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Design and Simulation of ANFIS based Brushless DC Motor Control

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ABSTRACT

BLDC motor control with ANFIS control methods was investigated and analysed, in this work. The results show that the ANFIS approach is simple, efficient and achieves the desired speed and torque values. The approach was developed and used in both industrial and literary applications. The ANFIS controller was compared with Fuzzy and PI controllers. ANFIS has proved its reliability and good performance. Besides its swift execution, speed control has demonstrated its capability to maintain a minimum cost and commitment track of the target speed values. The method is a basic method with light steps and no reference processing or synchronisation is required.

Keywords: - BLDC motors, PI control, fuzzy control, fuzzy rules.

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INTRODUCTION

BLDC(Brushless Direct Current) motor is a motor that uses a decoder and an inverter to control the armature current, using a permanent magnet synchronous motor. The BLDC uses electronic switching without the mechanical switching and brushing equipment instead of a mechanical switch as in the traditional dc motor, which makes it practically maintenance-free known as "Brushless Direct Current Motor." The BLDC engine's operating features are identical to those of the traditional dc permanent magnet engine. The rotor location sensors are necessary to start and have the right switching sequence to transform the control devices on the inverter bridge. The control devices are sequentially shifted every 60° on the basis of the rotor position. The motor requires sufficient speed controllers to reach the optimal output level.

Brushless direct current motors possess several advantages over other motors, such as low inertia, fast response, high power density, high reliability, excellent performance of speed-control, high efficiency and maintenance-free reputation. The rotor will not generate significant heat, resulting in easy cooling. Further, due to the advancement in the design of small size, simple structure and large output torque, BLDC motors have attracted many users. The operating characteristics of BLDC motor resemble that of a conventional commutated dc permanent magnet motor but without the mechanical commutators and brushes. Hence many problems associated with brushes such as radio-frequency interference and sparking which is the potential source of ignition inflammable atmosphere are

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eliminated. Therefore, they offer a viable option for variable speed electrical drives, particularly for applications with high temperature and hostile operating environment. In the past two decades, many soft-switching converter techniques were proposed and they have the combined advantages of conventional PWM converters and resonant converters.

BLDC motor is usually supplied by a hard-switching PWM inverter, which normally has relatively low efficiency since the power losses across the switching devices are high. The high dv/dt and di/dt will result in severe EMI and rigorous problem with the reverse recovery of the freewheeling diodes, especially in high switching frequency. As the switching frequency is within audio spectrum, it may produce severe acoustic noise. In order to solve these problems, many soft-switching inverters have been designed in the past. Unfortunately, high device voltage stress, large dc link voltage ripples, complex control scheme and so on are noticed in the existing soft-switching inverters. The objective of this research work is to design an efficient control mechanism for the BLDC motor using Adaptive Neuro Fuzzy Control strategy.

Literature Review

There are several ways to control the BLDC motors. The main differences between them are motor performance and profitability and costs in their implementation in real time. Here are some of the recent works that talk about the implementation of effective control methods for BLDC motor controlling.

Dhawale et al[1] have proposed a position control of four switch inverter for three phase BLDC motor using PWM control. In this method, the desired dynamic response and static speed-torque characteristics were obtained. Further, the conduction losses were reduced by implementing reduced number of controllable switches and freewheeling diodes.

In addition to the electric rotor location search table for BLDC motor drive with two phase conduction system, SalihBarisOzturk et al.[2] suggested a new DTC scheme including the existing pre storage back EMF constants using four switch inverter. The low-frequency torque ripples and torque response time were minimised relative to traditional four BLDC motor operated transfer PWM current and voltage.

In order to achieve high precision and rapid response, Ting Yu Chang et al. [3] have suggested a newer Phase Locked Loop module configuration for PMBLDC motor drives. In addition, the PSL controller's PWM control was used for a phase-current sensing system which reduces drive costs. A novel reconfigurable BLDC digital controller using Fuzzy Logic was designed by Albert Rajan et al [4]. Using the reconstructable Vertex II Pro built board this technique was applied. This proposed energy-efficient controller uses less power compared to traditional controllers (70 mW).

In order to increase the efficiency, reliability and reduce the maintenance AlphonsaRoslin Paul & Mary George[5] have proposed a simple digital PWM technique for BLDC motor. With the help of two predefined state variable techniques, the proposed digital control treats BLDC motor as digital system and regulates speed. Hence the controller design was very simple and further reduces the cost and complexity of the motor control.

A basic sensor-less DTC control system for the BLDC motor has been studied by SalihBarisOzturk and Hamid Toliyat[6]. Like traditional DTC, torque and flux were simultaneously controlled for sinusoidal AC engines. The torque switch is based on the current torque switch. The VSI powered BLDC engine compared to trapezoid and sinusoidal back EMF by Kamran Tabarraee et al.[7], respectively. Back EMF harmonics have been sufficiently taken into consideration when determining the relationship between the stator phased current and the electromagnetic torque. This shows that the EMF back trapezoidal model has increased its performance compared with the EMF back sinusoidal model.

Krishnakumar and Jeevanandhan introduced the non-linear BLDC motor drive simulation model with four three-phase turn inverters[8]. MATLAB/Simulation Platform for the nonlinear model has been used in this scheme. They used traditional PI controls for speed controllers. In addition to the topology of the four switch inverters, a potential three-stage BLDC motor drive mechanism was tested. In addition, a novel direct-current operated PWM system has been developed for the development of the desired dynamic and static torque.

Sangsefidi et al. [9] provided an additional voltage source in the non-converting process during switching to the switching ripple torque reduction on BLDC motor drives. This additional voltage supply was provided by a condenser that discharges during switching and was charged during non-commutation. 48% of the torque waver in the BLDC motor drives was minimised by this process.

Kai Sheng Kan and Ying YU Tzou [10] have proposed adaptive wide angle control scheme with adjustable modulation waveform to obtain wide speed control range by efficiency optimization. Under the same testing condition, the RMS value of phase current was lower than conventional 120° conduction mode. Besides the torque ripple was significantly reduced.

PROPOSED WORK

A brushless dc motor is a dc motor turned inside out, so that the field is on the rotor and the armature is on the stator. The brushless dc motor is actually a permanent magnet ac motor whose torque-current characteristics mimic the dc motor. Instead of commutating the armature current using brushes, electronic commutation is used. This eliminates the problems associated with the brush and the commutator arrangement, for example, sparking and wearing out of the commutator-brush arrangement, thereby, making a BLDC more rugged as compared to a dc motor. Having the armature on the stator makes it easy to conduct heat away from the windings, and if desired, having cooling arrangement for the armature windings is much easier as compared to a dc motor.The coupled circuit equation of the stator winding in terms of motor electrical constants are:

$$\begin{bmatrix} V_{as}-V_n \\ V_{bs}-V_n \\ V_{cs}-V_n \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + P \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \quad (1)$$

where Rs is the stator resistance per phase, Ia, Ib, Ic are the stator phase currents, p is the time derivative operator, Ea, Eb, Ec are the back emfs in the respective phases in equation 3.1 and Vn is the neutral point node voltage which is given by:

$$V_n = \frac{1}{3}\left[V_{as} + V_{bs} + V_{cs}\right] - \sum BEMFs \quad (2)$$

where BEMFs means summing up the individual phase emfs on an instant to instant basis. Based on this, the equivalent circuit of motors can be obtained as shown in Figure 1:

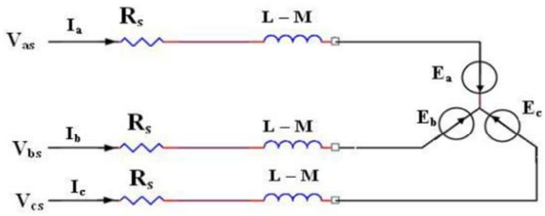

Figure 1: Equivalent Circuit for Stator Windings

The induced emfs are all assumed to be trapezoidal, whose peak value is given by:

$$E_p = (BLv)N = N(Blr\omega) = N\Phi\omega = \lambda\omega \quad (3)$$

where B is the flux density of the field in webers, L is the rotor length, N is the number of turns per phase, is the electrical angular speed in rad/sec, represents flux linkage = BLr and represents the total flux linkage which is given as the product of number of conductors and flux linkage/conductor.

Assuming that the three phases are symmetric, with same self and mutual inductances and the change in rotor reluctance is negligible with the change in rotor position equation is written as:

Assuming that the three phases are symmetric, with same self and mutual inductances and the change in rotor reluctance is negligible with the change in rotor position equation is written as:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R_s^* \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + P \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \quad (4)$$

Simplifying, we get the following equation:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R_s^* \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + P \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix} \quad (5)$$

The generated electromagnetic torque is given by:

$$T_e = \frac{\left[E_a I_a + E_b I_b + E_c I_c\right]}{\omega} \quad (6)$$

The induced emfs is written as:

$$\left.\begin{aligned} E_a &= f_a(\theta)\lambda\omega \\ E_b &= f_b(\theta)\lambda\omega \\ E_c &= f_c(\theta)\lambda\omega \end{aligned}\right\} \quad (7)$$

wherefa(θ), fb(θ), fc(θ) are functions having same shapes as back emfs and are given below:

$$f_a(\theta) = \begin{bmatrix} E & (0<\theta<\pi/6) \\ -(6E/\pi)\theta + 2E & (\pi/6<\theta<\pi/2) \\ -E & (\pi/2<\theta<7\pi/6) \\ (6E/\pi)\theta - 8E & (7\pi/6<\theta<9\pi/6) \\ E & (9\pi/6<\theta<2\pi) \end{bmatrix} \quad (8)$$

$$f_b(\theta) = \begin{bmatrix} -E & (0<\theta<\pi/2) \\ (6E/\pi)\theta - 4E & (\pi/2<\theta<5\pi/6) \\ E & (5\pi/6<\theta<9\pi/6) \\ -(6E/\pi)\theta + 10E & (9\pi/6<\theta<11\pi/6) \\ E & (11\pi/6<\theta<2\pi) \end{bmatrix} \quad (9)$$

$$f_c(\theta) = \begin{bmatrix} (6E/\pi)\theta & (0<\theta<\pi/6) \\ E & (\pi/6<\theta<5\pi/6) \\ -(6E/\pi)\theta + 6E & (5\pi/6<\theta<7\pi/6) \\ -E & (7\pi/6<\theta<11\pi/6) \\ (6E/\pi)\theta - 12E & (11\pi/6<\theta<2\pi) \end{bmatrix} \quad (10)$$

The electro-mechanical torque equation for the motor is written as:

$$J\frac{d\omega}{dt} + B\omega = T_e - T_l \quad (11)$$

whereTl is the load torque, J is the moment of inertia in kgm2, B is the friction coefficient in Nm/rad/sec. Electrical rotor speed and position are related by:

$$\frac{d\theta}{dt} = \left(\frac{P}{2}\right) * \omega \quad (12)$$

where P is the number of poles in the motor. From the above equations, the system state equations are written in the following form:

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (13)$$

where the states are chosen as x(t) = [IaIbIc]T

Thus the system matrices are given below:

$$A = \begin{bmatrix} -R_s/L_1 & 0 & 0 & (\lambda_p * f_a(\theta))/J & 0 \\ 0 & -R_s/L_1 & 0 & (\lambda_p * f_b(\theta))/J & 0 \\ 0 & 0 & -R_s/L_1 & (\lambda_p * f_c(\theta))/J & 0 \\ (\lambda_p * f_a(\theta))/J & (\lambda_p * f_b(\theta))/J & (\lambda_p * f_c(\theta))/J & -B/J & 0 \\ 0 & 0 & 0 & P/2 & 0 \end{bmatrix} \quad (14)$$

$$B = \begin{bmatrix} 1/L_1 & 0 & 0 & 0 \\ 0 & 1/L_1 & 0 & 0 \\ 0 & 0 & 1/L_1 & 0 \\ 0 & 0 & 0 & -1/J \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (15)$$

The input vector is defined as u(t) = [VaVbVcTl]^T

whereLl = L – M, L is the self inductance of the winding per phase, M is the mutual inductance per phase and Va, Vb, Vc are the per phase impressed voltage on the motor windings. All the equations form the entire state space model for the BLDC motor.

The BLDC machine structure, the ANFIS controller structure and the proportional integral(PI) control system for the BLDC motor has has been presented. The PI control system was discussed and presented as one of the most effective and simplest control techniques for DC motors..Instead of the standard PI controller, ANFIS controller will be used to improve system stability in transient and stable machine states.

The analysis and evaluation of the proposed methods of control and the contrast between the results obtained is based on this chapter of work.

Matlab and Simulink Tool has been used in this research work. A Simulink model of BLDC motor is used to simulate the results. The BLDC motor used in the model has been supplied with the required power via virtual power source,three phase source voltage inverter, controller model and theemf generator model. Figure 2 shows the general “circuit layout” for the simulation.

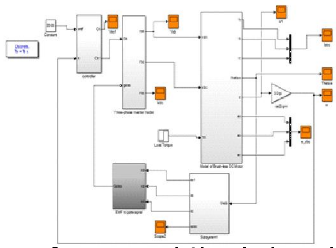

Figure 2: Proposed Simulation Diagram

Figure 3 shows the model of BLDC motor implemented in Simulink. It consists of current generator block, speed generator block and emf generator block. Figure 4.3 shows the models of these individual blocks.

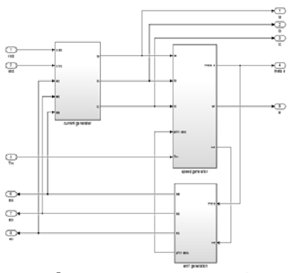

Figure 3: BLDC Model

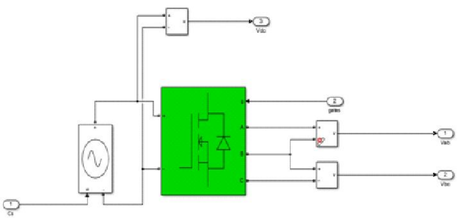

Figure 4: Three Phase Inverter Model

Figure 4 shows the model of the three phase inverter, which consists of the IGBT inverter. The control signal is fed to this inverter.

Due to the slow reaction of the motors relative to other electronic devices, abrupt speed changes can not be obeyed. The reference speed is then compared with the motor's actual measured velocity to produce controller feedback. The error is then fed to the controller to produce the correct torque value to be generated by the motor to make the error zero [11, 12].

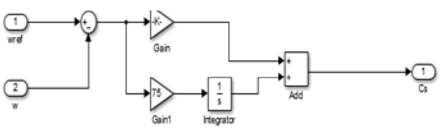

Figure 5: PI Control Block

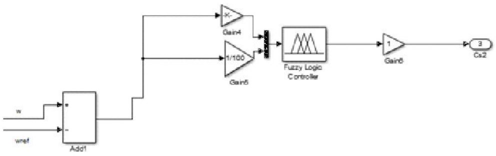

Figure 5: Fuzzy Control Block

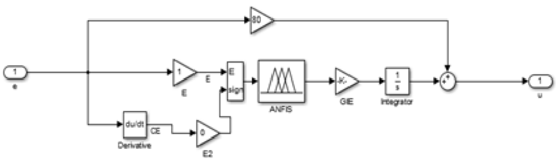

Figure 6: ANFIS control Block

Figure 4,5& 6 respectively show the three blocks for PI control, fuzzy control and ANFIS control.

The fuzzy rulelist is as shown below:

Table-1: Fuzzy rulelist for fuzzy and ANFIS block

e/ce	NB	NM	NS	ZO	PS	PS	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

A total 49 rules are defined based on the Error(E) and Change in Error(CE) inputs and the output of the system is Control Signal. The membership functions for each variable are Negative Big(NB), Negative Small(NS),Negative Medium(NM), Positive Big(PB), Positive Small(PS),Positive Medium(PM) and Zero(Z).

SIMULATION RESULTS

The results of simulation has been described in this section with simulation results in the form of speed control and rotor angle graphs for the three control strategies [13-17].

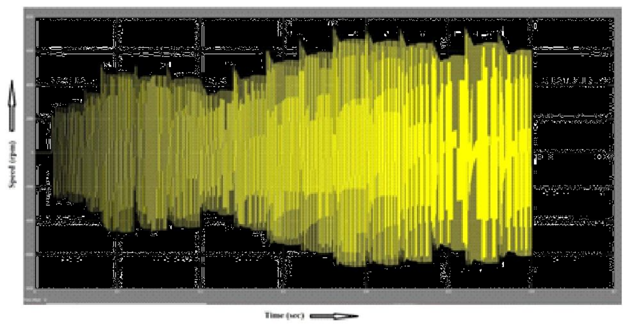

Figure 5: Speed Control using PI

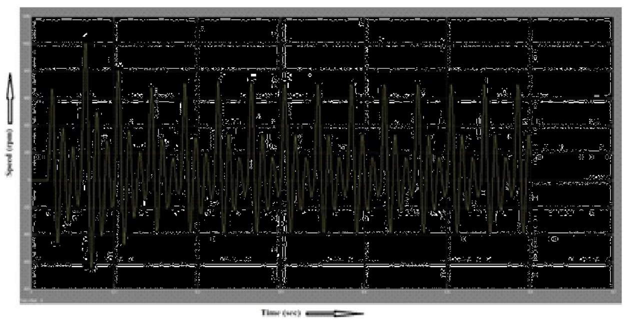

Figure 6: Motor Control using Fuzzy Block

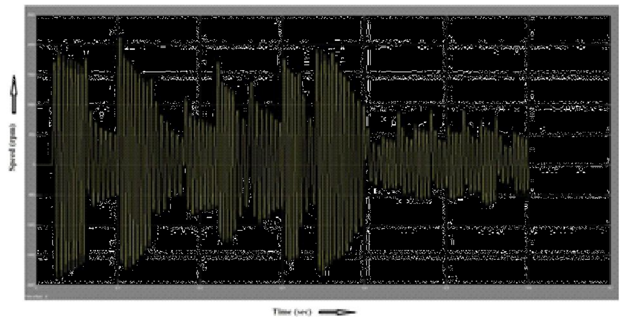

Figure 7: Speed control of ANFIS Control

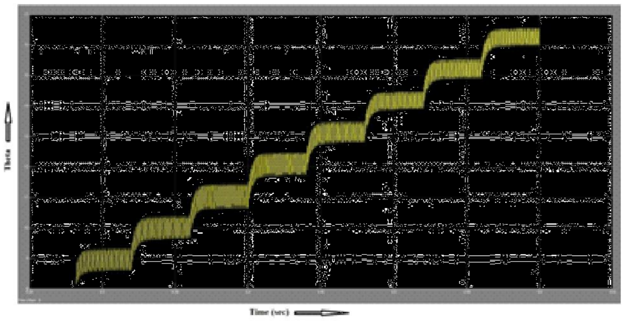

Figure 8: Rotor Angle Variation for PI

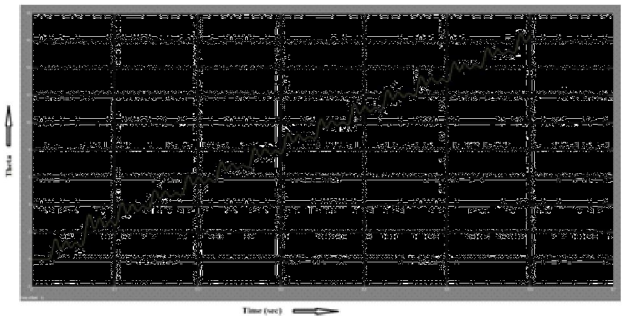

Figure 9(a): Rotor Angle for Fuzzy Control

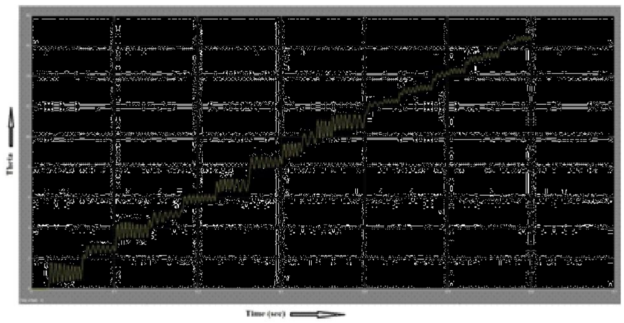

Figure 9(b): Rotor Angle for Fuzzy Control

CONCLUSION

The research and analysis done in this work addressed control of BLDC motors with ANFIS control method. The results obtained showed that use of the ANFIS method is simple, efficient and the desired speed and torque values are achieved. In this study, the use of ANFIS controller was suggested to increase the accuracy of speed results as well as the ability of the fuzzy logic controller to respond to sudden changes and system nonlinearity.

ANFIS controller has proven its reliability and good results. In addition to quick implementation, speed regulation has also demonstrated its ability to keep track of target speed values with minimal cost and effort. The method is a simple method with light measurement quantities and no need for any reference transformation or synchronization. The process does not mean a closed loop inverter regulation of the source voltage. From the results we have obtained we can infer that ANFIS control is a very good choice for controlling induction machines in terms of low cost, simplicity and performance. The control has shown this method's ability to track different speed values with perfect response away from very low velocities. In this study, an improvement was achieved through controlling BLDC motor. Improved results were obtained with sudden changes in the desired speed by replacing the conventional PI as well as the Fuzzy Control methods with a nonlinear ANFIS controller.

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