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Speed Control of Permanent Magnet Brushless DC Motor Using Fuzzy Logic Controller-Hardware Implementation

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Abstract- BLDC motors are very popular and are replacing brush motors in numerous applications. Because the BLDC motor does not require commutator and due to its superior electrical and mechanical characteristics and its capability to operate in hazardous conditions it is more reliable than the DC motor. Traditionally, three-phase inverters are generally used to control these motors, requiring a rotor position sensor for starting and for providing the proper commutation sequence to stator windings. The disadvantages of sensored motor control system are increased cost and size of the motor, and need special mechanical arrangement for mounting the sensors. Another problem associated with BLDC motor control is the use of Conventional controllers; these controllers poses difficulties under the conditions of nonlinearity, load disturbances and parametric variations. This paper presents the design and implementation of a fuzzy logic controller for the sensorless speed control of brushless dc motors which will be helpful in solving problems associated with sensored control and conventional controllers in order to reduce cost and complexity of the drive system without compromising the performance.

***Keywords*—**Fuzzy logic controller, BLDC motor drives, back-EMF, sensorless.

I. Introduction

Over the last few years, with the continuous technology development in power semi-conductors , microprocessors, logic ICs, adjustable speed drivers (ASDs) control schemes and increase in permanent-magnet brushless electric motor production have enable us the reliable and cost-effective solution for a broad range of adjustable speed applications. Brushless dc (BLDC) motors are gradually replacing dc motors and ac motors due to their high efficiency, silent operation, small size, reliability, high operating speed, low maintenance and excellent speed torque characteristics.

The BLDC motor drive system consists of a dc power supply switched to the stator phase windings of the motor through an inverter by power switching devices. The detection of rotor position will determine the switching sequence of the inverter. Three-phase inverters are generally used to control these motors, requiring a rotor position sensor for starting and for providing the proper commutation sequence to stator windings. These position sensors can be Hall sensors, resolvers, or absolute position sensors. However, the Hall sensors will lose its sensing capability at the temperature above 125 °C. Therefore Hall sensors are not feasible in high temperature conditions. The drawbacks of sensored motor control system are increased cost and size of the motor, and need special mechanical arrangement for mounting the sensors. Another major problem is associated with the conventional controllers that are widely used in the industry due to its simple control structure and ease of implementation. But these controllers pose difficulties under the conditions of nonlinearity, load disturbances and parametric variations. Traditional control systems are based on mathematical models in which the control system is described using one or more differential equations that define the system response to its inputs. In many cases, the mathematical model of the control process may not exist, or may be too expensive in terms of computer processing power and memory, and a system based on empirical rules may be more effective. Hence there is a need for intelligent controller.

So an attempt is made to remove the drawbacks associated with sensored control and use of traditional controllers by using sensorless control and fuzzy controller for PMBLDC motor. Thus this method of sensorless control of PMBLDC will provide advantages like cost reduction, reliability, elimination of difficulty in maintaining the sensor etc. and developing nonlinear system for embedded control.

II. Techniques in Sensorless Control

The BLDC motor provides an attractive candidate for sensorless operation because the nature of its excitation inherently offers a low-cost way to extract rotor position information from motor-terminal voltages. A Permanent Magnet brushless drive that does not require position sensors but only electrical measurements is called a sensorless drive [1].

For three-phase BLDC motor at one time instant, only two out of three phases are conducting current and the no conducting phase carries the back-EMF. If the zero crossing of the phase back EMF can be measured, we can know when to commutate
the current. Sensing methods for the PM BLDC motors and generators are classified in two categories; direct and indirect back-EMF detection [1].

Direct back-EMF detection methods: the back-EMF of floating phase is sensed and its zero crossing is detected by comparing it with neutral point voltage. The methods can be classified as:

Direct back-EMF detection methods are

- Back-EMF Zero Crossing Detection (ZCD) or Terminal Voltage Sensing and PWM strategies.

Indirect back-EMF detection methods:

- Back-EMF Integration, Third Harmonic Voltage Integration and Free-wheeling Diode Conduction or Terminal Current Sensing [1].

III. Proposed System

Figure 1 shows the block diagram of proposed system. It has a brushless dc motor, a voltage source, a voltage regular circuitry, a motor driver circuit, back-emf detector circuit, optocoupler circuit and a microcontroller board.

In Figure 1, ωref. is the reference speed (rad/sec), ωa is the actual rotor speed (rad/sec), u is the control signal used to reference moment (N-m), Vdc is the supply voltage of the inverter (Volt). In speed control loop as shown in the block diagram, the reference speed and the actual motor speed is compared and the error signal is obtained.

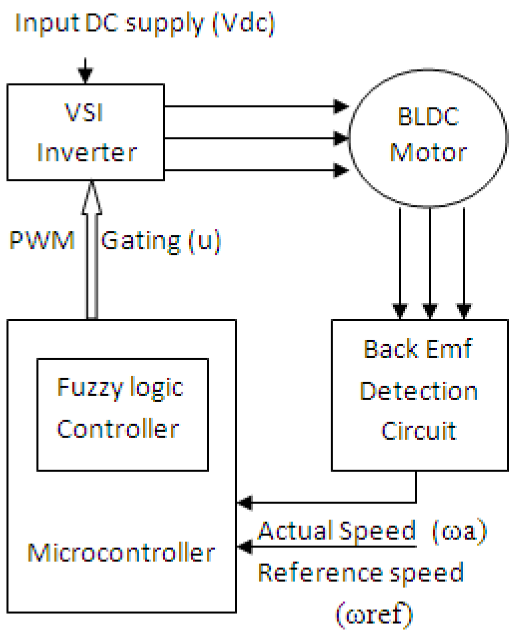

Fig.1.Block diagram of sensorless control of the BLDC motor drive system.

These signals are employed in fuzzy controller and reference current is produced for control system .The current control loop regulates the BLDC motor current to the reference current value generated by the speed controller. The current control loop consists of reference current generator, PWM current control unit and a three phase voltage source inverter (VSI). Position of the BLDC motor is obtained by employing zero crossing back emf detection method and thus eliminating position sensor requirement [3].

IV. Design Of Fuzzy Controller

Error (E) and change in error (CE) are the inputs for the fuzzy controller whereas the output of the controller is change in duty cycle (ΔDC). The error is defined as the difference between the ref speed and actual speed , the change in error is defined as the difference between the present error and previous error and the output, Change in duty-cycle ΔDC is which **c**ould be either positive or negative is added with the existing duty-cycle to determine the new duty-cycle (DCnew) Fig. 2 shows the basic structure of fuzzy logic controller. The fuzzy controller is composed of the following four elements: fuzzification, fuzzy rule-base, fuzzy inference engine and defuzzification [4].

Fuzzification

Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable in to a linguistic variable is called fuzzification [4].

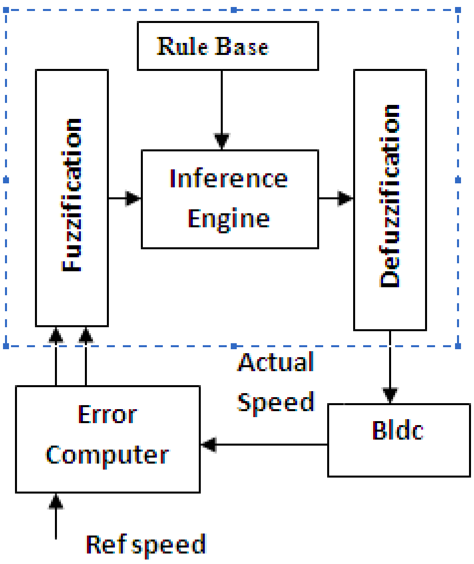

Fig. 2 Fuzzy logic controller

The fuzzifier includes two parts: choice of membership function and choice of scaling factor. The fuzzy variables error, change in error and change in duty-cycle are quantized using the linguistic terms NB, NM, NS, Z, PS, PM, and PB (negative big, negative medium, negative small, zero, positive small, positive medium and positive big respectively).

The motor maximum range of speed is 0-3000 rpm.The possible range of error is -3000 to +3000 rpm. The universe of discourse for error is -3000 rpm to +3000 rpm and for the change in duty cycle, defined as - 100 % and +100 %. In order to achieve faster control action and simplification, the inputs and output are normalized to +/-100 rpm, +/-100 rpm and +/-100 respectively. The membership functions used for inputs and output are given in figure 3.

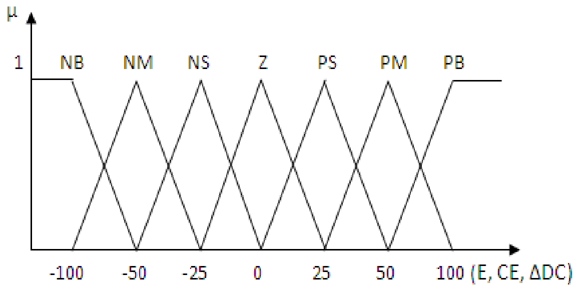

Fig.3 Membership functions for Error Change in Error and Change in Duty-Cycle.

Rule base and Inference engine

A rule base (a set of If-Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve control action. Once the rules have been established, a fuzzy logic system can be viewed as a mapping from inputs to outputs. Rules may be provided by experts or can be extracted from numerical data. The performance of the controller can be improved by adjusting the membership function and rules.

Different types of inferential procedures to help us understand things or to make decisions, there are many different fuzzy logic inferential procedures. The fuzzy inference operation is implemented by using the 49 rules. Some of these rules are

1. If error (E) is NB and change in error (CE) is NB then output is PB.

2. If error (E) is NB and change in error (CE) is NM then output is PB
3. If error (E) is NB and change in error (CE) is NS then output is PB
4. If error (E) is NB and change in error (CE) is NS then output is PM

Likewise 49 rules are defined. The same set of rules could be presented in a sliding mode format, a more compact representation given in Table 1.

Table 1. Rule Base

	Change in error(CE)						
Error(E)	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	PB	PB	PB	PB	PM	PS	Z
NM	PB	PB	PB	PM	PS	Z	NS
NS	PB	PB	PM	PS	Z	NS	NM
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NB	NB	NB
PB	Z	NS	NM	NB	NB	NB	NB

Defuzzification

Finally the fuzzy output is converted into real value output by the process called defuzzification. Centroid method of defuzzification is used because it can be easily implemented and requires less computation time. The defuzzified output is obtained by the following equation

$$z = \frac{\sum_{x=1}^{n} \mu(x)x}{\sum_{x=1}^{n} \mu(x)}$$

Where z is the defuzzified value, μ(x) is the membership value of member x [5]. .

V. Hardware Design

Top view of Hardware Setup is shown Figure 4. Hardware consists of five elements brushless DC motor, a voltage source, a voltage regular circuitry ,a motor driver circuit, back-emf detector circuit, optocoupler circuit and a dsPIC30F4011 microcontroller board.

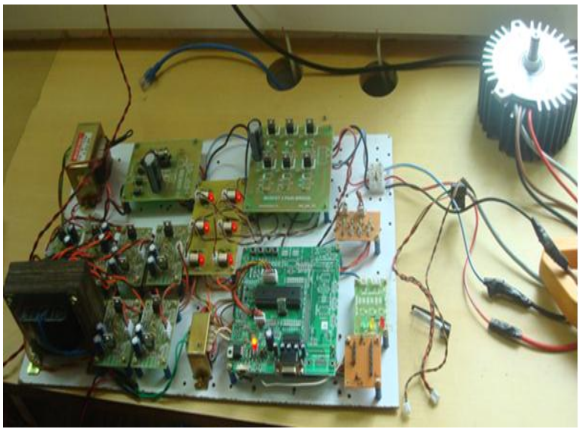

Fig .4 Top View of Hardware circuit

The duty-cycle of the devices are controlled based on the fuzzy controller output to control the armature voltage and hence the speed of the motor. The set speed is generated through a switch and it is given as another input to the A/D converter to determine the set speed. The function of the microcontroller is to compute the error and change in error, store these values, compute the fuzzy controller output, determine the new duty-cycle for the switching devices and perform electronic commutation

VI. Key Experiment Waveforms

Figure 5 shows Back Emf Waveform of R phase with respect to neutral point N and Y phase with respect to neutral point N through back Emf Detection Circuit. The motor windings produce trapezoidal back Emf. The back Emf generated in the windings are at 120 degrees out of phase to each other.

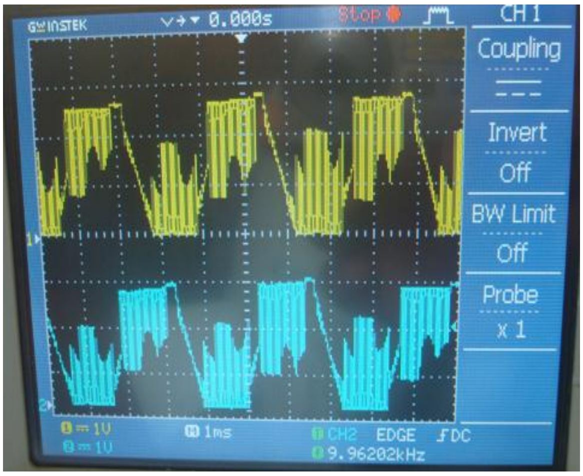

Fig.5 Back Emf Waveform RN and YN phase through back Emf Detection Circuit

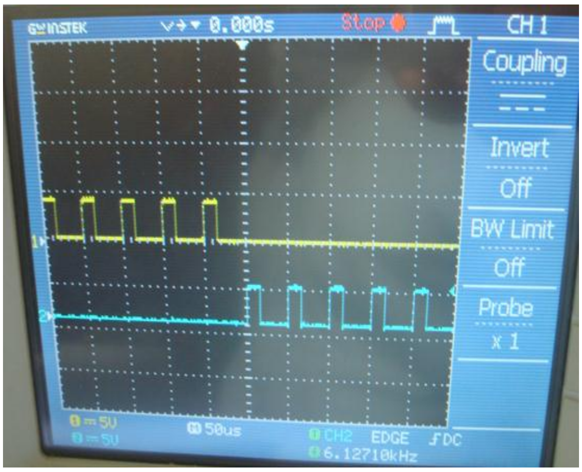

Figure 5 PWM pulse applied to MOSFETs of driver circuit.

Figure 5 shows PWM pulse applied to MOSFETs of driver circuit, which provide the control action for turning on and off of electronic switches for proper commutation of motor. Figure 7.14 shows PWM pulse and the zero-crossing point of back Emf waveform.

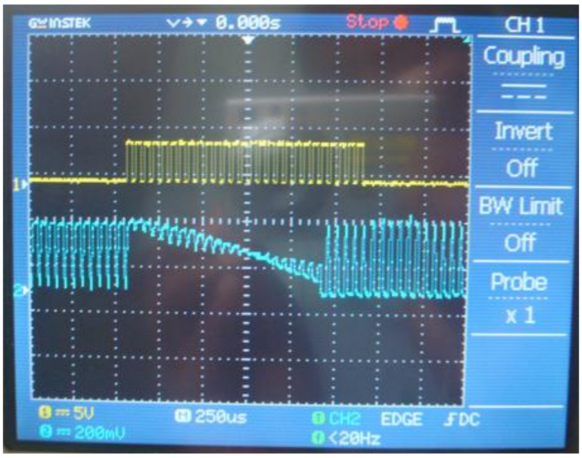

Figure 7.14 PWM pulse with the zero-crossing point.

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