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Speed Control of Brushless Dc Motor Using Fuzzy Controller

KEYWORDS: Brushless DC motors, speed control, PI controller, 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 track variations of speed references and stabilizes the output speed during load variations. The BLDC has some advantages compare to the other 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 is the input. In order to overcome this main problem, the fuzzy logic control is becomes the suitable control. The effectiveness of the proposed method is verified by developing the simulation model in MATLAB-Simulink. The simulation results show that the proposed fuzzy logic controller (FLC) produce significant improvement in control and performance compare to the PI controller for both condition controlling speed reference variations and load disturbance variations. Fuzzy logic is introduced in order to suppress the chattering and enhancing the robustness of the control system. Fuzzy boundary layer is developed to provide smoother transition to the equivalent control. Smaller overshoot in the speed response and much better disturbance rejecting capabilities.*

I. INTRODUCTION

The brushless DC motor (BLDCM) is getting wide attention in industrial applications because of their high efficiency, high torque density, reliability, longer life and small size. The advantages of the BLDC Motor made their wide spread usage in the variable speed drives.

Fuzzy Logic Controller (FLC) is chosen as a controller in this paper and the results are compared with the conventional controllers. The advantages of FLC are simplicity of control, low cost and the flexibility. It is suitable for speed control applications.

The structure of FLC consists of the following three major components namely fuzzifier which is used for measurement of the input or definition of the fuzzy sets that will be applied. The second one is fuzzy control unit or rule base which provides the system with the necessary decision making, logic based on the rule that determines the control policy. The third one 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. PRINC IPLE OF BLDC MOTOR

BLDC motor consists of the permanent magnet rotor and a wound stator. The brushless motors are controlled using a three phase inverter. 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. The electronic commutation eliminates the problems associated with the brush and the commutator arrangement, namely sparking and wearing out of the commutator brush arrangement, thereby, making a BLDC motor more rugged compared to a dc motor. Fig.1 shows the stator of the BLDC motor and fig.2 shows rotor magnet arrangements.

Fig..1 Stator of BLDC motor

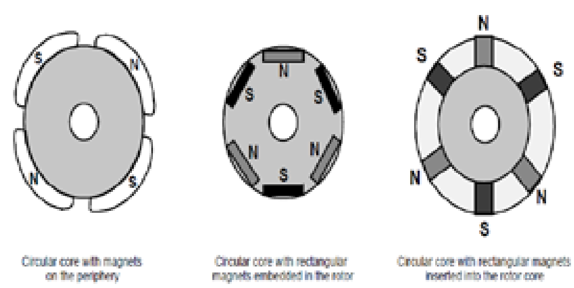

Fig. 2 Rotor magnet cross sections

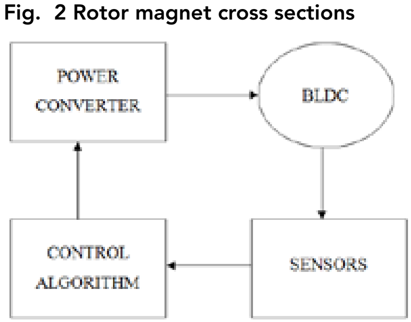

Fig. 3 Basic block diagram of BLDC motor

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The basic block diagram of brushless dc motor is as shown in Fig. 3. The brush less dc motor consist of four main parts Power converter, permanent magnet brushless DC Motor (BLDCM), sensors and control algorithm. The power converter transforms power from the source to the BLDCM 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 for permanent magnet brushless DC machine. The back emf waveform of the motor is indicated in the fig. 4. However, machine with a non sinusoidal back emf results in reduction in the inverter size and reduces losses for the same power level [1-2].

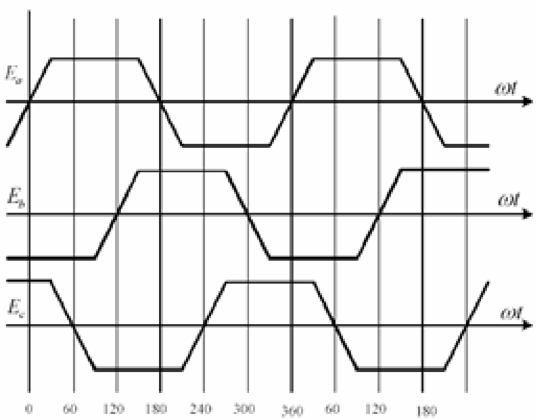

Fig. 4 Trapezoidal back emf of three phase BLDC motor

III. PI CONTROLLER

A proportional integral-derivative is control loop feedback mechanism used in industrial control system. In industrial process a PI controller attempts to correct the error between a measured process variable and desired set point by calculating and then giving corrective action that can adjust the process accordingly. The PI controller calculation involves two separate modes the proportional mode and 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

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.

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

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

$T_{ref}(t) = T_{ref}(t-1) + K_p[e(t) - e(t-1)] + K_1 e(t)$

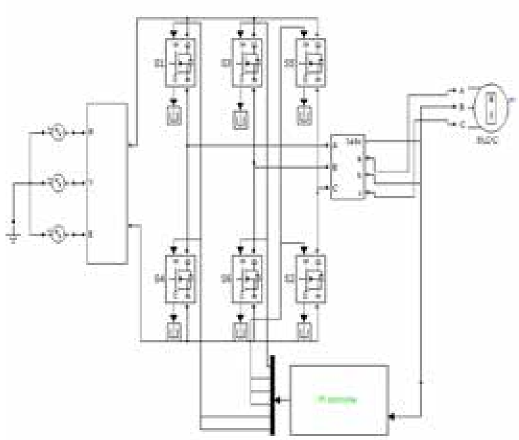

Fig. 5 Simulation model of PI controller

Fig..5 indicates the simulation circuit of the BLDC Motor with PI controller. The simulation results are shown in fig.. 6.

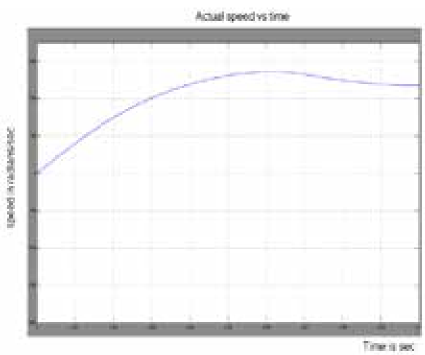

Fig. 6 Simulation results for speed performance with PI controller

The simulation results are taken between actual speed and time. The rated speed of the motor is 1500 rpm and with PI controller a maximum speed of 1116 rpm is reached. The dynamic response of the motor is not linear and the speed rises to a maximum and settles at 1116 rpm. So, we can say that the dynamic response is not linear.

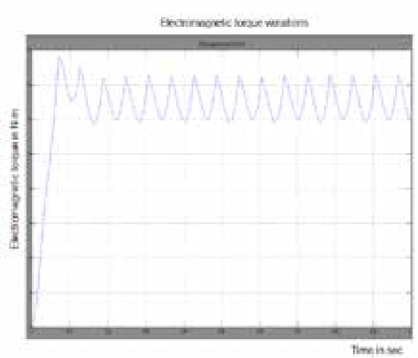

Fig. 7 Torque performance of PI controller

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.

IV. FUZZY LOGIC CONTROLLER

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There are specific components of a fuzzy controller to support a design procedure. Figure 8 shows the controller between the preprocessing block and post processing block. This fuzzy logic controller consists of Fuzzification, defuzzification and fuzzy interface block.

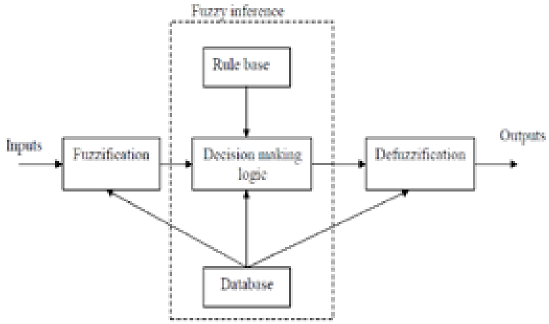

Fig. 8 Structure of fuzzy logic controller

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.

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.

Fuzzy Inference
Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned.

Fuzzy PI controller was applied with variable sampling effect using three fuzzy, three PI controllers are used which increases the cost [3]. Fuzzy gain scheduling PI controller is used for fixed sampling time intervals for different speeds which makes it efficient [4]. Here the fuzzy logic controller [5] fuzzy logic PI controller [6] is used for the speed control application. The DSP based fuzzy logic controller can also be used for the speed control of the BLDC motor which increases the cost. [7].

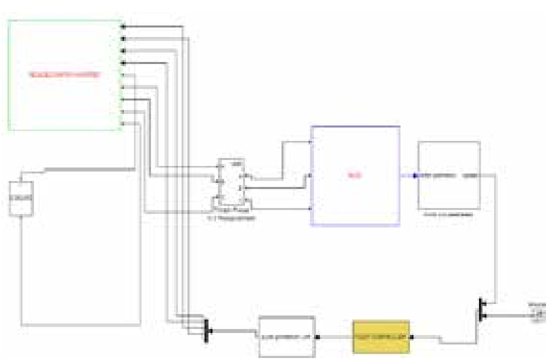

Fig. 9 Simulation model of fuzzy logic controller

In this paper the fuzzy logic controller is used for the speed control purpose and the results are compared with the conventional PI controller. The fuzzy logic controller was applied to the speed loop by replacing the conventional proportional integral (PI) controller. The fuzzy logic controlled BDCM drive system block diagram is shown in Fig.9.

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,

$dE/dt = DE/Dt = CE/T_S$

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

The controller output DU in brushless dc motor drive is Δi^*_{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.8 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 $-1 \le \omega_e \le +1$ and $1 \le \omega_{ce} \le +1$and the output variable torque reference current change Δi_{qs} is define in the range of $1 \le \Delta i_{qs} \le +1$

Table 1 Membership functions

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

The triangular shaped functions are chosen as the membership functions due to the resulting best control performance and simplicity. For all variables seven levels of fuzzy membership function are used. Table 1 show the 7 ×7 rule base table that was used in the system.

Seven membership functions 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).

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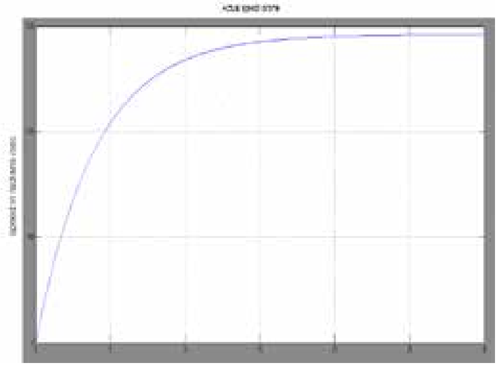

Fig. 10 Simulation result for speed performance with fuzzy logic controller

The fig 10 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 and I got a maximum speed output from the motor is 1445 rpm. 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.

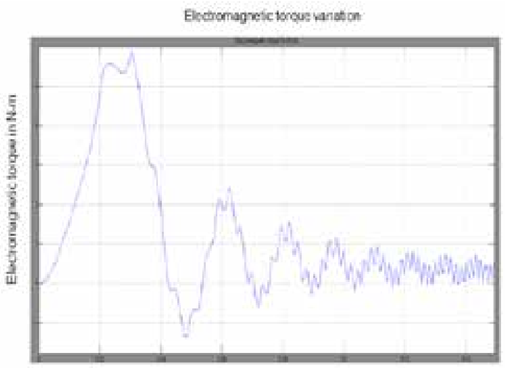

Fig. 11 Torque performance of fuzzy logic controller

The fig 11 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.

V. HARDWARE IMPLEMENTATION AND RESULTS

Fig. 12 Hardware implementation circuit

Fig.12 shows the hardware implementation of the circuit. The fig. 13 and 14 shows the pulse generated from the controller unit and the driver circuits. Table 2 gives the specifications of the BLDC Motor. Fig. 15 shows the comparison of the outputs of the PI and FLC controllers.

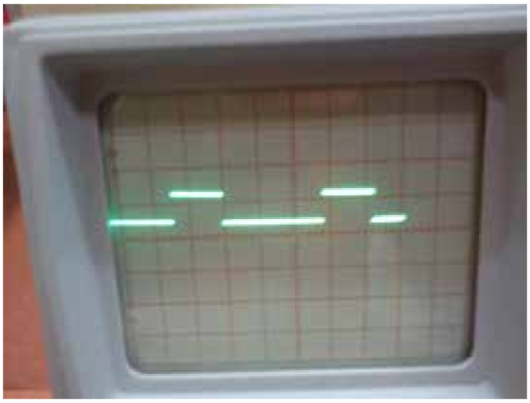

Fig. 13 Pulse generated from the controller unit (5V)

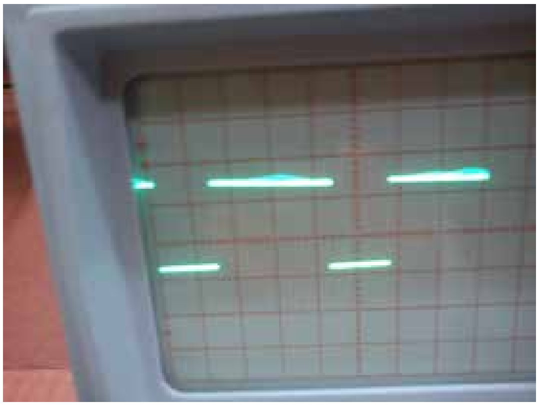

Fig.14 Pulse generated from the driver unit (12V)

Table 2 Specifications of BLDC motor

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	$0.175\omega_b$
Stator phase inductance	8.5mH
Inertia J	0.089kg.m^2

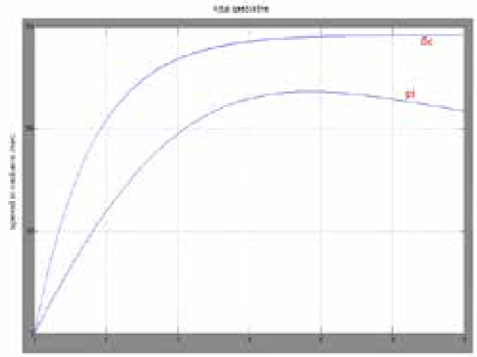

Fig. 15 Comparison of outputs of PI and FLC

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VI. CONCLUSION

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

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