Speed Control of Brushless Dc Motor Using Fuzzy Logic Controller

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Abstract: *This paper presents a control scheme of a fuzzy logic for the brushless direct current (BLDC) permanent magnet motor drives. The mathematical model of BLDC motor and fuzzy logic algorithm is derived. The controller is designed to tracks variations of speed references and stabilizes the output speed during load variations. The BLDC has some advantages compare to the others type of motors, however the nonlinearity of the BLDC motor drive characteristics, because it is difficult to handle by using conventional proportional-integral (PI) controller. The BLDC motor is fed from the inverter where the rotor position and current controller is the input. In order to overcome this main problem, the fuzzy logic control is learned continuously and gradually becomes the main effective control. The effectiveness of the proposed method is verified by develop simulation model in MATLAB-Simulink program. The simulation results show that the proposed fuzzy logic controller (FLC) produce significant improvement control performance compare to the PI controller for both condition controlling speed reference variations and load disturbance variations. Fuzzy logic is introduced in order to suppressing the chattering and enhancing the robustness of the controlled system. Fuzzy boundary layer is developed to provide smother transition to the equivalent control. Smaller overshoot in the speed response and much better disturbance rejecting capabilities.*

Keyword: *Brushless DC motors; Fuzzy logic controller; P controllers; PI controllers; Speed control.*

I. Introduction

DC motor is designed to run on a DC electric power which is used electrical energy and produce mechanical energy. There are two types of DC motor which is brushed and brushless DC motor. Brushless DC motor is chosen in this project because of brushless DC motor (BLDC) is a synchronous electric motor which is powered by DC electricity and which has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes In such motors, current and torque, voltage and rpm are linearly related. Other than that, brushless DC motor offer several advantages over the brushed DC motor. The advantages that provided by the brushless DC motor are higher efficiency and reliability, reduced noise, longer lifetime and elimination of ionizing sparks from the commutator.

Fuzzy Logic Controller (FLC) is chosen as a controller for this project because it consists of several advantages compared to the other classical controller. The advantages of FLC are such as simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. It is suitable for applications such as the speed control of DC motor which has nonlinearities. The structure of FLC consists of the following three major components which the first one is fuzzifier that used for measurement of the input or definition of the fuzzy sets that will applied. The second one is fuzzy control or rule base which provides the system with the necessary decision making logic based on the rule base that determine the control policy. The third method is defuzzifier which combines the actions that have been decided and produce single non-fuzzy output that is the control signal of the systems.

II. Operating Principleof Bldc Motor

BLDC A brush less dc motor is defined as a permanent synchronous machine with rotor position feedback. The brushless motors are generally controlled using a three phase power semiconductor bridge. The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter bridge. Based on the rotor position, the power devices are commutated sequentially every 60 degrees. Instead of commutating the armature current using brushes, electronic commutation is used for this reason it is an electronic motor. 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.
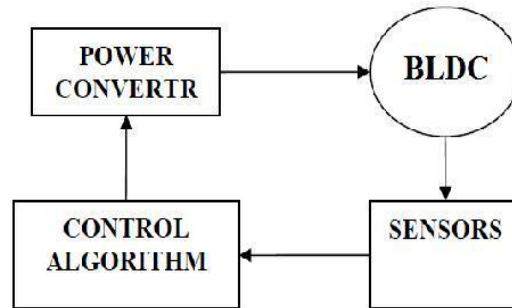
Fig1: Basic block diagram of BLDC motor

The basic block diagram brushless dc motor as shown Fig.2.1.The brush less dc motor consist of four main parts power converter, permanent magnet-synchronous machine (PMSM) sensors, and control algorithm. The power converter transforms power from the source to the PMSM which in turn converts electrical energy to mechanical energy. One of the salient features of the brush less dc motor is the rotor position sensors ,based on the rotor position and command signals which may be a torque command ,voltage command ,speed command and so on the control algorithms determine the gate signal to each semiconductor in the power electronic converter.

The structure of the control algorithms determines the type of the brush less dc motor of which there are two main classes voltage source based drives and current source based drives. Both voltage source and current source based drive used with permanent magnet synchronous machine with either sinusoidal or non-sinusoidal back emf waveforms .Machine with sinusoidal back emf (Fig.2.3) may be controlled so as to achieve nearly constant torque. However, machine with a non sinusoidal back emf (Fig.2.4) offer reduces inverter sizes and reduces losses for the same power level.
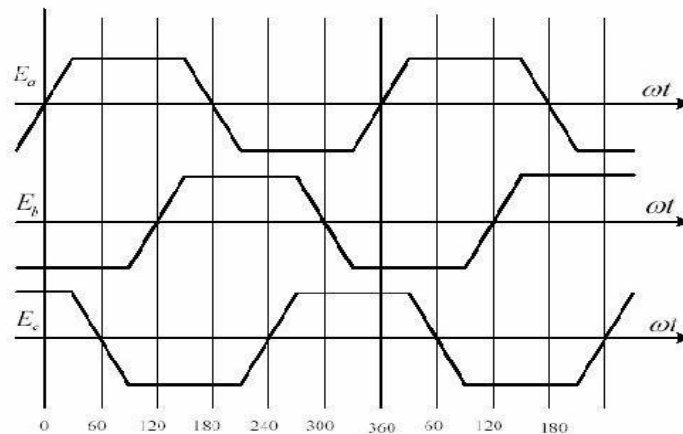

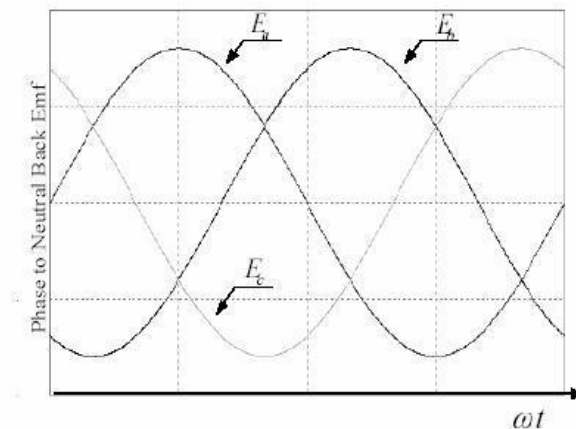**Fig2: Trapezoidal back emf of three phase BLDC motor**

Fig3: Sinusoidal phase back emf of BLDC motor

III. Rotor Position Sensors

Hall Effect sensors provide the portion of information need to synchronize the motor excitation with rotor position in order to produce constant torque. It detects the change in magnetic field. The rotor magnets are used as triggers the hall sensors. A signal conditioning circuit integrated with hall switch provides a TTL-compatible pulse with sharp edges. Three hall sensors are placed 120 degree apart are mounted on the stator frame. The hall sensors digital signals are used to sense the rotor position.
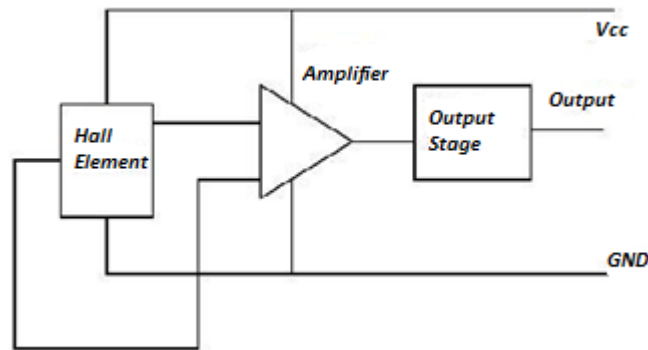

Fig4: Hall position sensors

IV. Pi Speed Controller Design

A proportional integral-derivative is control loop feedback mechanism used in industrial control system. In industrial process a PI controller attempts to correct that error between a measured process variable and desired set point by calculating and then outputting corrective action that can adjust the process accordingly. The PI controller calculation involves two separate modes the proportional mode, integral mode. The proportional mode determine the reaction to the current error, integral mode determines the reaction based recent error. The weighted sum of the two modes output as corrective action to the control element. PI controller is widely used in industry due to its ease in design and simple structure. PI controller algorithm can be implemented as

$$output(t) = K_p e(t) + K_I \int_0^t e(\tau)d\tau$$

Where $e_{(t)}$ = set reference value – actual calculated.

V. Pi Speed Control Of The Bldc Motor

The drive consists of speed controller, reference current generator, PWM current controller, position Sensor, the motor and MOSFETs based current controlled voltage source inverter (CC-VSI). The speed of the motor is compared with its reference value and the speed error is processed in proportional- integral (PI) speed controller.

$$e(t) = \omega_{ref} - \omega_m (t)$$

ω_m (t) is compared with the reference speed ω_{ref} and the resulting error is estimated at the nth sampling instant as.

$$T_{ref}(t) = T_{ref} (t-1) + K_p[e(t) - e(t-1)] + K_I e(t)$$
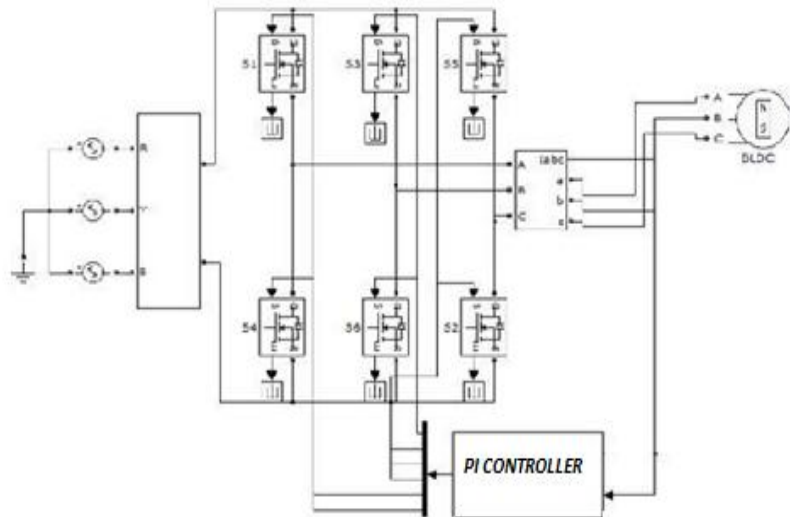
Fig5: Simulation model of PI controller

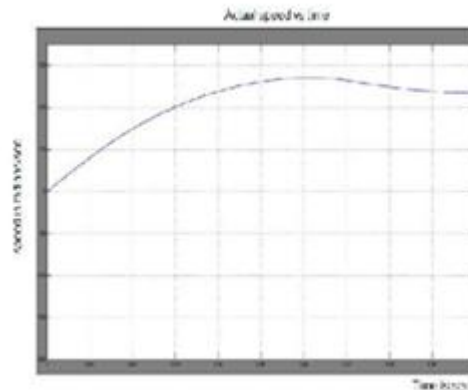## VI.   Simulation Results For Pi Controller

Fig6: Simulation result for speed performance with PI controller

      The above figure shows the simulation result for speed performance with PI controller. The simulation results are taken between actual speed and time. The rated speed of the motor is 1500 rpm/sec and we get a maximum speed output from the motor is 1116 rpm/sec. As we can observe that the dynamic response of the motor is not speed linear and we can also observe that the speed rises to a maximum and settles at 1116 rpm. So, we can say that the dynamic response is not linear.
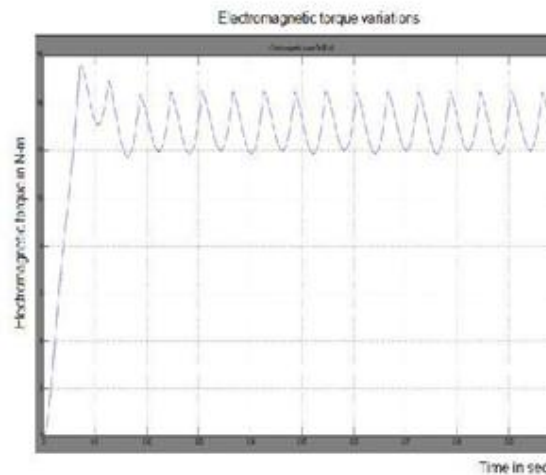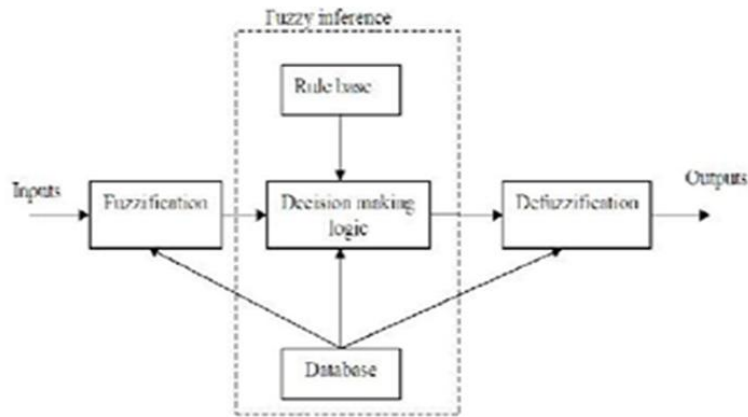

Fig7: Torque performance of PI controller

The above figure shows the torque performance of PI controller. The simulation result gives the electromagnetic variation in the speed of the motor. The electromagnetic torque rises up to 16N-m and later it becomes constant at 12N-m. We can observe repulsions in the torque.

VII.   Structure Of Fuzzy Logic

There are specific components characteristic of a fuzzy controller to support a design procedure. Figure 3 shows the controller between the preprocessing block and post processing block.

VIII.   Fuzzification

The first block inside the controller is fuzzification which converts each piece of input data to degrees of membership by a lookup in one or several membership functions. The fuzzification block matches the input data with the conditions of the rules to determine. There is degree of membership for each linguistic term that applies to the input variable.

IX.   Defuzzification

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control signal of the system. The output levels are depending on the rules that the systems have and the positions depending on the non-linearities existing to the systems. To achieve the result, develop the control curve of the system representing the I/O relation of the systems and based on the information; define the output degree of the membership function with the aim to minimize the effect of the non-linearity.

X.   Fuzzy Logic Control Of The Bldc Motor

The fuzzy logic controller was applied to the speed loop by replacing the classical polarization index (PI) controller. The fuzzy logic controlled BDCM drive system block diagram is shown in Fig
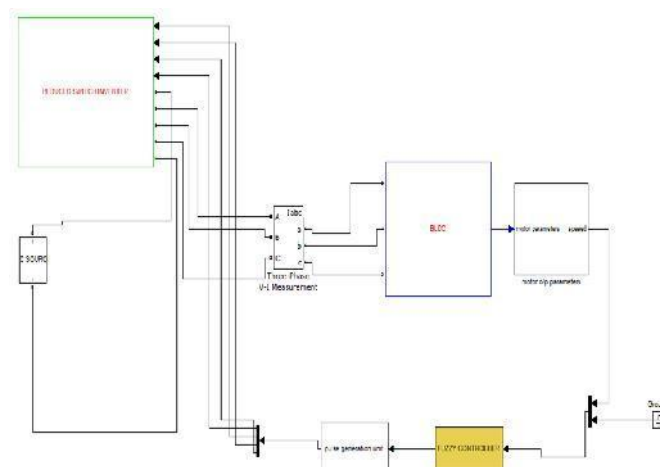

Fig 9: Simulation model of fuzzy logic controller

The input variable is speed error (E), and change in speed error (CE) is calculated by the controller with E .The output variable is the torque component of the reference (i_{ref}) where i_{ref} is obtained at the output of the controller by using the change in the reference current.

The controller observes the pattern of the speed loop error signal and correspondingly updates the output DU and so that the actual speed ω_m matches the command speed ω_{ref} .There are two inputs signals to the fuzzy controller, the error E $=\omega_{ref} - \omega_m$ and the change in error CE, which is related to the derivative

$$dE/dt= \Box E/\Box t = CE/ T_S$$

Where CE $=\Box$ E in the sampling Time T_S CE is proportional to dE/dt

The controller output DU in brushless dc motor drive is $\Box$ i^*_{qs} current. The signal is summed or integrated to generate the actual control signal U or current i^*_{qs} .where K_1 and K_2 are nonlinear coefficients or gain factors including the summation process shown in Fig. We can write

$$\int DU = \int K_1 Edt + \int K_2 CEdt$$
$$U = K_1 \int Edt + K_2 E$$

Which is nothing but a fuzzy P-I controller with nonlinear gain factors. The non linear adaptive gains in extending the same principle we can write a fuzzy control algorithm for P and P-I-D.The input variable speed error and change in speed error is defined in the range of $-1 \leq \omega_e \leq +1$ and $1 \leq \omega_{ce} \leq +1$ and the output variable torque reference current change $\Box$ i_{qs} is define in the range of $1 \leq \Box i_{qs} \leq +1$

The triangular shaped functions are chosen as the membership functions due to the resulting best control performance and simplicity. The membership function for the speed error and the change in speed error and the change in torque reference current are shown in Fig. For all variables seven levels of fuzzy membership function are used .Table show the 7 $\times$ 7 rule base table that was used in the system. Seven membership function has used, functions defined as: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB)

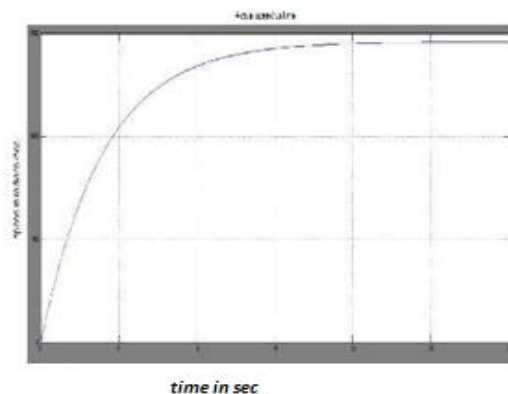| e/ce	NB	NM	NS	ZO	PS	PS	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

Table1: Membership functions

Fig10: Simulation result for speed performance with fuzzy logic controller

The above figure shows the simulation result for speed performance with fuzzy logic controller. The simulation results are taken between actual speed and time. The rated speed of the motor is 1500 rpm/sec and we get a maximum speed output from the motor is 1445 rpm/sec. As we can observe that the dynamic response of the motor is linear and we can also observe that the repulsions in the dynamic response are very weak.
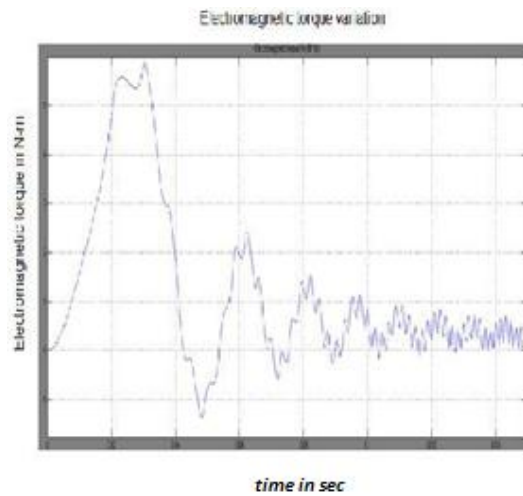

Fig11: Torque performance of fuzzy logic controller

The above figure shows the torque performance of fuzzy logic controller. The simulation result gives the electromagnetic variation in the speed of the motor. The electromagnetic torque rises up to 6N-m and later it becomes constant. We can observe that the sudden increase in the torque increases the performance of the motor and it gives good dynamic response with very less repulsions.

XI.   Implemented Hardware Results

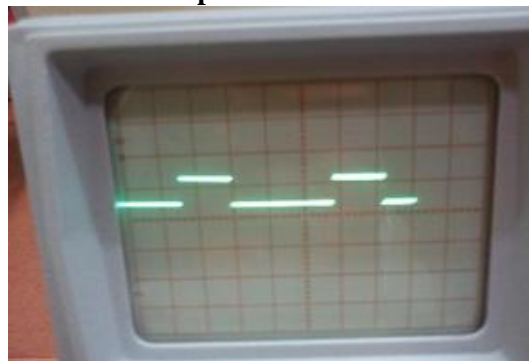**Fig12: Implemented hardware circuit**

XII.   Experimental Results

Fig13: Pulse generated from the controller unit (5V)

Fig14: Pulse generated from the driver unit (12V)

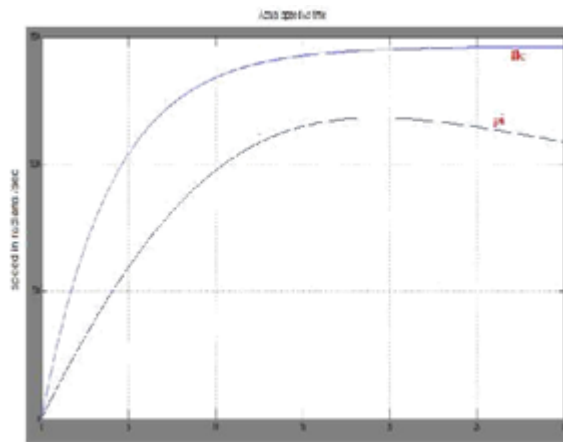| Operating range	9-16
Rated voltage	12V
Number of poles	4
Rated speed rpm	1820
Rated torque	14N m
Stator resistance	0.7 ohm
Rotor resistance	1.8 ohm
Flux inductance by magnet	0.175H
Stator phase inductance	8.5mH
Inertia J	0.089kg.m²

Table 2: Specification of BLDC Motor

Fig15: Comparison of pi and flc

XIII. Conclusion

A speed control of brushless dc (BLDC) motor drive system was simulated with both fuzzy logic controller and a conventional PI and their performances were compared. Simulation results showed that the fuzzy logic controller has better dynamic response than the dynamic response of the PI controller in speed. Overall simulation results that the fuzzy controller has superior, higher performance than PI controller.

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