Hardware Implementation of Fuzzy Logic Controller for Sensorless Permanent Magnet BLDC Motor Drives

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Abstract-Various industrial applications such as robotics, Automotive, Appliances, automotive fuel pumps, machine tools, aerospace and many other applications Permanent Magnet Brushless DC (PMBLDC) motor are widely used due to their superior electrical and mechanical characteristics. Conventional methods of motor control fail to yield desired performance of BLDC motor due to non linearity arising because of variation in the system parameters and varying load. Fuzzy logic controller can be used to improve BLDC performance. Another challenge is to reduce size and cost of the drive system . Sensorless control has advantages like cost reduction, reliability, elimination of difficulty in maintaining the sensor etc. sensorless control is highly advantageous when the motor is operated in dusty or oily environment, when cleaning and maintaining of Hall sensors is required for proper sensing of rotor position.In this paper the hardware design and implementation of fuzzy logic controller for sensorless control of PMBLDC motors using PIC16F877 microcontroller is presented.

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

I. Introduction

THE brushless dc motors are gradually replacing dc motors and ac motors because of their small size, high operating speed, high efficiency, less maintenance and excellent speed torque characteristics. They are used in robotics, computer disk drives, machine tools, electric vehicle and battery powered applications. The conventional control schemes such as proportional (P), proportional integral (PI) and proportional integral derivative (PID) have been developed for speed control of BLDC motors. However, these controllers need an accurate mathematical model and can be applied only to highly linear systems. These controllers fail to yield better performance when the system becomes non-inear and it is a cumbersome process to tune these controllers. In practice, the BLDC motor control systems are non-linear because of the variation in their parameters and varying loads[1].Since the PMBLDC motor is highly coupled non-linear multivariable system, it is difficult to obtain its accurate mathematical model. Hence there is a need for intelligent controller. So an attempt is made to develop fuzzy controller for PMBLDC motor. The fuzzy logic controller uses fuzzy logic as a design methodology, which can be applied in developing nonlinear system for embedded

control. Simplicity and less intensive mathematical design requirements are the most important features of the FLC [2].
Another major challenge is to reduce the size of the drive system, and its cost without compromising its performance. There are two methods of controlling PMBLDC motor namely sensor control and sensorless control. The latter has advantages like cost reduction, reliability, elimination of difficulty in maintaining the sensor etc. Sensorless control is highly advantageous when the motor is operated in dusty or oily environment, where cleaning and maintaining of Hall sensors is required for proper sensing of rotor position [3]. In recent year, with the development of IC mixed-signal technology, SOC (system-on-chip) devices are feasible SOC devices have many advantages, including lower system cost, reduced board space, and superior system performance and reliability. The 8-bit microcontroller has been the mainstay of embedded-control systems for nearly 20 years. The devices are available for a low cost; instruction sets are easy to use [4]. As a result, the back EMF detection circuit is integrated with a standard PIC16F87X family microcontroller core to become a low cost sensorless BLDC microcontroller design.

II. Different Methods of Sensorless Control

Hall sensors can be completely eliminated, thus reducing cost and size of motor assembly, in those applications in which only variable speed control (i.e., no positioning) is required and system dynamics is not particularly demanding (i.e., slowly or, at least, predictably varying load). In fact, some control methods, such as back-EMF and current sensing, provide, in most cases, enough information to estimate with sufficient precision the rotor position and, therefore, to operate the motor with synchronous phase currents. A PM brushless drive that does not require position sensors but only electrical measurements is called a sensorless drive [5].

The BLDC motor is used for sensorless operation because the nature of its excitation inherently offers a low-cost way to extract rotor position information from motor-terminal voltages. In the excitation of a three-phase BLDC motor, except for the phase-commutation
periods, only two of the three phase windings are conducting at a time and the non conducting phase carries the back-EMF. There are many categories of sensorless control strategies; however, the most popular category is based on back electromotive forces or back-EMFs . Sensing back-EMF of unused phase is the most cost efficient method to obtain the commutation sequence in star wound motors [5]. Sensing methods for the PMBLDC motors are classified in two categories; direct and indirect back-EMF detection.

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: These methods are the following: Back-EMF Integration, Third Harmonic Voltage Integration and Free-wheeling Diode Conduction or Terminal Current Sensing [5].

III. Sensorless control of BLDC motor

Figure 1 shows the block diagram of proposed system. It has a brushless dc motor, six step inverter, and gate drive for inverter, fuzzy controller and switching logic. Due to the presence of parameter variation and load disturbance in a BLDC motor, closed loop control is necessary, to reach a desirable behavior. BLDC motor has three phase windings on stator and Permanent Magnet on rotor [6].

In Figure 1, ωref. is the reference speed (rad/sec), ωa is the actual rotor speed (rad/sec), θ is the rotor position (degree), u is the control signal used to reference moment (N-m), ia , ib , ic are the actual phase currents (Ampere), $i_a$ref, $i_b$ref, $i_c$ref are the reference phase currents (Ampere), $S1 - S6$ are switches of the inverter and 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. 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 [7].

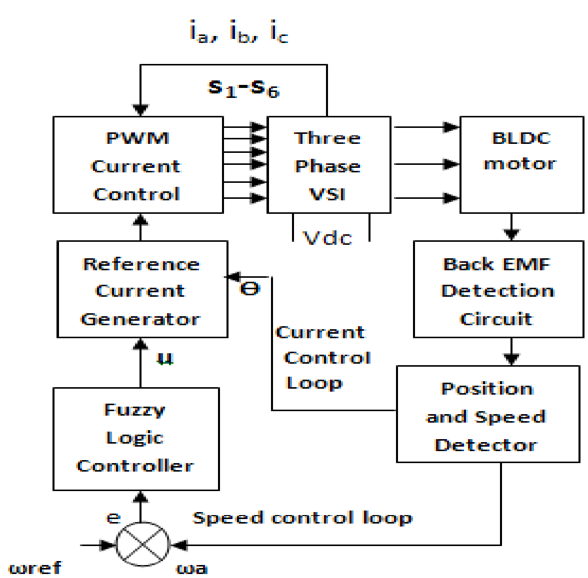

Figure 1. Block diagram of sensorless control of the BLDC motor drive system.

IV. Fuzzy Logic Controller Design

Generally PI controller is widely used in BLDC motor control; however it does not give satisfactory results when control parameters and loading condition changes rapidly The fuzzy logic controller (FLC) will guarantee a stable operation, even if there is a change in motor parameters and load disturbances [2]. Fuzzy controllers are used to control consumer products, such as washing machines, video cameras, and rice cookers, as well as industrial processes, such as cement kilns, underground trains, and robots. Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as "computing with words rather than numbers''; fuzzy control can be described simply as "control with sentences rather than equations''. A fuzzy controller can include empirical rules, and that is especially useful in operator controlled plants [8].

Structure of a fuzzy controller

The fuzzy logic controller generally consists of four steps as given in Figure.2. They are fuzzification, fuzzy rule-base, fuzzy inference engine and defuzzification. The design steps are as follows.

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 [6]. To perform fuzzy computation, the inputs must be converted from numerical or crisp value into fuzzy values and the output should be converted from fuzzy value to crisp value. The fuzzy variables ie. error, change in error and change in duty-cycle are quantized using the following linguistic terms Negative Big (NB),Negative Medium (NM), Negative

Small (NS), Zero (Z),Positive Small (PS), Positive Medium (PM), and Positive Big (PB).

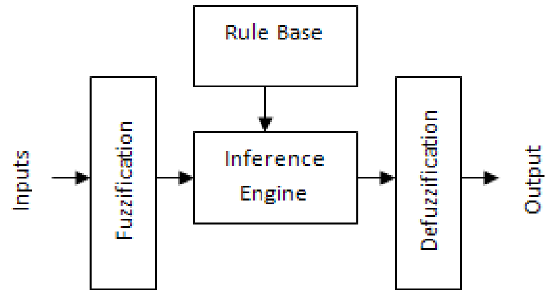

Figure 2. Structure of fuzzy logic controller

Fuzzy membership functions are used as tools to convert crisp values to linguistic terms. A fuzzy variable can contain several fuzzy subsets within, depending on how many linguistic terms are used. Each fuzzy subset represents one linguistic term. In order to define fuzzy membership function, the designer can choose many different shapes such as triangle, a trapezoid, a Bell shaped based on their preference and experience [1]. Figure. 3 illustrates the membership function of fuzzy logic controller that used the "fuzzification" of two input values ie error (E) and change in error(CE) and "defuzzification" output ie change in duty cycle.

Rule Base

Instead of using mathematical formula, FLC uses fuzzy rules to make a decision and generate the control action. The rules are in the form of IF-THEN statements. A sliding mode rule base used in FLC. The fuzzy inference operation is implemented by using the 49 rules. The min-max compositional rule of inference and the center-of-gravity method have been used in defuzzifier process. In many systems, the rules are presented to the end-user in a format as shown below

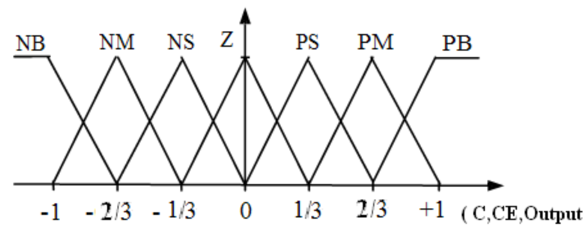

Figure3.Membership functions of fuzzy logic Controller

1. If error (P_1) is NB and change in error (P_2) is NB then output is PB
2. If error (P_1) is NB and change in error (P_2) is NM then output is PB
3. If error (P_1) is NB and change in error (P_2) is NS then output is PM

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-linearity's existing to the systems.

V. Experimental set-up

The block diagram of the experimental set-up is shown is Fig.4. The experimental set-up consists of five elements. They are Voltage source inverter, BLDC motor, back emf detection circuit ,speed measuring circuit, and microcontroller.

The BLDC motor is an electronically commutated motor. The built-in hall sensors generate three signals according to the rotor position. But in this paper sensorless speed detection method is utilized ie. Back emf detection technique. The back-EMF sensing technique is based on the fact that only two phases of a Brushless DC motor are energized at a time .The third phase is a non-fed phase that can be used to sense the back-EMF voltage. Being other things constant this back emf is directly proportional to the speed of motor. This signals energize the appropriate windings by switching the appropriate switches in the power inverter.

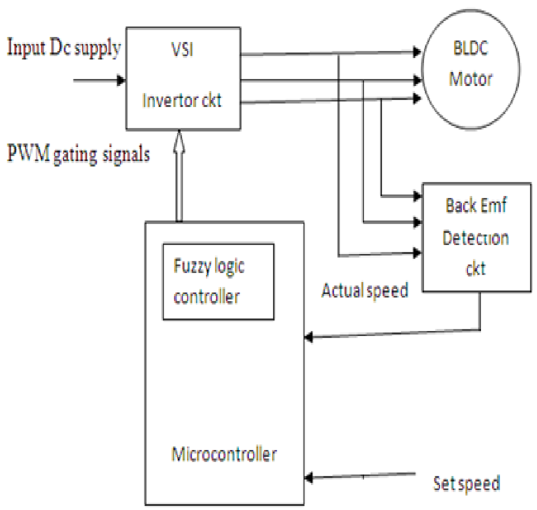

Figure 4. Block diagram of the experimental set-up

The system uses PIC16F877 for the system microcontroller, and double closed loops control system of sensorless brushless DC motor is established. In the experimental study, sensorless control of the BLDC motor was implemented successfully using conventional fuzzy controller, fuzzy controller was implemented in high level C programming language; 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.

A method used for detecting the BEMF zero crossover is using the A/D converter channels, The PIC microcontrollers have a high-speed A/D converter that can be used for this purpose. Using a potential divider, the BEMF signal is brought down to a level that the microcontroller can measure. This signal is sampled by the A/D, and is continuously compared with a digital value corresponding to the zero point. When the two values match, the commutation sequence is updated. When there is a speed variation, the winding characteristics may fluctuate, resulting in variation of BEMF. In such situations, the microcontroller has complete control over the determination of the zero crossover point. Also, digital filters can be implemented to filter out the high-frequency switching noise components from the BEMF signal.

VI. Experiment Waveforms

The observed waveforms when motor is running at rated speed are as shown. Figure 5 shows the phase current waveforms i_a ,i_b ,i_c respectively.

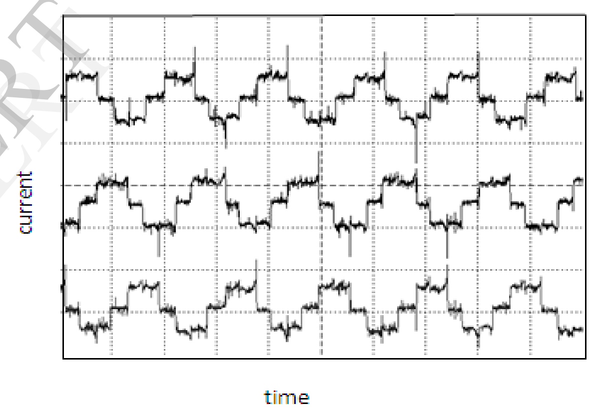

Figure 5. Phase currents

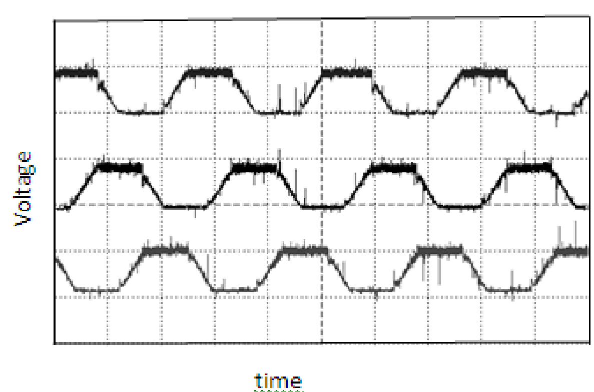

Figure 6. Phase Voltages

Figure 6 shows the phase voltages of phases a,b,c. The back EMF waveform of three Phase PMBLDC is depicted in Fig 7. The back emf waveforms are trapezoidal as shown.

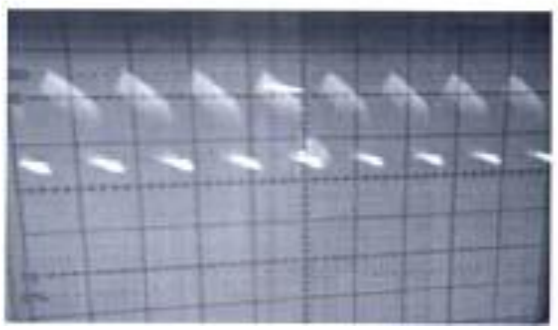

Figure 7. Back Emf waveform

It is found that the speed of the motor varies smoothly as the set speed is varied and the motor produces required torque to drive the load. It is found that there is no overshoot and system respond is faster when motor is subjected to step change in load. The speed of the motor reached the desired value or steady state at approximately 5ms. The performance of the system with fuzzy logic controller is found better as compared with conventional PI controller. The response of the system with PI controller is found to have large settling time with overshoot. Moreover, its response is poor when the system dynamics changes, particularly due to change in load.

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