A Performance Analysis of Brushless DC Motor by using PID Controller

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Abstract: *Increase in need of industry for high productivity is placing new demands on mechanisms connected with electrical motors. This leads different problems in operation due to fast dynamics and instability. The stability of the system is essential to work at desired set targets. The non- linear effects caused by a motor frequently reduce stability, which reduces the controller's ability to maintain speed or position at set points. Hence number of the industrial process applications requires speed & position control of DC motor. A brushless DC motor described as magnet being the rotor and its stationary windings forming the stator. This design provides many advantages over the brush DC motor. Brushless DC (BLDC) motor drives are becoming widely used in various consumer and industrial systems, such as servo motor drives, home appliances, computer peripherals, and automotive applications in recent years because of their high efficiency, silent operation, compact form, reliability, and low maintenance.*

Keywords: BLDC, PID, Speed Control, Stability, PMBLDC

1. Introduction

The economic constraints and new standards legislated by governments placed increasingly higher requirements on electrical systems. New generations of equipment must have higher performance parameters such as better efficiency and reduced electromagnetic interference. System flexibility must be high to facilitate market modifications and to reduce development time. All these improvements must be achieved while, at the same time, decreasing system cost. Brushless motor technology makes it possible to achieve these specifications. Such motors have combine high reliability with high efficiency, and for a lower cost in comparison with brush motors. The Brushless DC Motor (BLDC) motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal back Electro Motive Force (EMF) waveform shape.

A system based on the Direct Current (DC) motor provides a good, simple and efficient solution to satisfy the requirements of a variable speed drive. Although DC motors possess good control characteristics and ruggedness, their performance and applications in wider areas is limited due to sparking and commutation problems. Induction motor do not possess the above mentioned problems, they have their own limitations such as low power factor and non-linear speed torque characteristics. With the advancement of technology and development of modern control techniques, the Permanent Magnet Brushless DC (PMBLDC) motor is able to overcome the limitations mentioned above and satisfy the requirements of a variable speed drive.
Electric motors influence almost every aspect of modern living. Refrigerators, vacuum cleaners, air conditioners, fans, computer hard drives, automatic car windows, and multitudes of other appliances and devices, use electric motors to convert electrical energy into useful mechanical energy. In addition to the common place appliances that we use every day, electric motors are also responsible for a very large portion of industrial processes.

1.1 Permanent Magnet Brushless DC Motor

Conventional DC motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance free motors were realized. These motors are now known as brushless DC motors. The construction of modern brushless motors is very similar to the AC motor, known as the permanent magnet synchronous motor. The stator windings are similar to those in a poly-phase ac motor, and the rotor is composed of one or more permanent magnets. Brushless DC motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position (or magnetic poles) to produce signals to control the electronic switches as shown in Fig.1.1The most common position/pole sensor is the Hall element, but some motors use optical sensors.
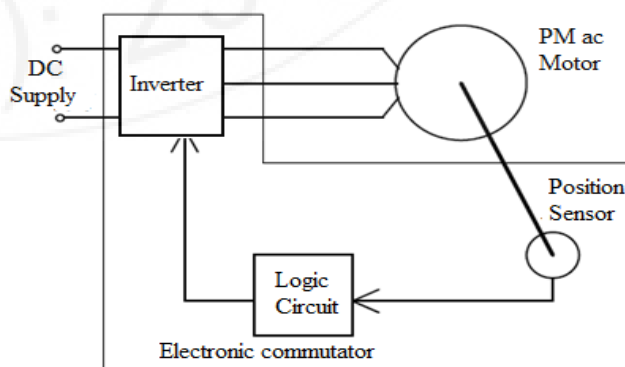

Figure 1: Permanent Magnet Brushless DC motor

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The brushless DC motor is essentially configured as a permanent magnet rotating part, a set of current carrying conductors. In this respect, it is equivalent to an inverted DC commutator motor, in that the magnet rotates while the conductors remain stationary. In both cases, the current must reverse polarity every time a magnet pole passes by, in order that the torque is unidirectional. In the DC commutator motor, the commutator and brushes perform the polarity reversal. Brushless DC motors usually come in fixed voltages, such as 5V, 6V, 12V, 24V,48Vetc, with one of the most common ones in use being the 12V type. When the rated voltage is applied to the motor it will rotate with maximum speed, but by changing this applied voltage the motor speed can be controlled. Naturally, when the voltage is high, the speed is higher and vice versa.

The brushless DC motors are generally controlled using a three-phase inverter, requiring a rotor position sensor for starting and for providing the proper commutation sequence to control the inverter. These position sensors can be Hall sensors, resolvers, or absolute position sensors. Those sensors will increase the cost and the size of the motor, and a special mechanical arrangement needs to be made for mounting the sensors. These sensors, particularly Hall sensors, are temperature sensitive, limiting the operation of the motor to below about 75 degree Celsius
Brushless DC motors usually consist of three main parts:
1. Stator
2. Rotor
3. Hall Sensors.

2. Different methods of controlling BLDC

The control schemes of BLDC motor are mainly classified in following two ways
• Sensor based control
• Sensor less control

In sensor based control, a Hall sensor is used which detects the position of the rotor magnet and gives a signal which is used to give appropriate excitation to the stator winding. Hall sensor Works on Hall Effect which states that when a current carrying conductor is placed in magnetic field, it exerts a transverse force on the conductor. The sensor based control scheme is shown in Figure.2 Micro controller based control using Hall sensors gives effective control on BLDC motors.
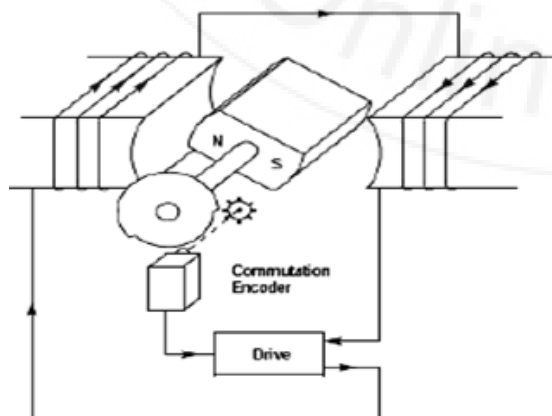
Figure 2: Sensor based control scheme

The sensor less drive principle is based on the detection of the rotor position using various techniques one of which is the EMF detection. There are various methods for position and velocity estimation based on the induced Back EMF detection. Various micro controllers and DSP controllers are available for sensor less control.

2.1 BLDC Motor with Hall Sensors

Brushless DC motors works similar to the conventional DC motor with the mechanical Commutation replaced by an electronically controlled commutation system. These motors have the rotating permanent magnets and stationary armature. The BLDC motor that are utilized in the proposed control design is star connected BLDC motor. The power distribution is achieved by the intelligent electronic controller. The electronic controller requires rotor position information for proper commutation of currents in the respective stator windings. The rotor position can be sensed using Hall Effect sensors embedded in the stator and thus stator windings are energized accordingly. BLDC motor drive control can be done in sensor or sensor less mode. Though the sensor less control offers the advantage of reduced cost, the sensor less control offers low performance at transients or low speed range with increase in complexity of the control Electronics and algorithms make the use of Hall sensors more efficient. It is control of BLDC motors using PIC16F882 generates a PWM signal that controls the inverter topology there by controlling the drive. High flexibility of control can be obtained by implementing efficient control algorithm in the controller. The rotor position is sensed which enables commutation logic for the three phase inverter circuits that contain MOSFET switches.
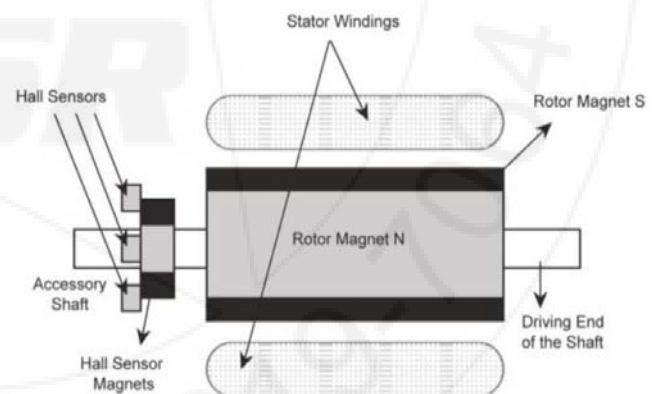
Figure.3 BLDC Motor Transverse Section with Hall Sensors

Table 4.1: Clockwise Hall Sensor Signals and Drive Signals

H_a	H_b	H_c	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6
0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	1	0
0	1	0	0	1	1	0	0	0
0	1	1	0	1	0	0	1	0
1	0	0	1	0	0	0	0	1
1	0	1	1	0	0	1	0	0
1	1	0	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0

Where Ha, Hb, Hc represents the Hall sensor signals. Q1 – Q6 represents the MOSFET's in the Switching circuit. The Hall sensors should be kept 120̊ apart to obtain symmetrical operation of motor phases. With the rotor position sensed, three bit codes of Hall sensed signal is obtained as shown in Table 1. Each code value specifies the rotor position and the corresponding stator windings that are to be energized. Ha, Hb, Hc signals are high or low depending whether the sensor is near the N or S pole of the rotor magnets. Depending on these signals the switches Q1 – Q6 are ON/OFF. From Table 1 it is seen that when Hc is high, the switch Q4-Q5 conducts energizing the corresponding stator windings. Digital PWM signals are generated and speed regulation is achieved by using high and low level duty cycles.

2.2 Proposed Control Scheme

The proposed control for BLDC motor control using PIC microcontrollers of MICROCHIP with device name PIC16F882 as PID controller is shown in the figure 4.
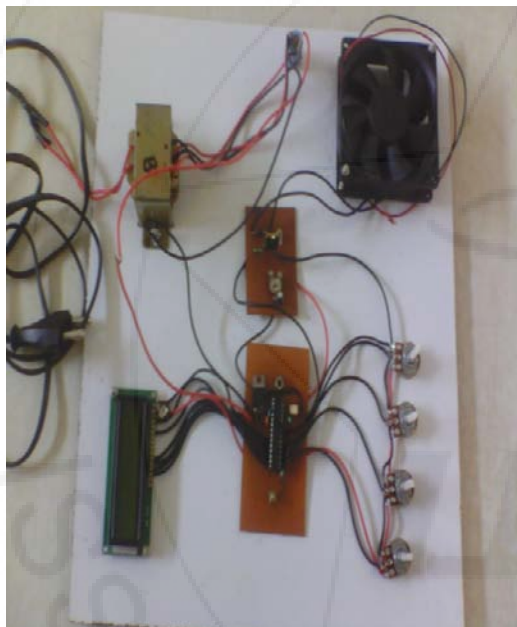

Figure 4: Proposed Control Scheme prototype model

The base drive to the MOSFETS in the Inverter circuit is given by the PIC16F882 micro-controller. The Hall signals from the motor are fed as inputs to the PIC16F series device and based on the Hall position and the direction of rotation of the motor specified by the manufacturer the corresponding gate drive is made active by the microcontroller and fed to the stator of the BLDC motor. The commutation sequence for rotating the motor in clock wise direction, when viewed from the non-driving end is given in the Table 4.3 It also shows the sequence for rotating the motor in clockwise direction when viewed from non-driving end.

PID Controller

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism widely used in industrial control systems. The PID is the most commonly used feedback controller. A PID controller calculates an error value as the difference between a measured process variable and a desired set point.

The controller attempts to minimize the error by adjusting the process control inputs. The PID controller calculation involves three separate constant parameter, and is accordingly sometimes called three-term control namely the proportional, the integral and derivative values denoted as P, I, and D respectively. These values can be interpreted in terms of time. P depends on the present error, I on the accumulation of past errors and D is a prediction of future errors based on current rate of change. The weighted sum of these three actions is used to adjust the process. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability. PID control is a very useful method used in feed-back control systems. The error generated after the comparison between the measured signal and the target signal is proportionally multiplied (proportional), integrated (integral) and differentiated (derivative) and the outputs of the three operators are linearly summed to generate the signal applied to the actuator.
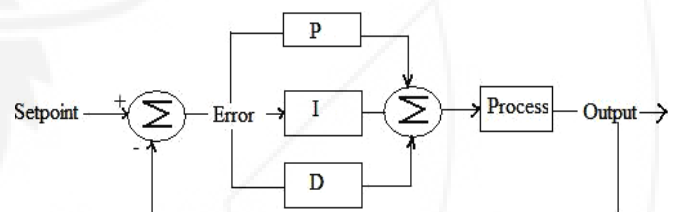

Figure 5: Basic block diagram of PID controller

Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called as PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

3. Conclusion

Electric machines are used to generate electrical power in power plants and provide mechanical work in industries. The DC machine is considered to be a basic electric machine. The Permanent Magnet Brushless DC (PMBLDC) motors are one of the electrical drives that are rapidly gaining popularity, due to their high efficiency, good dynamic response and low maintenance. The brushless DC (BLDC) motors and drives have grown significantly in recent years in the appliance industry and the automotive industry. BLDC drives are very preferable for compact, low cost, low maintenance and high reliability system.

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Table 2: Observation table

SR. No.	P	I	D	%SET Speed	Actual Time
1	0	50	100	80%	20 sec
2	100	50	100	80%	15 sec
3	200	50	100	80%	10 sec
4	250	50	100	80%	05 sec
5	100	0	100	80%	05 sec
6	100	100	100	80%	10 sec
7	100	200	100	80%	15 sec
8	100	250	100	80%	20 sec
9	100	100	0	80%	20 sec
10	100	100	100	80%	15 sec
11	100	100	200	80%	10 sec
12	100	100	250	80%	05 sec

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