# Speed Control of BLDC motor using ANFIS over conventional Fuzzy logic techniques

V.SURESH[1], JOSEPH JAWAHAR[2]
1. Department of ECE, Mar Ephraem College of Engineering and Technology, Marthandam, INDIA.
2. Department of EEE, Arunachala College of Engineering for Women, Vellichandai, TamilNadu, INDIA

*Abstract*- This work proposes a specific controller for Brushless DC motor and a comparative study has been reviewed with intelligent controllers like fuzzy logic controllers and Adaptive Neuro Fuzzy Inference system. A detailed analysis is done through simulation using Matlab Simulink tool. The performance of Brushless DC motor is analyzed and the dynamic characteristics of the motor is also observed .The system control parameters like peak overshoot, undershoot, rise time recovery time and steady state error are measured and their results are compared with the ANFIS and Fuzzy controllers. To validate the performance of the controller different conditions and loading criteria has been done.
Keywords - brushless DC (BLDC) motor, Adaptive Neuro Fuzzy Inference system (ANFIS), Fuzzy Tuned PID

## 1. Introduction

Brushless DC motors are the best choice for different applications using motors where compactness and weight plays an important role. There are two categories of permanent magnet Brushless DC motor based upon the waveform obtained from the EMF equation called as brushless AC (BLAC) and brushless DC (BLDC) motors [1]. The advantages of BLDC motors over conventional brushed DC motors and induction motors are low cost, reliable, easy control, good speed versus torque characteristics, dynamic response is high, efficiency is high, operating life is more, noiseless operation and wide range of speeds [2].Since the BLDC motors are having number of advantages, these motors are widely used in many applications.

The Brushless dc motor provides the commutation operation, which controlled by the controllers. Because of the sectional structure of the controller mechanism, while the motor rotates, the current that is passing through the rotor windings also changes which creates some problems in brushless dc motors. Therefore, the function of the brush collector mechanism carried out by the controller [3].The various varieties of control schemes used in BLDC motor are Proportional Integral Derivate (PID), Non-Adaptive Fuzzy logic controller (FLC) and Adaptive fuzzy logic controller. Fuzzy logic can considered as a mathematical theory and artificial intelligence used to simulate the human approach in the solution of various problems by using an approximate reasoning to relate data sets and to make decisions. It has been seen that compared to other classical controllers, fuzzy controllers are more reliable to plant parameter changes.

An Adaptive Neuro-fuzzy Inference system or adaptive network-based fuzzy inference system (ANFIS) is a category of artificial neural network that is using Takagi-Sugeno fuzzy inference system. ANFIS is the combination of both neural networks and fuzzy logic principles therefore, it integrates the benefits of both the soft computing techniques. Inference system consists of a set of fuzzy IF-THEN rules, which have the learning capability that is used to approximate functions, which are nonlinear. Since the performance of ANFIS is considered to be better it is also called as a universal estimator. For obtaining better results using the ANFIS, the controller can be optimized using the parameters obtained by genetic algorithm.

The organization of the paper is as follows: A Brushless DC motor is developed and its performance is improved by using adaptive Neuro Fuzzy Inference system (ANFIS).Another controller such as Fuzzy Logic Controller is developed and it performance is compared with ANFIS.

## 2. Construction and Working Principle

Brushless dc motors belong to the category of synchronous motors. A BLDC motor uses electronic commutation using rotor position feedback and finds when to switch the current. These motors do not have slip as found in other induction motors.

### Hall sensors

To measure the rotor position, Hall effect sensors are used. These sensors mounted in the motor senses the rotor position and communicates this signal to the electronic controller unit to rotate the motor at the right time and direction. The magnetic field is provided by the permanent magnet operates the Hall effect sensors. These Hall effect sensors also known as magnetic sensors decides when the motor should be operated to make the magnets move in the right direction. Depending on the combination of sensors and signal level, the commutation sequence will be formed.

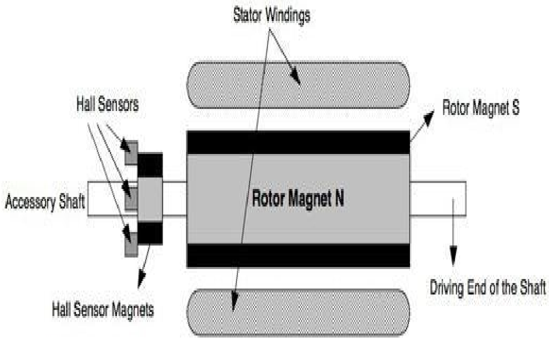



Figure 1: Rotor and hall sensors of BLDC motors

# 3.Theory of operation

Electric switches are used in brushless dc motor for commutation so that the motor runs continuously. Commutation provided by the brushless dc motor depends on the feedback obtained from the rotor position which decides when to on the switches so as to create high torque. The accurate position is detected using a position sensor. The most commonly used position sensor is the Hall sensor. Almost all brushless dc motors have Hall sensors positioned in into the stator.

# 4. Mathematical model of BLDC motor Drive

As the name implies, in brushless dc motor brushes are absent and therefore in this motor, electronic commutation is implemented by means of a drive amplifier that makes the switches to transfer current in the windings with respect to the feedback obtained from the rotor position. With this concept , the brushless dc motor can be can be said as equivalent to a commutator motor in which the conductors remain stationary and the magnet will be rotating.

.The following equations describes the stator windings with respect to the electrical constants.

$$V_X = Ri_X + L\frac{di_X}{dt} + e_X \qquad \text{----- 1}$$

$$V_y = Ri_y + L\frac{di_y}{dt} + e_y \qquad \text{----- 2}$$

$$V_Z = Ri_Z + L\frac{di_Z}{dt} + e_Z \qquad \text{----- 3}$$

$$T_e = K_f . \omega_m + j\frac{d\omega_m}{dt} + T_L \qquad \text{----- 4}$$

Where V,I and e are the voltage, current and back-emfs of phase X, Y and Z. R is the resistance of each phase and L the inductance of each phase. Te is the electrical torque and $T_L$ is the load torque, j is the rotor inertia, $K_f$ is the friction and $\omega_m$ is the rotor speed.

# 5. Adaptive Neuro-fuzzy Inference system (ANFIS) based controller

The general structure of ANFIS controller consists of the FIS block and the network block. The block consists of four main blocks and they are fuzzification, knowledge base, inference and defuzzification. The network block consists of five layers of processes. Layer 1 has input variables, which represents the membership functions in which triangular or bell shaped membership functions are commonly used. The function of layer 2 is to check the weights of each membership functions and receives the values from the first layer. The main function of layer 3 or rule layer is to perform the matching between the fuzzy rules. In addition, this layer calculates the activation function of each rule. The function of layer four is to obtain the defuzzified output. The function of the final layer or the output layer is to get the summed output of all the outputs coming from the previous layer, which results in a crisp value.

The systems are modeled using Takagi-Sugeno (T-S) type systems and it should posses the following properties. Firstly it must be a first order or zero order T-S type system. The output obtained should be a single output using weighted average defuzzification method. The membership functions considered at the output should be of same type and it can be either a linear or a constant value. In addition, it should not posses rule sharing. This means that the same output membership function should not be shared by different rules. The number of output membership functions must be equal to the number of rules for each rule. The weight considered should be unity. For tuning, the ANFIS structure by automatic means least-square estimation and the back-propagation algorithm are used. Since this method is flexible, this ANFIS structure can be used for many control applications.

# 6. Modeling of BLDC Motor

The brushless dc motor consists of a rotor with permanent magnets and three stator windings. Because of high resistivity of both magnets, rotor induced currents are neglected. The system is modeled base on the assumptions that the rotor induced currents and the iron and stray losses are neglected. The motor model was considered highly flexible because the modeling of brushless dc motor is done using the conventional modeling equations. The equations are derived based on the dynamic equivalent of the motor. It is also assumed that the resistances of all the windings are equal and there is no variation in the rotor reluctance

. Modelling equations involves,

Dynamic model equation of motion of the motor,

$$\omega_m = (T_e - T_l) / J_s + B \text{ ----- } 5$$

$T_e$ = electromagnetic torque

$T_l$ = load torque

$J_s$ = moment of inertia

B = friction constant

Rotor displacement can be found out as,

$$\Theta_r = (P/2)\ \omega_m\ /s \text{ ----- } 6$$

P = Number of poles

Back EMF will be of the form

$$E_{xs} = k_b f_{xs} (\Theta_r)\ \omega_m \text{ ----- } 7$$

$$E_{ys} = k_b f_{ys} (\Theta_r)\ \omega_m \text{ ----- } 8$$

$$E_{zs} = k_b f_{ys} (\Theta_r)\ \omega_m \text{ ----- } 9$$

$K_b$ = back EMF constant

Stator phase currents are estimated as,

$$I_x = (V_{xs} - E_{xs}) / (R+Ls)$$

$$I_y = (V_{ys} - E_{ys}) / (R+Ls)$$

$$I_z = (V_{zs} - E_{zs}) / (R+Ls)$$

R = resistance per phase

L = inductance per phase

Electromagnetic torque developed,

$$T_e = (E_{xs}\, i_{xs} + E_{ys}\, i_{ys} + E_{zs}\, i_{zs}) / \omega_m$$

# 7. Fuzzy logic controller for BLDC motor

Nowadays fuzzy logic have gained more interest in control applications. Fuzzy logic controller can be used fo r modeling non-linear systems. One of the main advantages of fuzzy logic controller its adaptive characteristics so that it is able to achieve robust performance to system having parameters variation with uncertainty and disturbances in load.

Unlike conventional systems that are expressed in mathematical equations, Fuzzy logic systems are expressed using linguistic variables. The fuzzy logic controller performs fuzzification , fuzzification inference and defuzzification. The major function of the fuzzy logic is to scale the error speed obtained from PI controller.

**Development of simulink model and training of ANFIS controller using MATLAB:**

Simulink model for the control of BLDC motor drive has been developed in MATLAB environment using the appropriate toolboxes. Below figure shows the simulink model of the proposed controller. The simulink model consists of DC supply, PWM inverter, motor measurement system, ANFIS controller, switching logic circuit and BLDC motor. The DC supply input is given to PWM inverter and output of the inverter is fed to the BLDC motor. Rotor position and speed are sensed by hall sensor and tacho-generator model. The output of the tacho-generator is compared with reference speed error is obtained by differentiating the speed error. The speed error and the rate of change of speed error are given as input to the ANFIS speed controller. Based upon the inputs, ANFIS controller generates control signal for the switching logic circuit.

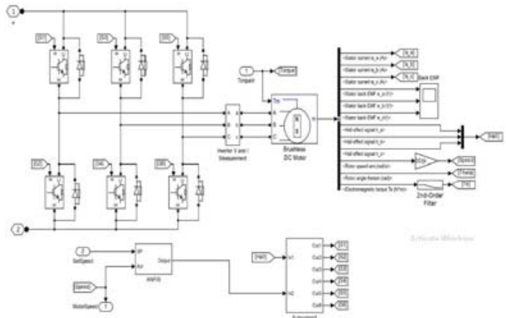


Fig Combinational Model of Fuzzy and ANFIS

# 8. Simulink model for fuzzy logic

Fuzzy logic Toolbox software is designed to work in simulink environment. After creating the fuzzy system using the GUI tools the system is embedded directly into a simulation. The ANFIS controller network is trained in off-line using MATLAB Simulink toolbox. The result of Fuzzy tuned PID controller is collected as the training data set. The input and output data obtained are modified into desired data based upon the desired output. The desired output will be trained using the function “ANFIS” in the MATLAB toolbox. From the training, a fuzzy inference system with adjusted membership functions has been obtained.

The figure below shows the speed control of BLDC motor using Fuzzy logic controller. The simulation results provide the necessary waveforms for the analysis of speed control of BLDC motor drives.

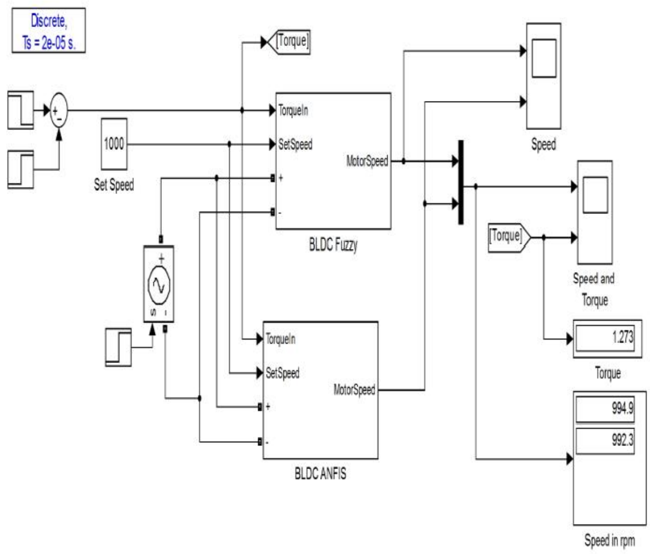


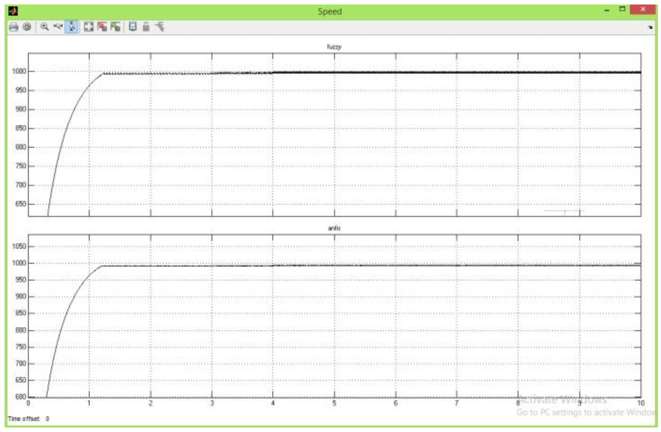

Fig a) ANFIS Module and b) Fuzzy Logic Module

## 9. Results

In this paper, for generating the initial membership function and for creating the input output training data sets the grid partitioning clustering methods are used. In this grid partitioning technique, each input variable exclusively determines the number of rules. In this system, two inputs and seven membership functions are considered, so that there are 49 if then rules. Hybrid learning algorithm is used which combines the effect of gradient descent and least square estimation for obtaining the parameters necessary for ANFIS. In each iteration there will be a forward and backward pass sequence.

During forward pass, after giving an input data, the node outputs are updated every layer by layer until the final layer was reached. This process is repeated for all training input-output data sets, and then the resulting parameters are identified by least squares estimation. During backward pass, the derivative of the error signals with respect to each node propagates from the output towards the input. Finally, the gradient vector is accumulated for each training input-output data set. At the end of the backward pass for all training data sets, the parameters are updated by gradient descent method. After the parameters updation are completed, proper set of membership function and rule base are selected for fuzzy inference system. After the rules are selected the firing of the control signal required to obtain the optimal output.

To start simulations, first step is the identification process, i.e, the dynamic process of finding the input – output relations for a system.. To prevent the system from saturation condition, the input – output data set is processed through closed loop using fuzzy tuned PID controller. ANFIS based identifier has two inputs which are functions of the error signal and rate of change of error of the BLDC motor. The problem is to find the proper parameter values for the ANFIS structure and control signal for the switching logic circuit to minimize identifier output error for all input values.




Result : 1. Fuzzy logic and 2 ANFIS [ Time vs Speed ] Graph.

| Parameters | Fuzzy Logic | ANFIS |
|---|---|---|
| Rise Time | 0.7170 | 0.7025 |
| Setting time | 1.1036 | 1.0654 |
| Setting Min | 899.9401 | 894.6954 |
| Setting Max | 1.005e+03 | 995.0421 |
| Overshoot | 0.0518 | 0.0951 |
| Undershoot | 0.0475 | 0.0478 |
| Peak | 1.0005e+03 | 995.0421 |
| Peak time | 7.7520 | 5.337 |

Tab 1: Comparison of parameters of Fuzzy and ANFIS

## 10 .Conclusion

In this paper, a detailed analysis of brushless DC drive system has been performed by using fuzzy logic controller and Adaptive Neuro-fuzzy Inference system (ANFIS) based controller. for the speed control of PMBLDC motor drive and analysis of results of the performance A fuzzy logic controller (FLC) has been employed . This paper explains the modeling and simulation of the complete drive system. Effectiveness of the model is obtained by the prediction of performance over a wide range of operating conditions.

The simulation model which is implemented under MATLAB/Simulink environment effectively considers the dynamic characteristics of the brushless dc motor. Furthermore, the control algorithms, FLC and ANFIS have been compared by using the developed model. It is seen that the desired real speed and torque values could be reached in a short time by ANFIS controller and comparison paved better result for rise time and setting time. The results show that the performance of the motor is improved by using FLC and ANFIS.

References

[1] G.Sakthival,T.S.Anandhi and S.P. Natarajan, "Real time implementation of DSP based Fuzzy logic controller for speed control of BLDC motor,"Int.Jou.Comp.App.vol.10,no.8.2010

[2] K.NagaSujatha, K. Vaisakh and Anand.G,"Artifical Intelligence based speed control of brushless DC motor",IEEE trans.vol..10,no.4,2010

[3] Yen-Shin Lai,Yong-kaiLin,"A unified approach to zero-crossing point detection of back EMF for brushless DC motor drives without current and hall sensors", IEEE Trans,PowerElectron,vol 26.no 6,2011

[4] SalihBarisOzturk, Hamid A, Toliyatcai,"Direct torque and indirect flux control of brushless DC motor",IEEE ASME Trans,Mech,16,2011.

[5] Nikola AnandSathyan, Young-jooMilivojevic,MaheshLee,"An FPGA-based novel digital PWM control scheme for BLDC motor drives",IEEE Trans.Ind.Electron.vol.56,no 6,2009.

[6] M.R.Alizaedehpahlavani,M.Barakat,"Comparsion between fuzzy and adaptive fuzzy controllers for BLDC motors",IEEE trans.ppo1-08.2011.