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Design and Development of Digital PID Controller for Brushless DC Motor Drive System

Mr. Namdev K. Barhate [1], Prof. K. S. Ingle[2]

***Abstract*—**

In this paper, Digital PID developed using 8-bit AVR Microcontrollers (ATmega328). The main purpose of AVR microcontroller to reduce the size of control system and simplify the system implementation, also to covert analog input into the digital in the form of (PWM) for controlling speed of BLDC. Digital PID is implemented in the Form of hardware and software for experimental result verification. Both the outer velocity control loop and inner current control loop uses PID controller that has been implemented by programming in AVR Microcontrollers (ATmega328). According to the analog input and hall sensor feedback signal and control algorithm, the PWM pulses for each phase generated by the AVR Microcontrollers (ATmega328) is given input to the MOSFET driver. The output of the MOSFET driver is six independent PWM pulses that has to be given to the corresponding gate of the six MOSFET power switches used in the three-phase bridge inverter whose output is given to the stator of the BLDC motor.

***Index Terms*— Brushless DC motor, Commutation using Hall Sensor, AVR Microcontrollers (ATmega328) and MOSFET driver.**

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I. Introduction

The Brushless DC (BLDC) motor becomes popular in various application because easy control through the Digital Controller and of its good controllability over a widely speed. The brushless DC motor has high efficiency, high power factors, high torque. Due to this features There is lot off Scope in researches on BLDC motors. So, it is very significant to research such a control system with quick response, powerful regulation capability and good reliability. Due to the functional simplicity and reliability of Brushless DC motors it's easy to develop PID controller for it, the PID controller is one of the most popular controllers in the industry. It provides robust and reliable performance for most systems. The PID parameters are determined or tuned to ensure a satisfactory performance. The conventional design in the time domain as a digital controller is normally performed using the PWM method; this method, certainly improves the characteristics of the system, but doesn't give the designer any control about the final specifications of the system. The conventional design is also performed by the direct conversion of the analog PID (previously designed in the continuous time domain) to its digital counterpart [2] .The Digital Controller main procedure is the sampling time of the D/A and A/D converters is used. In this method The design of digital PID controllers in the frequency domain is never considered. Actually it is part of the digital system or PWM signal which are produce by the Microcontroller.

II. II SYSTEM DEVELOPMENT

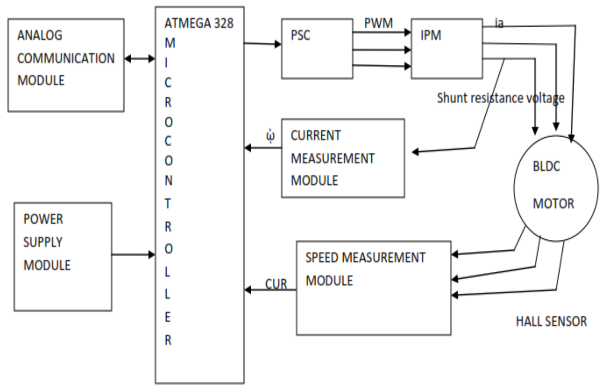

Fig.1. System Block Diagram

This is the main modules of the system. The System block diagram consist current measurement module, speed measurement module, integrate power module, communication module and controlling all of these parameters by using AVR Microcontroller module etc[1]. The main purpose of this system is to implement digital control algorithm in this system and simplifies the hardware circuit design and make system more flexible to modify with software. In order to meet the purpose of reducing system's size and simplify the system's circuit, the system is implemented use the IPM as the system's inverter instead of traditional separate component and mixed the control circuit and power drive circuit in one PCB without use the optical isolator.

A. Speed measurement module

The Speed measurement in BLDC control system it very critical problem. The velocity feedback is derived from the hall sensor whose signal can be easily measured using analog comparator which is integrated in microcontroller.

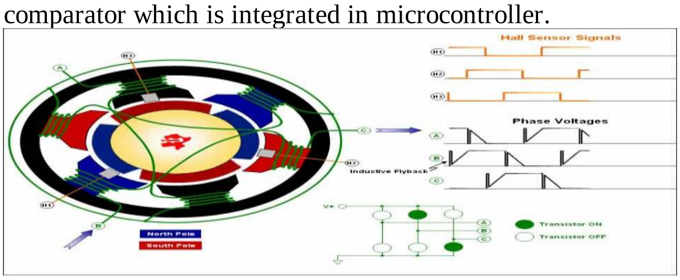

Fig.2. Brushless DC Motor With Hall sensor & Phase Voltage.

When the motor in rotation, the hall sensors which are 60 degree apart installed in the motor generate three square waves which an apart 120 degrees respectively. Analog comparator can trigger the hall sensor voltage level's changes used to estimate the time interval between two commutation phases and send that signal to speed estimator module that calculate the velocity of motor.

B. Current measurement module

The current measurement module is implemented in this system by using a shunt resister and Analog to Digital convertor (ADC). The shunt resistor is used to sense the current. In this system only one current is measured actually all three phase current are same if we get single phase current then all reaming phase current are equal because brushless DC motor generate equal current in all phase. Procedure to calculate current is that The voltage drop across the shunt resister is converted by ADC module, once it has been amplified to address the whole conversion range using amplification. It cannot sample the current at the beginning of the MOSFET conduction because the current is increasing and not stabilize. The best sample time is in the middle of the MOSFET conduct period.

C. Power stage control module

In brushless speed controlling Power Stage consist of The commutation pattern is controlled with a three-phase bridge .The three half bridges have six power switches (MOSFET transistors) which are switched according to the defined commutation pattern.

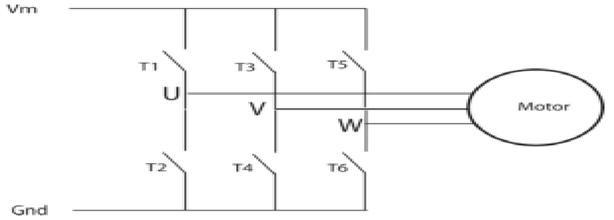

Fig.3. The three half bridges have six power switches.

In BLDC Motor to control the torque and speed of motor, the duty cycle of the PWM is regulated to control the flow of motor current at a constant voltage. This system's PWM wave is generated by the Power Stage Control (PSC) module which can generate six ways PWM wave with adjustable frequency. PSC module which can generate six ways PWM wave with adjustable frequency in a widely range between 32 KHz to 64 MHz and activate the interrupt flag of ADC sample program in the middle time of MOSFET transistor is conveniently to use and have high reliability.

D. IPM module

In Brushless DC motor Speed controlling module there is total six MOSFET are used, during the switching of the MOSFET There is some delay due to this problem in driver system There is over current and overheat. Therefore it is necessary protection circuit of MOSFET. The control system adopts the integrate Power Module (IPM) as the switch inverter instead of the tradition separate component to act a corresponding driver. Intelligent power module used as the main switch inverter device has many advantages: First, a built-in temperature monitor and over-current protection, along with the short-circuit rated MOSFET and integrated under-voltage lockout function, deliver high level of protection and fail-safe operation; Second, it is provided the maximum 600V voltage pressure value and 10A flow current, and easily supplied by using +15V electrical power source; Third, the integration of the bootstrap diodes for the high-side driver section, and the single polarity power supply required to drive the internal circuitry.

E. Communication module

Universal Serial interface is the most common communication interface for microcontroller. This System is implemented the communication interface between the controller of BLDC motor driver and microcontroller module. By this interface, the system's status and configuration can be operated and the system's configurations can be adjusted by variable register or other control system.

III. BRUSHLESS DC MOTOR THEORY OF OPERATION

The three-phase BLDC motor stator consists of three coils arranged in three directions, Ua, Ub, and Uc. A permanent magnet forms the rotor. The rotor in a BLDC motor consists of an even number of permanent magnets. The number of magnetic poles in the rotor also affects the step size and torque ripple of the motor. More poles provide smaller steps and less torque ripple. The permanent magnets go from one to five pairs of poles. In certain cases it can go up to eight pairs of poles. Here the rotor is outlined as a bar magnet with its rotary axis at the intersection of the three axes Ua, Ub, and Uc. Perpendicular to the plane of these axis. The orientation/position of the permanent magnet can be controlled by driving a configuration of currents through the three coils. The bar magnet comes to position when a current is driven from Ua through Ub,Uc and it comes to the following orientation driven when a current is driven from Ub to Uc.[1]

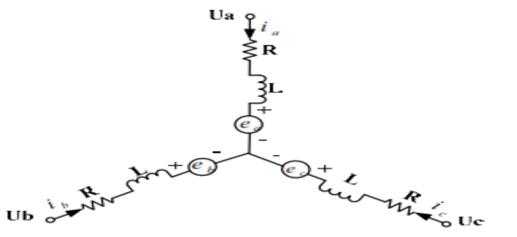

Fig. 4.Equivalent circuit model of BLDC

A brushless DC motor has the physical appearance of a three phase permanent magnet synchronous motor that is supplied from a inverter that convert a voltage to three phase alternating current with frequency corresponding instantaneous to motor. According to the above description the voltage equation for brushless dc motor is.

$$\begin{bmatrix} U_a & 0 & 0 \\ 0 & U_b & 0 \\ 0 & 0 & U_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix}\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

In this equation Where R is the phase resister, L is the phase inductor and the i are the phase current of phase A, B and C, respectively. The ea eb and ec are the back EMFs of the phase A, B and C, respectively.

$$T = \frac{1}{\omega}(i_a e_a + i_b e_b + i_c e_c)$$

The generated torque of the motor is given by Equation .Where is ω the motor's angular velocity. T is the torque export of the motor. Equation clearly shows that by controlling the current between three-phase winding, the torque of the motor can be controlled accordingly.

A. **Digital PID Controller**

The three main parameters involved are Proportional (P), Integral (I) and Derivative (D). The proportional part is responsible for following the desired set-point, while the integral and derivative part account for the accumulation of past errors and the rate of change of error in the process respectively.

$$u(t) = Kp\ e(t) + Ki \int_0^t edt + Kd \frac{de}{dt}$$

Where,
Error, e(t) =Set point- Plant output
Kp=proportional gain
Ki=integral gain
Kd = derivative gain

In This paper the digital PID is develop using PWM method through this method speed of the brushless DC motor is controlled through using AVR atmega328 microcontroller.PID control algorithm is implemented in software.AVR atmega328 is based on Arduino open source IDE(integrated Development Environment). In This paper the PID control system are develop in software and also this code execute in Proteus simulation software.

VI. EXPERIMENT RESULETS

A. SOFTWARE IMPLEMENTATION

The Digital PID controller algorithm in the system, the floating Point data operation must be executed in the AVR Atmega328 microcontroller. It is simply to get the motor's position by detected the output of hall sensors when the motor is in rotation. The changes of the hall sensors' output are activated the commutation interrupt service runtime which controls the on-off modes of inverter components with a switch table.

Table Switching for Phase Current.

Rotor Position (Degree)	Switch Closed		Phase Currents		
			I_a	I_b	I_c
0-60	Q_1	Q_5	+	-	Off
60-120	Q_1	Q_6	+	Off	-
120-180	Q_2	Q_6	Off	+	-
180-240	Q_2	Q_4	-	+	Off
240-300	Q_3	Q_4	-	Off	+
300-360	Q_3	Q_5	Off	-	+

After calculating the velocity of motor by the velocity measurement module, we acquire the reference current from the speed controller. Every sampling time, the current measurement module requires the input voltage of the shunt resister and output the phase current of this time after the over current protect detection executed. The phase current and reference current, which is calculated through the speed controller use recent velocity, is sent to the current PID controller before the current loop launched. In the current loop, a new duty cycle of the PWM wave is acquired by passing through a current PID controller. In order to protect the integral of the PWM wave, the PSC registers, which storage the parameters of the PWM wave, can only be altering at the end of PWM cycle.

Experiment results.

The method for energizing the motor windings in the sensor method described in this paper is the six-step commutation. Each step, or sector, is equivalent to 60 electrical degrees. Six sectors make up 360°, or one electrical revolution. The winding of the brushless dc motor flows the current in each of the six sectors. The graph following experiment result shows the stator current of brushless dc motor. The voltage applied at each lead of the motor during the six sectors. Sequencing through these six sectors moves the motor one electrical revolution. For every sector, two windings are energized and the third winding is floating (not energized). Connecting the coils to the power and neutral bus induces the current flow.

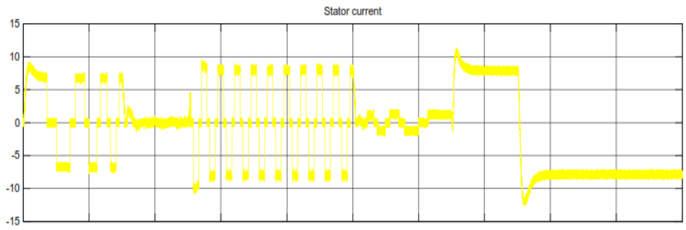

Fig.5. Stator Current

A. *Rotor Speed of brushless DC Motor*

The following figure shows that the rotor speed of the brushless DC motor at initial stage the speed of the rotor is very low. When the MOSFET is fully conducting stage the speed of the rotor is increasing and maximum speed is calculated is that
300rpm/s.

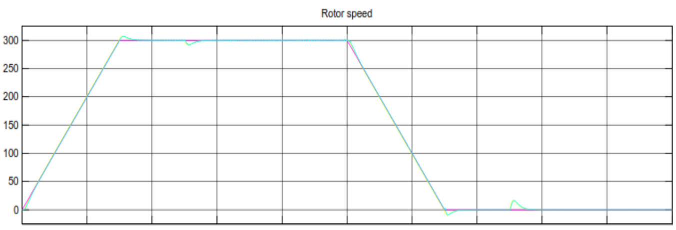

Fig.6. Rotor Speed of the BLDC motor

a. **ELECTROMAGNETIC TORQUE.**

The strength of the magnetic field determines the force and speed of the motor. By varying the current flow through the coils, the speed and torque of the motor can be adjusted. The most common way to control the current flow is to control the average current flow through the coils. PWM (pulse width modulation) is used to adjust the average voltage and, thereby, the average current, inducing the speed.

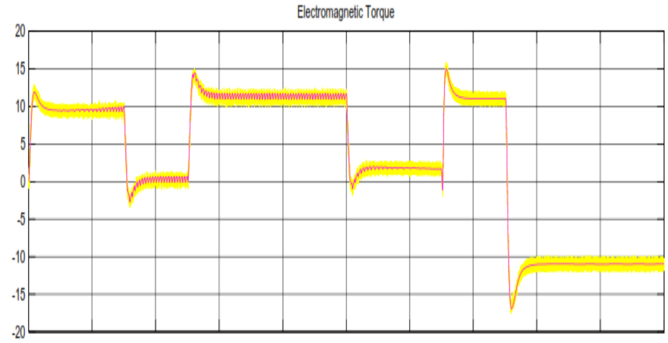

Fig.7. Electromagnetic Torque of BLDC motor.

B. Power Stage

The power stage module shows that the controlling voltage of the each steps in the three phase bridge DC voltage. The three half bridges have six power switches MOSFET transistors which are switched according to the defined commutation pattern and provide the Different voltages to the Each steps.

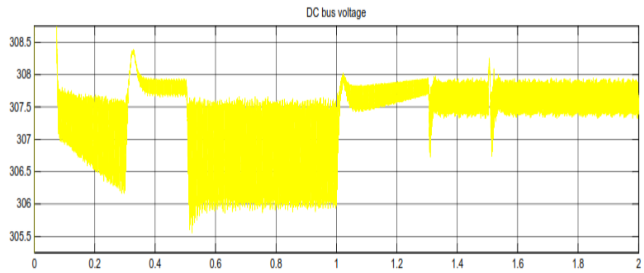

Fig.8.DC Bus Voltage of BLDC Motor.

VII. CONNCLUSION

In this Paper, a High Performance Digital PID controller are implemented using AVR microcontroller. A real time Digital PID controller has been developed and closed loop approach is adapted to control the speed of the BLDC motor using embedded system. Character device driver program is developed for Brushless DC motor control strategy. This design is implemented on AVR Microcontrollers (ATmega328). Proportional, integral and derivative parameters are obtained for various load conditions to set the speed. In order to reach the high performance goals, the speed and current Measurement systems are implemented through AVR Microcontrollers (ATmega328).The Digital PID controller System work according to the PID control Algorithm. This PID system is also developed in Simulation Software Proteus and Check all the waveform as per mention in and shown in the experimental result.

The controller of the BLDC motor Drive Systems is applied in various products due to small size and easy controlling technology through Microcontroller without human interface. In this controller due to fully digitized can be Current upto 5Amp & the Motor speed up to 15000 rpm and makes the vibration Bar fully functional digital electromechanically.

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Ali Azidehae, Mohammad Hoshyari2, Maziar Ahmad Sharbafi3
Mechatronics Research Laboratory, ECE Department, Qazvin Islamic Azad University,Qazvin, Iran
'a.azidehak@qiau.ac.ir'mohammad.hoshyari@qiau.ac.ir
3sharbafi@ut.ac.ir

First Author: [1]M. E. Student Electronics and Communication Department, Deogiri Institute of Engineering and Management, Maharashtra, India.
Second Author: 2Asst. Professor, Electronics and Communication Department, Deogiri Institute of Engineering and Management Maharashtra India.