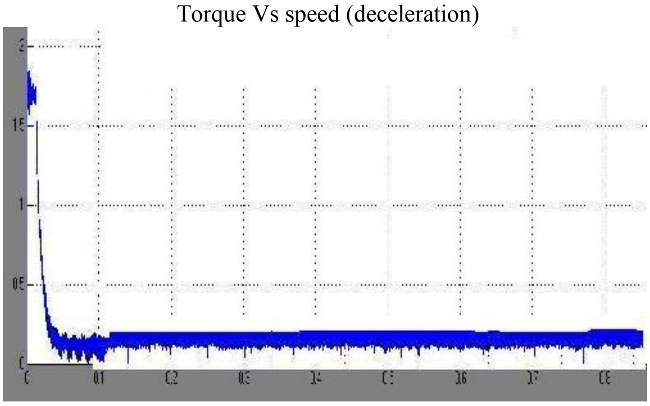


Fig.8 ANFIS torque contr

Speed Vs Time (step change in speed)

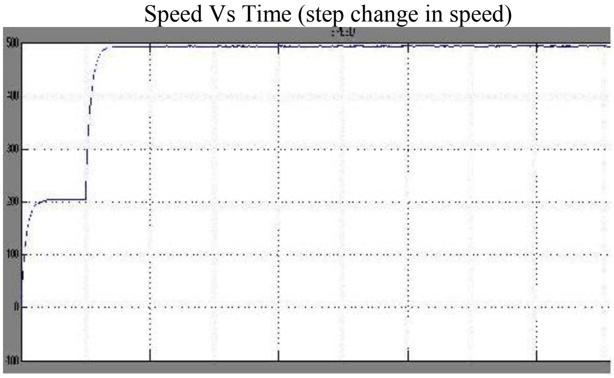


Fig.9 ANFIS speed control

Torque Vs Time (step change in speed)

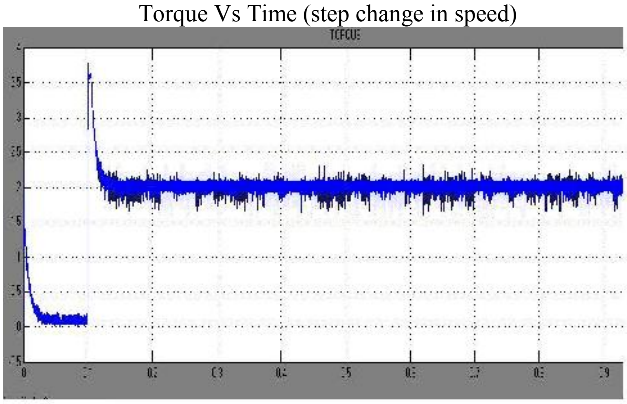


Fig.10 PID torque control for step change in speed

Torque Vs Time (step change in speed)

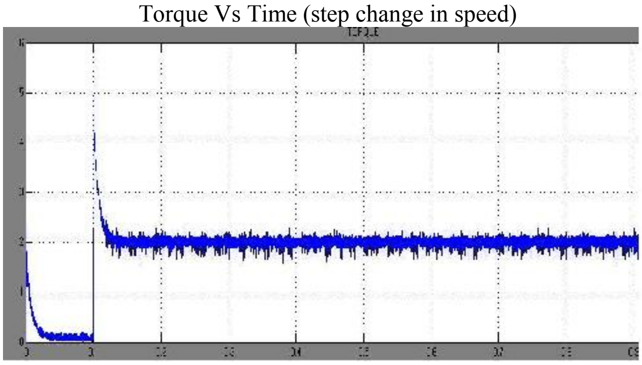


Fig.11 ANFIS torque control for step change in speed

4. CONCLUSION

In this paper, ANFIS controller is applied on brushless DC motors for a system simulation. The simulation results show that ANFIS control of brush-less DC motors has many characteristics of fast response, non-overshoot, small torque ripple, strong robustness, and good anti -interference ability. Meanwhile, it shows that ANFIS controller is very feasible for critical load conditions.

ANFIS control takes advantage of fuzzy control and genetic algorithms theory with less rules and simple and flexible application.

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