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An Intelligent speed control of Brushless DC motor

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Abstract- Brushless DC (BLDC) motors are widely used for many industrial applications because of their high efficiency, high torque and low volume. This paper proposed a improved Fuzzy PID controller to control speed of Brushless DC motor. The proposed controller is called proportional–integral–derivative (PID) controller and Fuzzy proportional–integral–derivative controller. This paper provides an overview of performance conventional PID controller and Fuzzy PID controller. Using a typical traditional PID controller to achieve satisfactory control characteristics and adjust the settings is a challenging task. The BLDC motor is controlled by a Fuzzy PID controller, which is devised because fuzzy logic may satisfy control criteria and is computationally easy. The experimental findings confirm that a fuzzy PID controller outperforms a traditional PID controller in terms of control performance. The software program MATLAB/SIMULINK has been used for the modeling, control, and simulation of the BLDC motor.

Keywords: - Brushless DC (BLDC) motors, Proportional Integral Derivative (PID) controller, Fuzzy PID controller.

INTRODUCTION

There are mainly two types of dc motors used in industry. The first one is the conventional dc motor where the flux is produced by the current through the field coil of the stationary pole structure. The second type is the brushless dc motor where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles. BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal Back EMF waveform shape. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. Recently, high performance BLDC motor drives are widely used for variable speed drive systems of the industrial applications and electric vehicles.

In practice, the design of the BLDCM drive involves a complex process such as modeling, control scheme selection, simulation and parameters tuning etc. An expert knowledge of the system is required for tuning the controller parameters of servo system to get the optimal performance. Recently, various modern control solutions are proposed for the speed control design of BLDC motor. However, Conventional PID controller algorithm is simple, stable, easy adjustment and high reliability, Conventional speed control system used in conventional PID control.

But, in fact, most industrial processes with different degrees of nonlinear, parameter variability and uncertainty of mathematical model of the system. Tuning PID control parameters is very difficult, poor robustness, therefore, it's difficult to achieve the optimal state under field conditions in the actual production. Fuzzy PID control method is a better method of controlling, to the complex and unclear model systems, it can give simple and effective control, play fuzzy control robustness, good dynamic response, rising time, overstrike characteristics. Fuzzy Logic control (FLC) has proven effective for complex, non-linear and imprecisely defined processes for which standard model-based control techniques are impractical or impossible. Fuzzy Logic, deals with problems that have vagueness, uncertainty and use membership functions with values varying between 0 and 1.

This means that if a reliable expert knowledge is not available or if the controlled system is too complex to derive the required decision rules, development of a fuzzy logic controller become time consuming and tedious or sometimes impossible. In the case that the expert knowledge is available, fine-tuning of the controller might be time consuming as well [8][9]. Furthermore, an optimal fuzzy logic controller cannot be achieved by trial-and-error. These drawbacks have limited the application of fuzzy logic control. Some efforts have been made to solve these problems and simplify the task of tuning parameters and developing rules for the controller.

The aim of this paper is that it shows the dynamics response of speed with design the fuzzy logic controller to control a speed of motor for keeping the motor speed to be constant when the load varies. This paper presents design and implements a voltage source inverter for control a speed of BLDC motor. This paper also introduces a fuzzy logic controller to the PID in order to keep the speed of the motor to be constant when the load varies.

METHODOLOGY

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.

Principle operation of Brushless DC (BLDC)Motor

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. The basic block diagram brushless dc motor as shown Fig.1. The brushless dc motor consists of four main parts power converter, permanent magnet-synchronous machine (PMSM), sensors, and control algorithm.

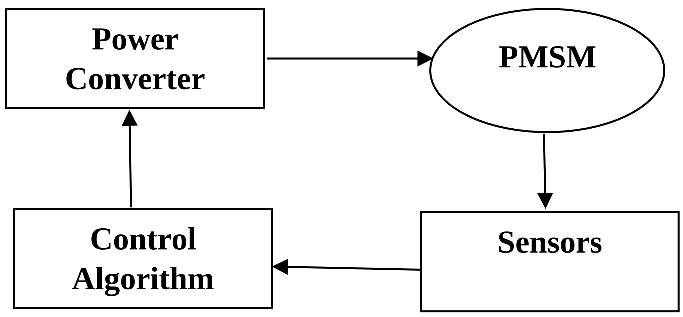

Fig.1. Basic block diagram of BLDC motor

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.

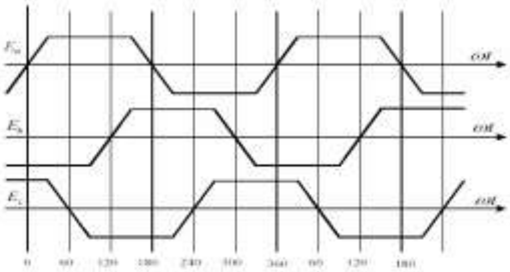

Fig.2. Trapezoidal back emf of three phase BLDC motor

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.

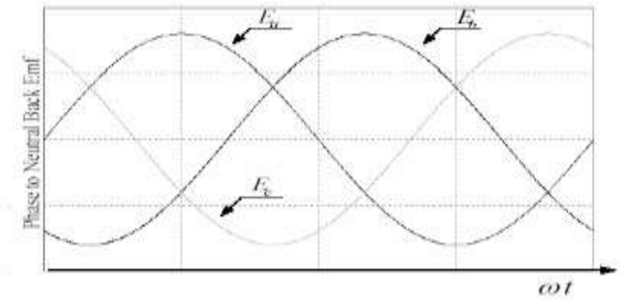

Fig.3. Sinusoidal phase back emf of BLDC motor

Machine with sinusoidal back emf (Fig 3) may be controlled so as to achieve nearly constant torque. However, machine with a non-sinusoidal back emf (Fig 4) offer reduces inverter sizes and reduces losses for the same power level.

Speed Control System of BLDC Motor

Below Fig. 1 shows the whole block diagram for the three-phase BLDC motor's speed control. The BLDC motor is controlled by two control loops. The inverter gate signals and electromotive forces are synchronized via the inner loop. By adjusting the DC bus voltage, the outer loop regulates the motor's speed. The BLDC motor's voltage source inverter circuit is depicted below in Figure 2.

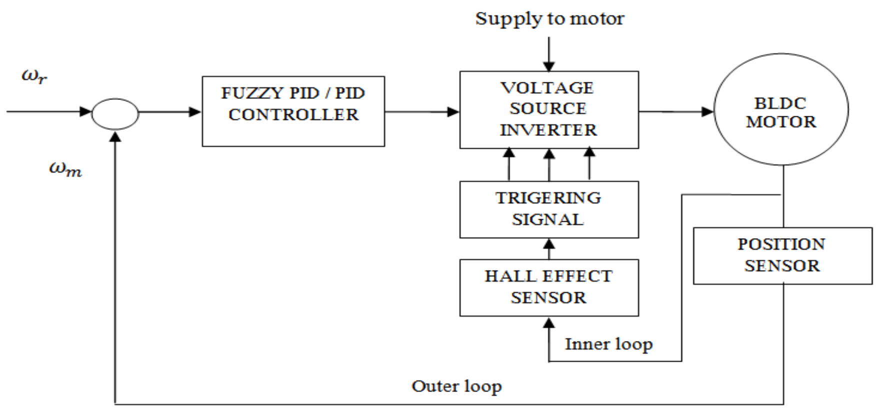

Fig .4. Block Diagram of speed control of BLDC Motor

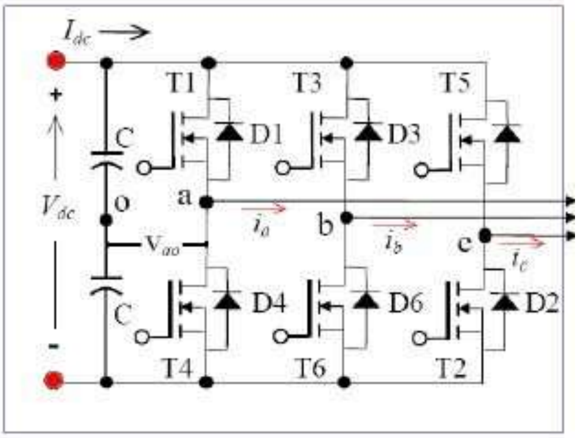

Fig .5. Voltage Source Inverter

The driving circuitry comprises of three phase power convertors that simultaneously activate two BLDC motor phases by means of six power transistors. Three Hall sensors installed on the stator are used to detect the rotor position, which controls the MOSFET transistors' switching order. The Decoder block creates the back EMF signal vector by utilizing the Hall sensor data and the reference current generator's generated sign. Giving opposing current is the fundamental principle of operating a motor in the opposite direction.

Table I is used to calculate the back EMF for clockwise motion and to determine the gate logic that converts electromagnetic forces into the six signals on the gates.

Table I. Clockwise Rotation

Hall sensor A	Hall sensor B	Hall sensor c	EMF A	EMF B	EMF C	EMF A	EMF B	EMF C	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	-1	1	0	-1	1	0	0	0	1	1	0
0	1	0	-1	1	0	-1	1	0	0	1	1	0	0	0
0	1	1	-1	0	1	-1	0	1	0	1	0	0	1	0
1	0	0	1	0	-1	1	0	-1	1	0	0	0	0	1
1	0	1	1	-1	0	1	-1	0	1	0	0	1	0	0
1	1	0	0	1	-1	0	1	-1	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Controlling Circuit

Design of Fuzzy PID Control: -

Consider the characteristics parameters – proportional (P), integral (I), and derivative (D) controls, as applied to the diagram below in Fig.6.

A PID controller is simple three-term controller. The letter P, I and D stand for P- Proportional, I- Integral, D-Derivative. The transfer function of the most basic form of PID controller, is

Where KP = Proportional gain,

KI = Integral gain and

KD= Derivative gain.

$$C(S) = K_P + \frac{K_I}{S} + K_D S \quad (1)$$

$$C(S) = \frac{K_D S^2 + K_P S + K_I}{S} \quad (2)$$

Where K_P = Proportional gain, K_I = Integral gain and K_D =Derivative gain. The control u from the controller to the plant is equal to the proportional gain (K_P) times the magnitude of the error plus the integral gain (K_I) times the integral of the error plus the derivative gain (K_D) times the derivative of the error.

$$u = K_P + K_I \int edt + K_D \frac{de}{dt} \quad (3)$$

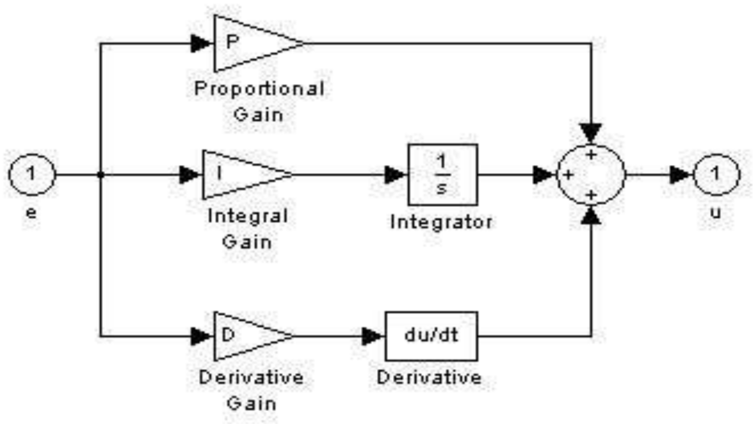

Fig.6. Simulation model of PID Controller

The control u from the controller to the plant is equal to the Proportional gain (KP) times the magnitude of the error pulse the Integral gain (KI) times the integral of the error plus the Derivative gain (KD) times the derivative of the error. Due to its simplicity and excellent if not optimal performance in many applications PID controllers is used in more than 95% of closed-loop industrial processes

We are most interested in four major characteristics of the closed-loop step response. They are

a. Rise Time: the time it takes for the plant output Y to rise beyond 90% of the desired level for the first time.
b. Overshoot: how much the peak level is higher than the steady state, normalized against the steady state.
c. Settling Time: the time it takes for the system to converge to its steady state.
d. Steady-state Error: the difference between the steady- state output and the desired output.

Fuzzy logic controller (FLC)

Fuzzy logic expressed operational laws in linguistics terms instead of mathematical equations. Many systems are too complex to model accurately, even with complex mathematical equations; therefore traditional methods become infeasible in these systems.

However fuzzy logics linguistic terms provide a feasible method for defining the operational characteristics of such system. Fuzzy logic controller can be considered as a special class of symbolic controller. The configuration of fuzzy logic controller block diagram is shown in Fig.7.

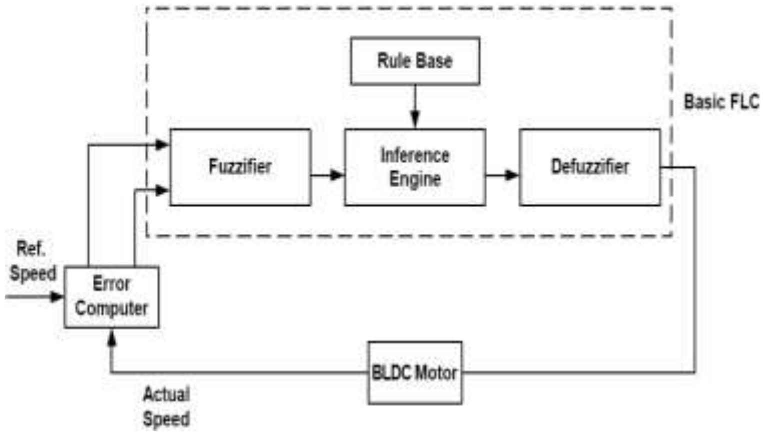

Fig.7. Structure of Fuzzy logic controller

The fuzzy logic controller has three main components

- Fuzzification
- Fuzzy inference
- Defuzzification

Fuzzification

Multiple measured crisp inputs first must be mapped into fuzzy membership function this process is called fuzzification. Performs a scale mapping that transfers the range of values of input variables into corresponding universes of discourse. Performs the function of fuzzification that converts input data into suitable linguistic values which may be viewed as labels of fuzzy sets.

Fuzzy logic linguistic terms are often expressed in the form of logical implication, such as if- then rules. These rules define a range of values known as fuzzy member ship functions. Fuzzy membership function may be in the form of a triangular, a trapezoidal, a bell or another appropriate from. The triangle membership function, Triangle membership functions limits defined by Val1, Val2 and Val 3.

The inputs of the fuzzy controller are expressed in several linguist levels. As shown in Fig.4.3 these levels can be described as Positive big (PB), Positive medium (PM), Positive small (PS) Negative small (NS), Negative medium (NM), Negative big (NB) or in other levels. Each level is described by fuzzy set.

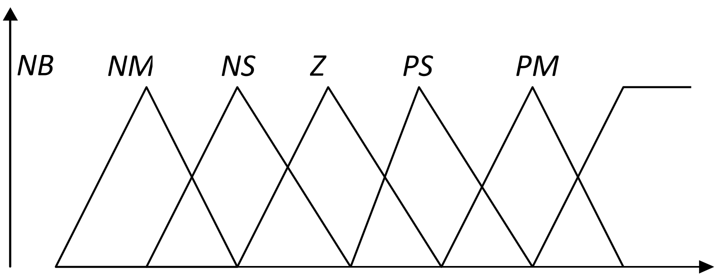

Fig.8. Seven levels of fuzzy membership function

Fuzzy inference

The inference mechanisms employed in an FLC are generally much simpler than those used in a typical expert system, since in an FLC the consequent of a rule is not applied to the antecedent of another. In other words, in FLC we do not employ the chaining inference mechanism, since the control actions are based on one-level forward

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 9.

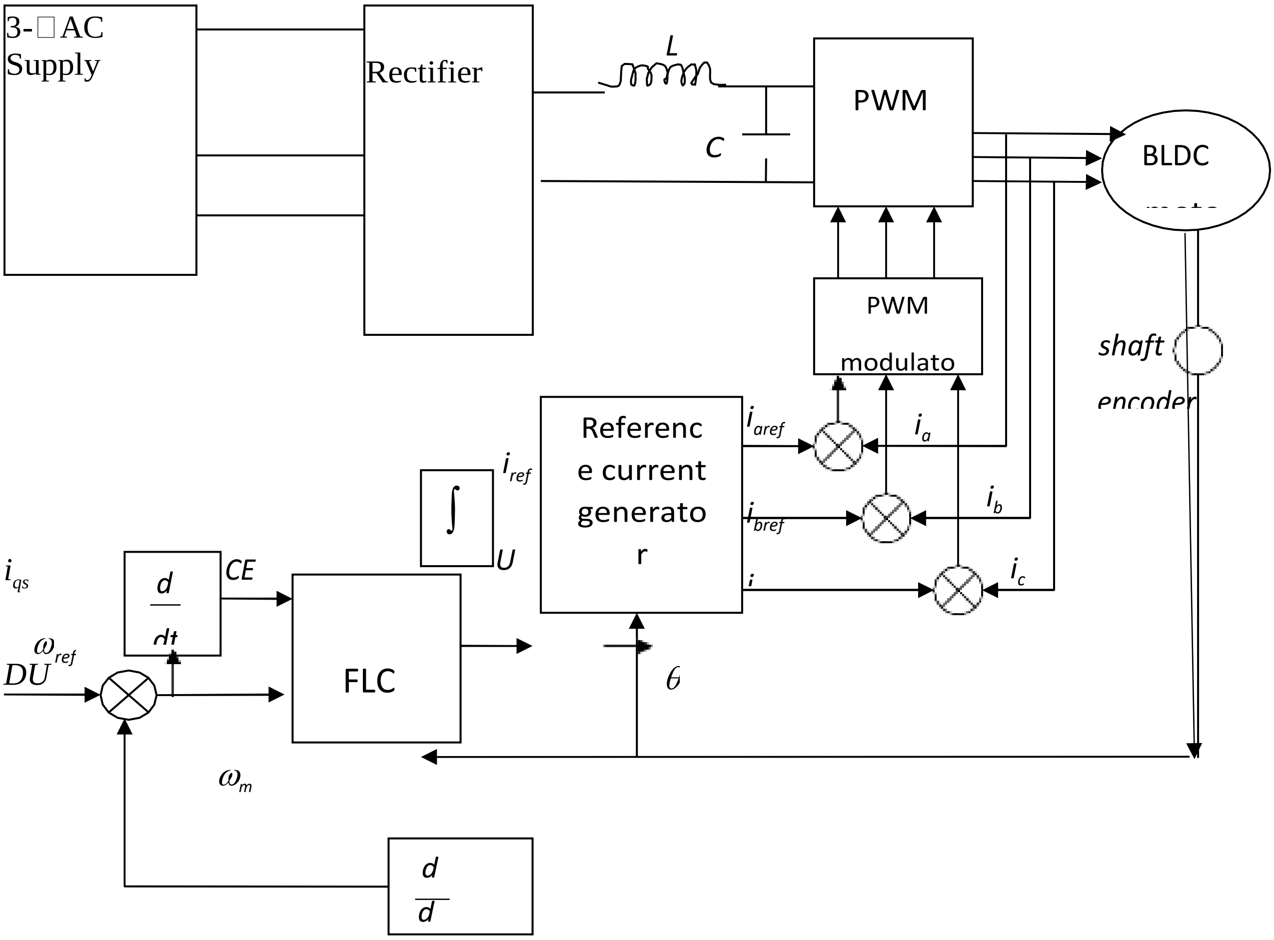

Fig.9. Fuzzy speed control block diagram of the BLDC motor

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 (iref)

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. 9. For all variables seven levels of fuzzy membership function are used. Table 2 shows the 7*7 rule base table that was used in the system.

Table 2. 7×7 Rule base table used in the system

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 steps for speed controller are as

- Sampling of the speed signal of the BLDC.
- Calculations of the speed error and the change in speed error.
- Determination of the fuzzy sets and membership function for the speed error and change in speed error.
- Determination of the control action according to fuzzy rule.
- Calculation of the □iqs by center of area defuzzification method.
- Sending the control command to the system after calculation of□iqs

SIMULATION RESULTS AND DISCUSSION

To evaluate the performance of the system, a series of measurements has been accomplished. The performance comparison between PID controller and Fuzzy PID controller of three phase BLDC Motor is shown in below Table V. We consider the following characteristics Rise Time (tr), overshoot (Mp) and Settling Time (ts).

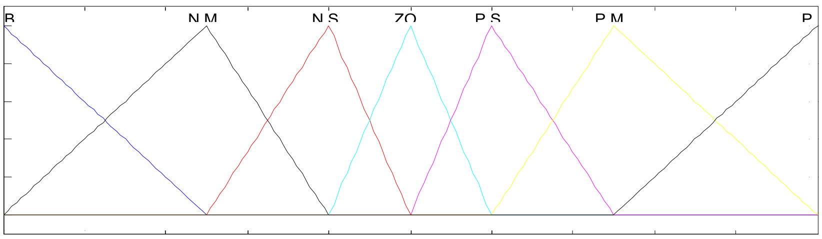

Fig. 10a. Fuzzy membership function for the speed error

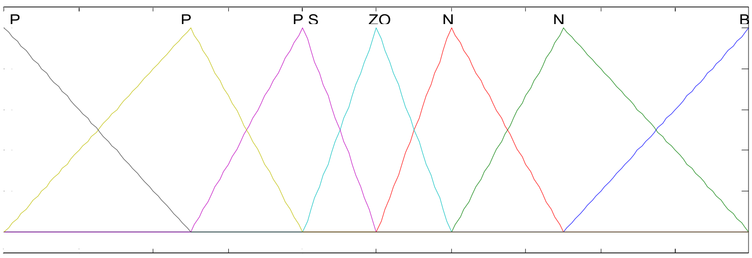

Fig. 10b.Fuzzy membership function for the change in speed error

In drive operation, the speed can be controlled indirectly by controlling the Voltage Source inverter. The speed is controlled by fuzzy logic controller whose output is the inner dc Voltage controller. The Voltage is controlled by varying the dc voltage. The drive performance of voltage source controller is improved by employing two sets of fuzzy logic controllers.

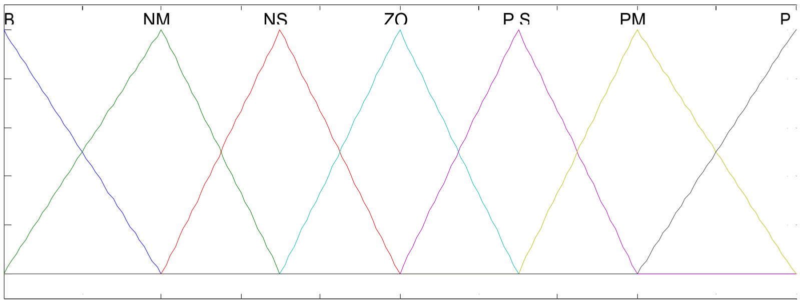

Fig. 10c. Fuzzy member ship function for the change in torque reference current

One set of fuzzy logic controller is used in the inner loop for controlling the torque of the motor which is proportional to DC link current Idc, and another set is used in the outer loop for controlling the actual motor speed.

Fuzzy PID controller used in this paper is based on two input FLC structure with coupled rules. Real interval of variables is obtained by using scaling factors which are Se, Sde and Su. The fuzzy control rule is in the form of: IF e=Ei and de=dEj THAN UPD=UPD(i,j). These rules are written in a rule base look-up Table 2.

FLC has two inputs and one output. These are error (e), error change (de) and control signal, respectively. Linguistic variables which imply inputs and output have been classified as: NB, NM, NS, Z, PS, PM, PB. Inputs and output are all normalized in the interval of [-10,10] as shown in Fig. 11.

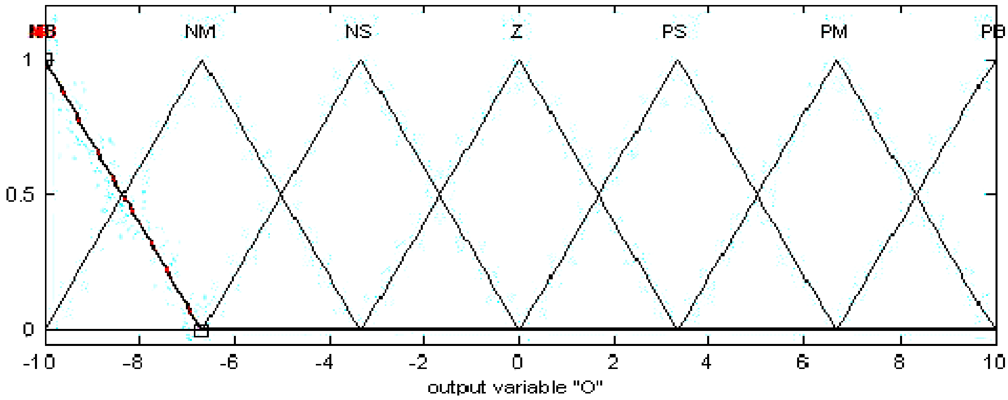

Fig.11. Membership functions of output

CONCLUSION

Since brushless DC (BLDC) motors have high torque, low volume, and excellent efficiency, they are often employed in a variety of industrial applications. This study suggested a better fuzzy PID controller to regulate the brushless DC motor's speed. This research compares simulation results of traditional PID controllers versus fuzzy PID controllers for three phase BLDC motors. Conventional PID control does not need adjusting the control parameters when the reference speed changes. Simulation findings show that BLDC speed control utilizing the Fuzzy PID controller approach outperformed the traditional PID controller for the identical operation conditions, particularly at lower and higher motor speeds. Additionally, the motor speed should remain consistent despite varying loads.

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