A Project Report on

"TUNING OF PID CONTROLLER FOR BLDC MOTOR"

A Project Report is submitted in partial fulfillment of the requirement

For the Degree in **Bachelor of Engineering**

In

Electrical Engineering

By

VIDAN GADIVADAR (18)

AMOL GHEVADEKAR (22)

VAIBHAV NARKHEDE (55)

SRIKANTH VEMULA (72)

Under the Guidance of

Prof. A. A. KALE

ACPCE

Where Knowledge is Second Nature

University of Mumbai

Department of Electrical Engineering

A C Patil College of Engineering, Kharghar

Navi Mumbai- 410210

2018-19

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M2. To improve technical skills by industry institute interaction

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Program Outcome Code	Program Outcomes
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Year: 2018-2019

BE Project- II (EEC805) **Semester VIII**

Course Objective of Project – II

EEC805.1: Students will be able to design the project of predefined problem.

EEC805.2: Students will be able to implement the project using appropriate tools.

EEC805.3: Students will be able to verify functionary & test the performance of designed project.

CO	Course Outcome: At the end of the course student will be able to:	Cognitive level (Remember, Understand, Apply, Create, Analyze, Evaluate)
EEC805.1	Design the project of predefined problem	Apply
EEC805.2	Implement the project using appropriate tools	Analysis
EEC805.3	Verify functionary & test the performance of designed project	Evaluate

Project Guide

Prof. A. A. Kale

Head of Department

Dr. S. R. Deore

Jawahar education society
A. C. Patil College of Engineering, Kharghar
Navi Mumbai.

CERTIFICATE

This is to certify that the project synopsis title " **TUNING OF PID CONTROLLER FOR BLDC MOTOR"** is submitted in fulfillment of the project work for the Bachelor's degree in Electrical Engineering from University of Mumbai in academic year 2018-19.

By:

1. Vidan Gadivadar -- 18
2. Amol Ghevadekar -- 22
3. Vaibhav Narkhede --55
4. Srikanth Vemula --72

Mr. Atul Kale
(Project Guide)

(Internal Examiner)

Dr.S.R.Deore
(HOD of Electrical Department)

Dr.D.G.Borse
(Principal)

External Examiner

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Firstly, we would like to dedicate this dissertation to our caring, loving, and supportive family. Without their parental duties, the dissertation was simply invaluable. We would also like to thank our classmates and the Electrical Department staff for helping us throughout the project of final year. We sincerely hope this project is a source of help for people and students working on such projects in the future.

Table of contents

Abstract

Brushless DC motor (BLDC) are widely used for many industrial applications because of their high efficiency, high torque and low volume. The speed control of the Permanent Magnet Brush Less Direct Current (PMBLDC) Motor is of high importance since it indirectly controls the mechanical output required and hence the efficiency. The control on this parameter has been demonstrated in various research literatures using various controllers like PWM, PI, Fuzzy and Neural Networks (NN) etc. This project focuses on speed control of BLDC motor using soft computing technique. The problems related to control systems are undesirable overshoot, longer settling times and vibrations while going from one state to another. To overcome the maximum overshoot and longer settling times, PID and Fuzzy control techniques were used in the closed loop controller architecture.

In this project, we are focusing on speed control of BLDC motor using Fuzzy logic. And get constant speed characteristics of BLDC motor.

The prototype model of BLDC motor is presented and the speed response of BLDC motor is observed by LCD display.

List of Figures

List of Symbol and Abbreviations

B - Friction Coefficient

BLDC - Brushless Direct Current

DC - Direct Current

DSP - Digital Signal Processing

ea, eb, ec- The Phase Back-EMF

eab, ebc, eca- Line-to-line Back-EMF

eia, eib, eic- Error Phase Current

EMF - Electromagnetic Field

Fabc(θr) - Function of rotor position

ia, ib, ic- Stator Phase Current

iaref, ibref, icref - Reference Phase Current

Imax- Reference Current

J - Moment of Inertia

jth- Numbers of Neuron

Ke- Back-EMF Constant

Kt- Torque Constant

L - Self-inductance

M - Mutual Inductance

N - North

PID - Proportional Integral Derivative

R - Phase Resistance

RPM - Round per Minute

S – South

N - North

Ta, Tb, Tc- Phase Electromagnetic Torque

Te- Electromagnetic Torque

TL- Load Torque

TP - Peak Torque

TR - Rated Torque

Va, Vb, Vc- Phase Voltage

Vdc- DC Supply Voltage

Vao, Vbo, Vco- Reference to Midpoint of DC Supply Voltage

ωm- Rotor Speed in mechanical

ωr- Rotor Speed in electrical

Y - Star connection

Δ - Delta connection

θr- Rotor Position

CHAPTER 1

INTRODUCTION

The Invention and evolution of First electric motor took place in between year 1800 to 1854.The first electric motor was a DC motor. In the year of 1887 Nikola Tesla invented the first Induction motor. At present there are different type of motors such as Induction motor, Synchronous motor, DC motor, Switched reluctance motor, Permanent Magnet motor and Brushless DC motor. Right from the evolution of electric motors, there has been a gradual up gradation of technology in this sector which has continued to go on to this day. Nowadays, trend is shifting towards the reliable, adequate and silent operation of electric motors as per need of application.

Brushless DC motor is perfect to satisfy all these conditions as compared to other types of motor. The use of brushless dc motor in the field of automation, defense industry and electric vehicles has been increased widely in past few years due to its advantage. It is used for applications such as Linear motor, Servo motor, Extruder drive motors, as an actuator for mobile robots and feeder drive for CNC machine. This is because of it tight speed regulation. Applications requiring especially reliable speed regulation benefit from using brushless DC motors. You get precise control because the brushless DC motor gives the controller feedback from the motor's commutation sensors. These sensors (usually the Hall Effect type) give a direct measure of rotor speed, rather than relying on indirect methods. Brushless DC motor has advantages like quieter operation, longer life, low maintenance, high torque density and high speed operations.

The heat-generating part of a brush-type DC motor is the armature winding, in the center of the motor. The heat-generating part of a brushless DC motor is the stator winding, which is close to the outside surface of the motor. Since it's easier for heat to dissipate from the outside of the motor than from the inside, the thermal resistance of the brushless DC motor is lower. Thus, you can produce more continuous power before exceeding the temperature limit than you could with a brush-type. This means a smaller brushless DC motor can provide the same continuous power output as a larger brush-type DC motor. Brushless DC motors are receiving wide attention in industry as well as defense applications because of their increasing torque densities, higher efficiencies and smaller size. For driving BLDC motor separate control circuitry is required. As BLDC motor not having its own commutator therefore stator coil supplied through separate commutation circuit containing three phase inverter made up of switch. The switching of these switches is controlled by using microcontroller. It provides PWM to these switches of pre decided frequencies as per speed requirement of application. In this paper we are designing the control circuitry which contains three phase inverter, microcontroller, PID feedback system and PLC.

Controller is one of the critical parts of any brushless DC motor for its safe and continued operation. Latest optimal control approaches based on H∞-norms lead to controllers of complicated structure and higher orders. These controller orders typically depend on the order of both nominal plant and weighing functions. But disadvantage involved is the difficulty in optimally tuning these controller parameters for best possible performance and robustness. In this paper, an approach to optimally tune the brushless DC motor speed controller by PID algorithm to make system precise and reliable has been presented.

1.1 Project Overview

Nowadays, Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. As the name implies, 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.

BLDC motors have many advantages over brushed DC motors and induction motors which is better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation and higher speed ranges. In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. The applications BLDC motor are widely used in many industries as growth as the rapidly developments in power electronic technology, manufacturing technology for high performance magnetic materials and modern control theory for motor drives. Modern intelligent motion applications demand accurate speed and position control due to the favorable electrical and mechanical properties of BLDC motor. Many machine and control method have been developed to improve the performance of BLDC motor drives. Based on previous studies in linear system model, controller parameters of proportional integral derivative (PID) controller are easy to determine and resulting good control performances. However, for nonlinear system model application such as BLDC motor drive, control performance becomes poor and difficult to determine the controller parameters. So that, PID Control will be used in order to improve the control performance.

1.2 Problem Statements

Direct Current (DC) motor was chosen for the speed control applications due to the control simplicity on the intrinsic decoupling between the flux and the torque. As the name implies, there are physical limitations to speed and life time because of brush wear. However, BLDC have been produced to overcome this problem. Since there are no carbon brushes to wear out, a BLDC motor can provide significantly greater life being now only limited by bearing wear. This advantage make BLDC motor becomes popular in the industry but this motor is a non-linear system hence, need more complex speed controller than the DC motor.

By this reason, the Proportional-Integral-Differential (PID) controller will be developed to improve the performance of variable speed for BLDC motor since the system of this motor is non-linear system.

1.3 Project Objectives

The objectives of this project are:

- To monitor the speed variation of BLDC motor.
- To develop model for BLDC motor speed control using Fuzzy logic.
- To improve speed performances of BLDC motor such as reduces

Overshoot; reduce rise time and steady state error by using Proportional-Integral-Differential (PID) controller.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to design and construct Proportional-Integral-Differential (PID) controller for BLDC motor speed, research in PID need to be performed. This chapter would discuss the previous study of PID that has been developing through the year.

2.2 Previous Case Study

Many approaches for designing controller based on the brushless DC motor has been proposed on the previous papers. The PID speed controller was chosen by the designer due to their property. PID provides a useful methodology to create a practical solution for controlling complex system. Siong T. C. et al. (2011) are proposed PID controller for BLDC permanent magnet drives. The results shows that the PID controller system provided a good dynamic performances in both simulation and experimental. A novel digital control technique for brushless DC motor drives is to introduce a novel concept for digital control of trapezoidal BLDC motor. Rodriguez et al. (2007) found that the proposed digital controller is well suited for applications where speed ripple is not of significant importance.

This rapid control prototyping approach to PID control of BLDC motor paper is study by Tuncay R. N. et al. In this paper, PID controller is successful controlling the motor and the model based programming of DSPs. PID logic controller is founded more robust and fast than other conventional control techniques. It is also very simple and versatile. This research has proposed a speed controller with adaptive PID tuning method for the BLDC motor drives by Kwon C. J. et al. (2003). The simulation results have confirmed the good speed response and the efficiency of the proposed adaptive PID logic scheme for changing motor parameter and load torque. In this paper, a speed control for the BLDC motor based on a combination between sliding mode control and PID logic is presented by Rusu C. The results of simulation and experiment show that the performance of the system drive has some advantages than using a pure siding mode control. The control precision of the system by using PID sliding mode control is improved. Cunkas M. et al. (2010) proposed realization of PID controlled BLDC motor drives using matlab/simulink. In this study, it is seen that the desired real speed and torque values could be reached in a short time by PID controller. The results show that

MATLAB paired with simulink is a good simulation tool for modeling and analyze PID controlled brushless DC motor drives. In addition, Parhizkar N. et al. (2011) have presented direct torque control of BLDC motor drives with reduced starting current using PID controller. Direct torque control offers some advantages such as simple algorithm, simplicity to implement, faster torque response, reduced torque ripple and less sensitivity to parameters variations. PID controller is used in order to eliminate overshoot exists in speed and torque responses. In addition by using PID controller, starting current reduced due to reliability of this controller. Brushless DC Motor Speed Control System Based on PID Neural Network Control has been proposed by LvY.etal. (2009).This paper presented PID –neural network controller, was successfully implemented herein in this study to achieve the control of the speed of the BLDCM. The simulation results show that the controller of the proposed method has a good adaptability and strong robustness when the system is disturbed, which is better than traditional controls.

Oyedepo J. A. et al. (2011) have proposed Implementation of a PID speed controller for a permanent magnet BLDC motor drive system. In this paper, the characteristics of permanent brushless DC motor, its steady state operation and its various torque-speeds/torque-current characteristics are studied. The speed of a BLDC Motor has been successfully controlled by using PID controller technique. A comprehensive analysis of BLDC drive system has been performed by using PID controller. Chen W. et al. (2006) have presented sensor less control of BLDC motor based on PID. The result shows that PID controller can reduce the torque ripple. There is also has no neutral voltage, phase shifted or silent phase are required in this method which ensure its accuracy and stability. Based on the previous case study, the researchers make a great effort to propose the good controller to control the speed of BLDC motor. Although the method is differ from each other, it is still can be conclude that PID controller is the better controller compared to other conventional controller. Therefore, in this paper will use the PID control as the controller of BLDC motor speed.

2.3 Brushless Direct Current Motor

Fig2.1 BLDC Motor(A2212/5T)

The Brushless Direct Current (BLDC) motor is the ideal choice for applications that require high reliability, high efficiency, and high power-to-volume ratio. Generally speaking, a BLDC motor is considered to be a high performance motor that is capable of providing large amounts of torque over a vast speed range. BLDC motors are a derivative of the most commonly used DC motor, the brushed DC motor, and they share the same torque and speed performance curve characteristics. The major difference between the two is the use of brushes. BLDC motors do not have brushes and must be electronically commutated. Commutation is the act of changing the motor phase currents at the appropriate times to produce rotational torque. In a brush DC motor, the motor assembly contains a physical commutator which is moved by means of actual brushes in order to move the rotor. With a BLDC motor, electrical current powers a permanent magnet that causes the motor to move, so no physical commutator is necessary. A BLDC motor is highly reliable since it does not have any brushes to wear out and replace.

2.3.1 Construction and Operating Principle

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and rotor rotate at the same frequency. BLDC motor does not operate directly off a DC voltage source. It consists of a rotor with permanent magnets, a stator with windings and commutation that is performed electronically. Normally three Hall sensors are used to detect the rotor position and commutation is performed based on Hall sensor inputs. There are two types of stator windings variants which are trapezoidal and sinusoidal motors.

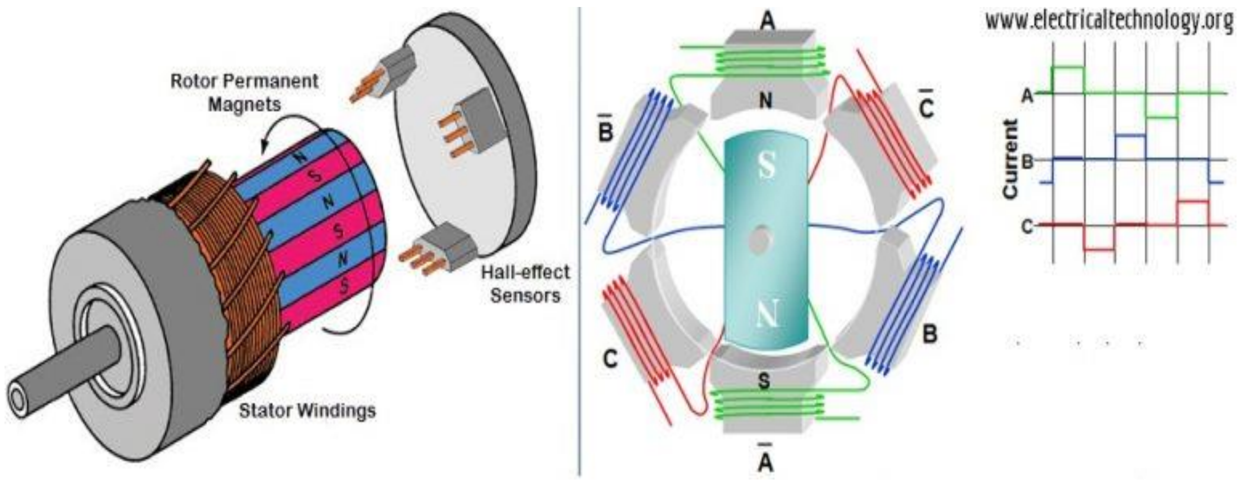


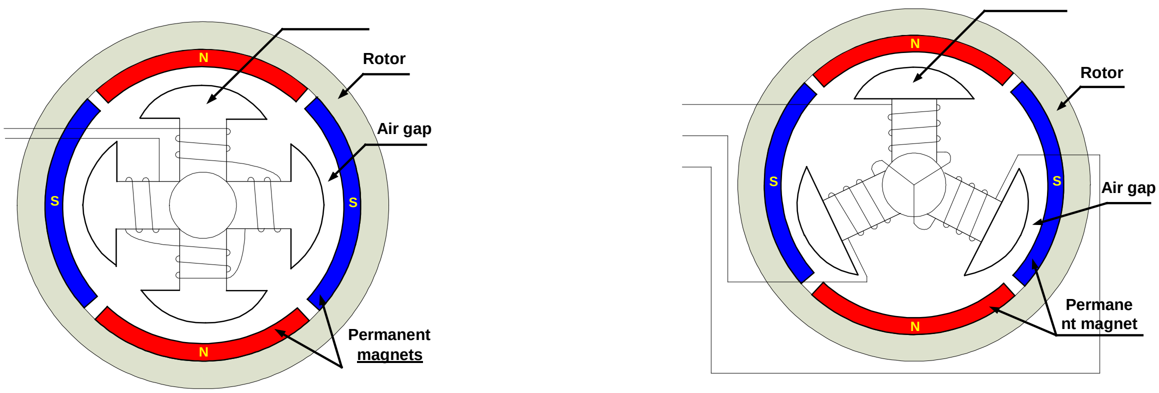
Fig 2.2 Construction, working principle And Operation of BLDC Motor

2.3.1.1 Stator

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery. Windings in a stator can be arranged in two patterns which is a star pattern (Y) or delta pattern (Δ). Most BLDC motors have three stator windings connected in star connection. The winding formed when each of these winding are constructed with numerous coils interconnected together.

A single-phase motor has one stator winding—wound either clockwise or counter-clockwise along each arm of the stator—to produce four magnetic poles as shown in Figure 2.3(a). By comparison, a three phase motor has three windings as shown in Figure 2.3(b). Each phase turns on sequentially to make the rotor revolve.

There are two types of stator windings: trapezoidal and sinusoidal, which refers to the shape of the back electromotive force (BEMF) signal. The shape of the BEMF is determined by different coil interconnections and the distance of the air gap. In addition to the BEMF, the phase current also follows a trapezoidal and sinusoidal shape. A sinusoidal motor produces smoother electromagnetic torque than a trapezoidal motor, though at a higher cost due to their use of extra copper windings. A BLDC motor uses a simplified structure with trapezoidal stator windings



(a) Single Phase **(b) Three Phase**

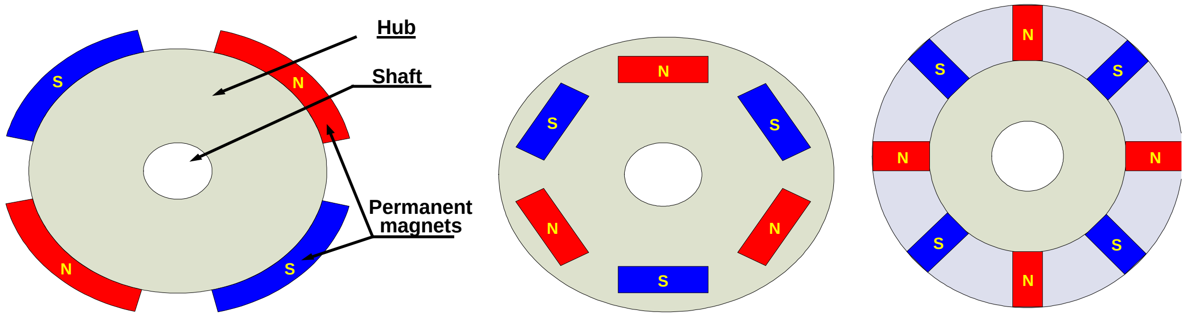
Figure 2.3: Simplified BLDC motor Diagram

2.3.1.2 Rotor

The rotor of a typical BLDC motor is made out of permanent magnets. Depending upon the application requirements, the number of poles in the rotor may vary. Increasing the number of poles does give better torque but at the cost of reducing the maximum possible speed. Another rotor parameter that impacts the maximum torque is the material used for the construction of permanent magnet; the higher the flux density of the material, the higher the torque.

A rotor consists of a shaft and a hub with permanent magnets arranged to form between two to eight pole pairs that alternate between north and south poles. Figure shows cross sections of three kinds of magnets arrangements in a rotor.

There are multiple magnet materials, such as ferrous mixtures and rare-earth alloys. Ferrite magnets are traditional and relatively inexpensive, though rare-earth alloy magnets are becoming increasingly popular because of their high magnetic density. The higher density helps to shrink rotors while maintaining high relative torque when compared to similar ferrite magnets.



(a) Surface-Mounted **(b) Embedded** **(c) Inserted**

Figure 2.4: Rotor Magnet Cross Section

2.3.1.4 Hall Sensor

Hall sensors work on the hall-effect principle that when a current-carrying conductor is exposed to the magnetic field, charge carriers experience a force based on the voltage developed across the two sides of the conductor. If the direction of the magnetic field is reversed, the voltage developed will reverse as well. For Hall-effect sensors used in BLDC motors, whenever rotor magnetic poles North (N) or South (S) pass near the hall sensor, they generate a HIGH or LOW level signal, which can be used to determine the position of the shaft. Most BLDC motor consists of three Hall Effect sensors and the combination of this sensor will produce the exact sequence of commutation. There are two output versions by referring the physical position of the Hall sensors either at 60˚or 120˚phase shift to each other.

2.3.1.5 Theory of Operation

Three windings on each commutation have different function. First windings will energized to positive power (current inflow into the winding), the second winding for negative (current out flow the winding) and the last winding is in a non-energized condition. The interaction between the permanent magnet and magnetic field generated by the stator coils will produce the torque. Basically, the peak torque occurs when these two fields are at 90˚to each other and falls off as the field move together. In order to keep the motor running, the magnetic field produced by the winding should shift position as the rotor moves to catch up with the stator field.

2.3.2 Torque/Speed Characteristics

Based on the Figure 2.4, the BLDC motor can define using two torque parameters, a peak torque (TP) and rated torque (TR). The motor can be loaded up to the rated torque during continuous operations. The torque remains constant in a BLDC motor for speed range up to the rated speed. Meanwhile it capable to run up to the maximum speed which is 150% of the rated speed but the torque starts dropping during this situation.

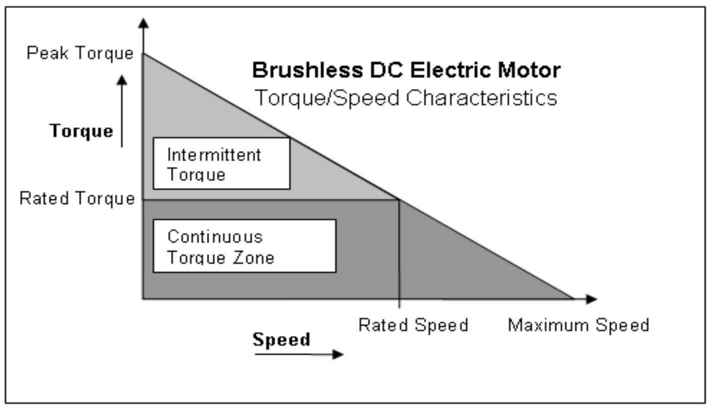


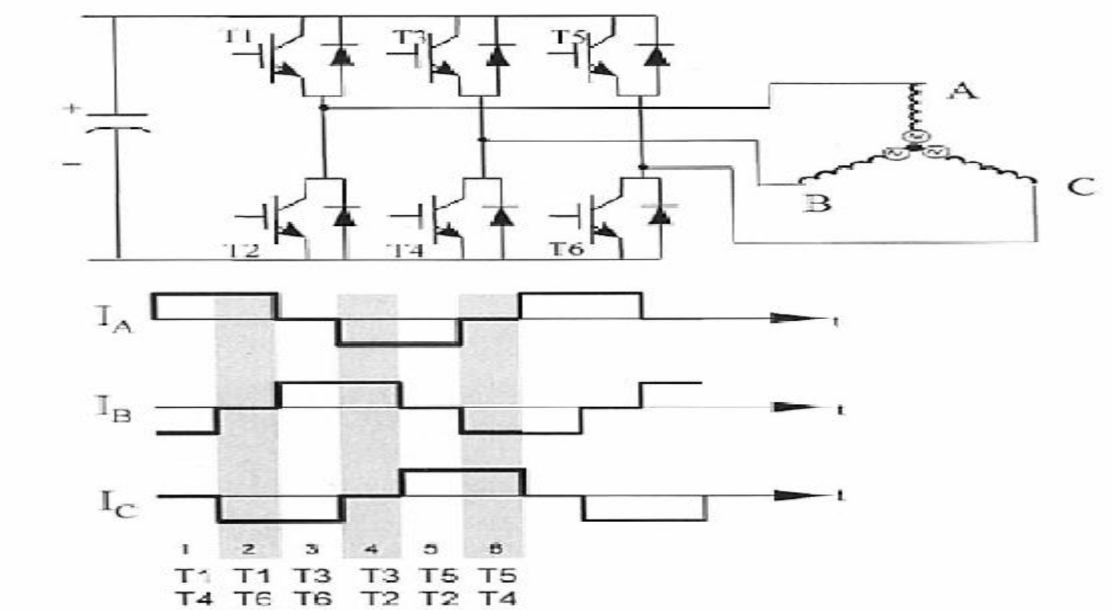
Figure 2.5: Torque/Speed Characteristic

2.3.3 Commutation Sequence

Every 60 electrical degrees of rotation, one of the Hall sensors changes the state. Given this, it takes six steps to complete an electrical cycle. In synchronous, with every 60 electrical degrees, the phase current switching should be updated. However, one electrical cycle may not correspond to a complete mechanical revolution of the rotor. The number of electrical cycles to be repeated to complete a mechanical rotation is determined by the rotor pole pairs. For each rotor pole pairs, one electrical cycle is completed. So, the number of electrical cycles equals the rotor pole pairs.

θ (°)	Hall Signals			Switching States					
	H_a	H_b	H_c	S_1	S_2	S_3	S_4	S_5	S_6
NA	0	0	0	0	0	0	0	0	0
0-60	0	0	1	1	0	0	0	0	1
60-120	0	1	0	0	1	1	0	0	0
120-180	0	1	1	0	0	1	0	0	1
180-240	1	0	0	0	0	0	1	1	0
240-300	1	0	1	1	0	0	1	0	0
300-360	1	1	0	0	1	0	0	1	0
NA	1	1	1	0	0	0	0	0	0

(A)



(B)

Figure 2.6: Commutation sequence of BLDC motor

2.3.4 Back EMF

According to Faradays law of electromagnetic induction, an EMF is induced or produced in a conductor and if a closed path is provided, the current will flows through it when a current carrying conductor is placed in a magnetic field.When the same thing happens in a brushless DC motor (BLDC) as a result of motor torque, the EMF produced is known as back EMF. It is so called because this EMF that is induced in the motor opposes the EMF of the generator. This back EMF that is induced in the brushless DC motor (BLDC) is directly proportional to the speed of the armature (rotor) and field strength of the motor, which means that if the speed of the motor or field strength is increased, the back EMF will be increased and vice versa. When the DC motor is first started, there is no back EMF induced and there is maximum current flow from the DC generator or distribution lines to the motor armature and as a result the motor toque will be maximum. During normal operation (rated speed) of DC motor, the back EMF induced will be maximum which reduces the motor armature current to its minimum level and as a result the motor torque is also reduced. When the load on the motor is increased, the motor speed (RPM) is decreased and this reduces the back EMF. This decrease in back EMF automatically increases the motor torque thereby bringing the motor to its rated speed.

2.4 MICROCONTROLLER

A microcontroller (or MCU, short for microcontroller unit) is a small computer (SoC) on a single integrated circuit containing a processor core, memory, and programmable Input/output peripherals. Microcontroller unit is required to supply switching pulses to gate of MOSFET. The output of Hall Effect sensor is fed to microcontroller and as per that it switches the appropriate MOSFETs of inverter. Here we are making use of single pulse width modulation. We are generating PWM by comparing high frequency triangular carrier wave with dc wave.

Pin Configuration:

PC0-PC5: MOSFET gate switching signal PD2-PD4: Motor hall sensor input

PD7: PWM pin PB0: DIRECTION

PB3: AIN0 for current sensing PB32: BRAKE

PA0: ADC pin for temperature sensing PD6: ENABLE

PA1: ADC pin for observing speed ref reading PD5: FAULT

Pin Diagram:

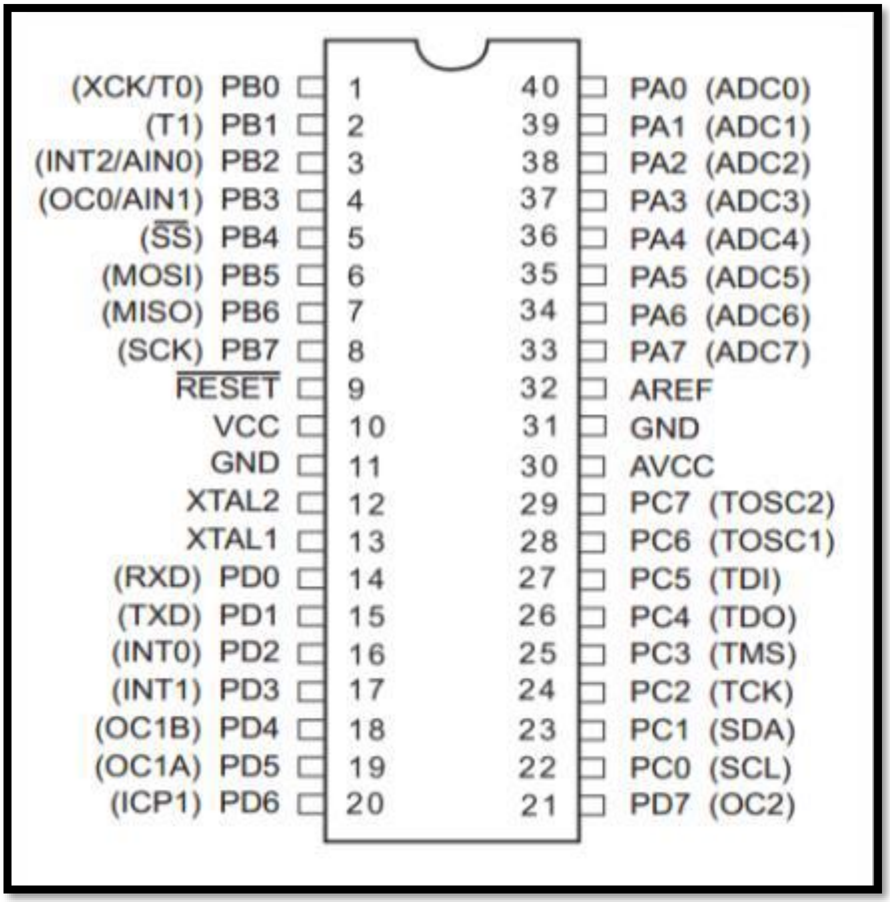


Figure 2.7: ATMEGA 32 pin configuration

2.5 PID Controller System

PID control theories added a new dimension to control systems engineering in the early 1970s. From its beginnings as mostly heuristic, somewhat ad-hoc, more recent and rigorous approaches to PID control theory have helped make it integral part of modem control theory and produced many exciting results. PID is a technique to embody human like thinking which is much less rigid than the calculations computer generally perform into a control system. PID controller can be designed to emulate human deductive thinking, that is, the process people use to infer conclusion from what they know. Meanwhile, conventional controller requires formal modeling of the physical reality of any plant. Apart from that, PID control incorporates ambiguous human logic into computer programs. It suit control problem that cannot be easily represented by mathematical model. Design of such controller leads to faster development and implementation cycles due to its unconventional approach.

CHAPTER 3

Report on Present Investigation

3.1 Block Diagram Design

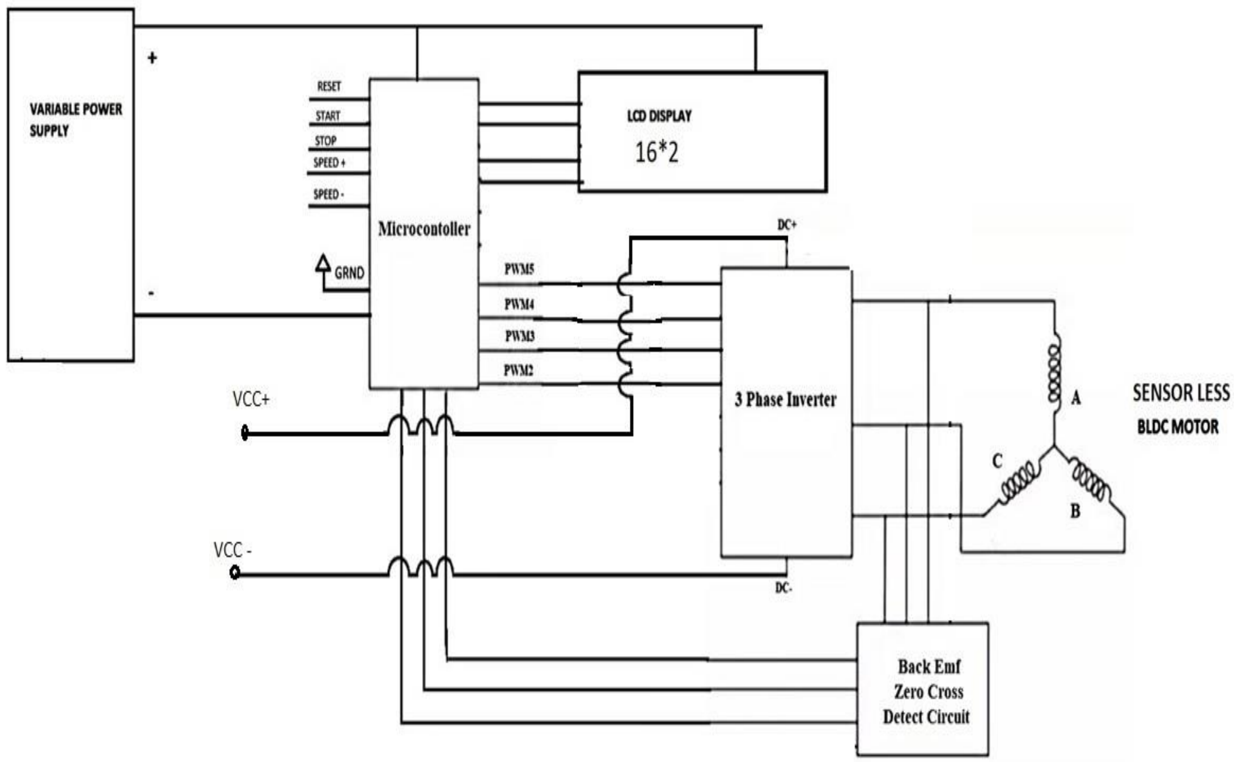


Fig 3.1 Block Diagram Design

3.2 General Circuit Diagram

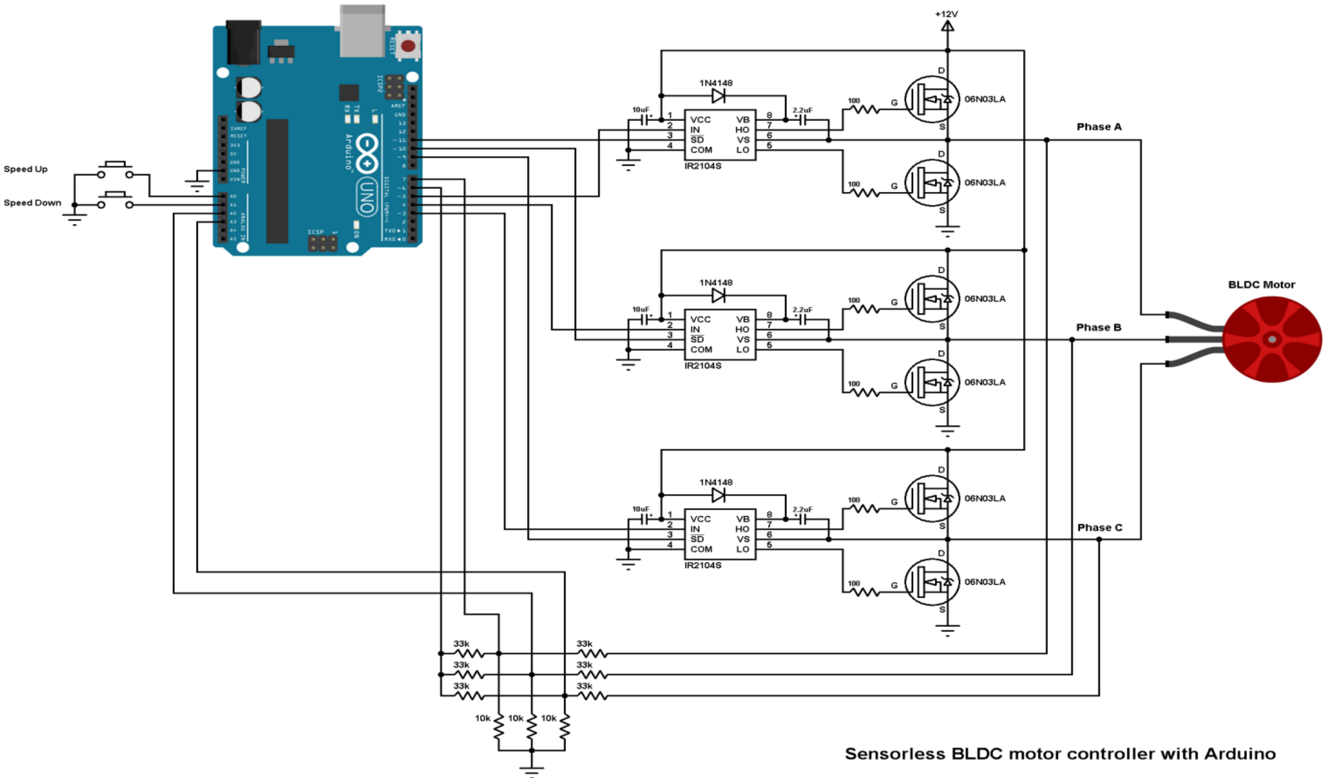


Fig 3.2 Circuit Diagram

3.3 SPECIFICATION OF BLDC MOTOR:

Motor: 2450 KV BLDC Motor

Specifications: KV: 2450

Max Efficiency: 80%

Max Efficiency Current: 3-10A (>75%)

Current Capacity: 12A/60s

No Load Current @ 10V: 0.5A

No. Of Cells: 2-3 Li-Poly

Motor Dimensions: Φ27.5 x 30mm

Shaft Diameter: Φ3.17mm

Package size: 17 * 10 * 4cm / 6.5 * 3.9 * 1.6in

Package weight: 259g / 9.1oz

3.4 Modeling of a BLDC motor

The analysis of BLDC motor is based on the assumption for simplification and accuracy. The BLDC motor is type of unsaturated. The stator resistances for all the winding are equal and the self and mutual inductance are constant. Semiconductor devices of inverter are ideal and iron losses are negligible. Meanwhile, the back-EMF wave-forms of all phases are equal. Based on the equivalent circuit of BLDC motor shown in Figure 3.5, the dynamic equations of BLDC motor using the assumption can be derived as

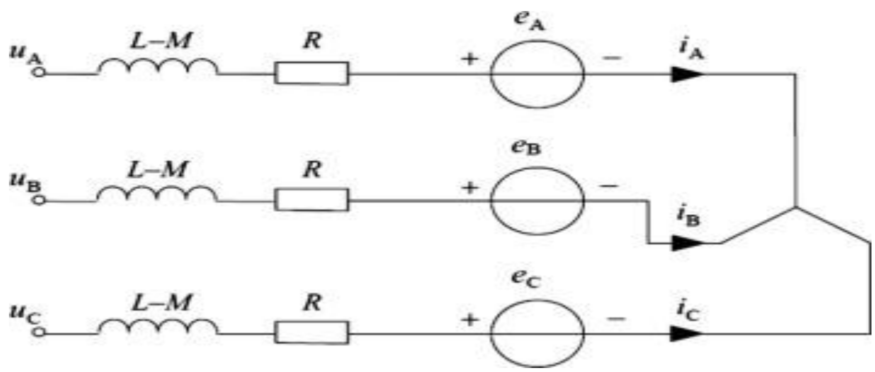


Fig 3.3 Equivalent circuit of BLDC motor

Va= RIa+ (L − M)di dta+ ea ………………… (3.1)

Vb= RIb+ (L − M)di dtb+ eb ………………….. (3.2)

V c= RIc+ (L − M)di dtc+ ec …………………. (3.3)

Where

Va, Vb, Vc= Stator phase voltages

ia, ib, ic= Stator phase current

ea, eb, ec=Phase back EMF

L = Self inductance

M = Mutual inductance

R = Phase resistance

3.5 PID controller:

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a desired set-point and a measured process variable. The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum: Where Kp, Ki, and Kd, all non-negative, denote the coefficients for the proportional, integral, and derivative terms, respectively (sometimes denoted P, I, and D). In this model,

- P accounts for present values of the error. For example, if the error is large and positive, the control output will also be large and positive.
- I accounts for past values of the error. For example, if the current output is not sufficiently strong, error will accumulate over time, and the controller will respond by applying a stronger action.
- D accounts for possible future values of the error, based on its current rate of change.

As a PID controller relies only on the measured process variable, not on knowledge of the underlying process, it is broadly applicable. By tuning the three parameters of the model, a PID controller can deal with specific process requirements. The response of the controller can be described in terms of its responsiveness to an error, the degree to which the system overshoots a set-point, and the degree of any system oscillation. The use of the PID algorithm does not guarantee optimal control of the system or even its stability.

Some applications may require using only one or two terms to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a 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. For discrete time systems, the term PSD, for proportional-summation-difference, is often used.

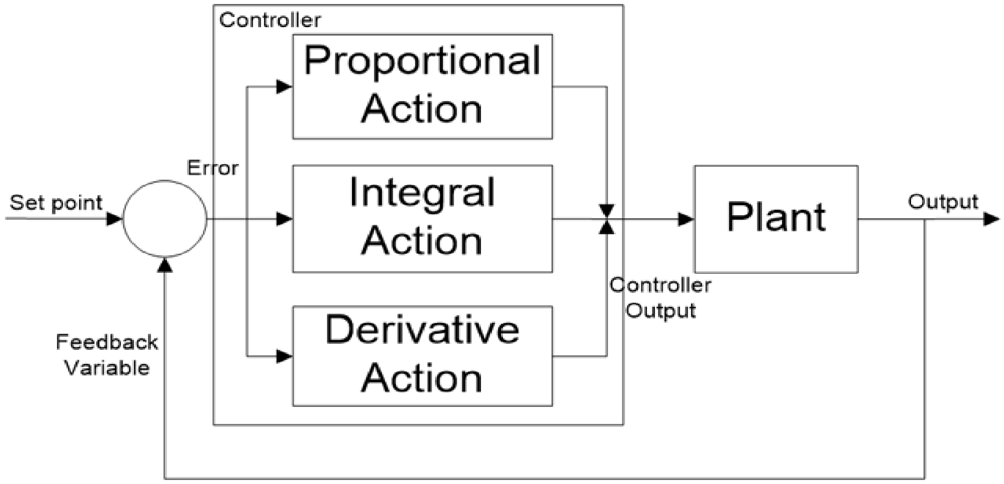


Fig. 3.4 Basic Schematic Block diagram of PID Controller

3.5.1 PID Modes of Control:

Proportional (P) response:

Term ‘P’ is proportional to the actual value of the error. If the error is large, control output is also large and if the error is small control output is also small, but gain factor (K_p) is Also taking in to account. Speed of response is also directly proportional to **proportional gain factor (K_p)**. So, the speed of response is increased by increasing the value of K_p but if K_p is increased beyond normal range, process variable starts oscillating at high rate and make system unstable.

$y(t) \propto e(t)$

$y(t) = k_i * e(t)$

Where K_p is proportional gain factor

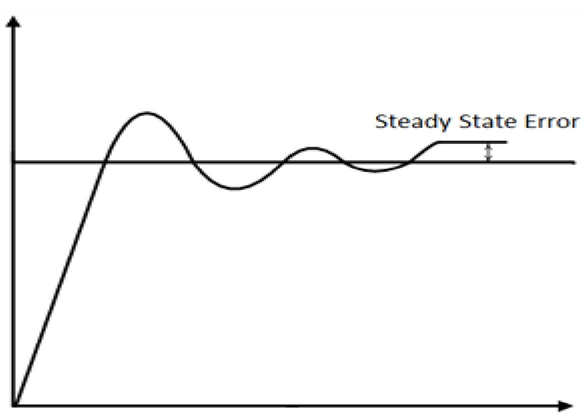


Fig. 3.5 PID controller Proportinal Responce

Here, the resulting error is multiplied with proportionality gain factor (proportional constant) as shown in above equation. If only P controller is used, at that time, it requires manual reset because it maintain steady state error (offset).

Integral (I) response:

Integral controller is generally used to decrease the steady state error. Term 'I' is integrate (with respect to time) to the actual value of the error**.** Because of integration, very small value of error, results very high integral response. Integral controller action continues to change until error becomes zero.

$$y(t) \propto \int e(t)$$

$$y(t) = k_i \int e(t)$$

Where K_i is a Integral gain factor.

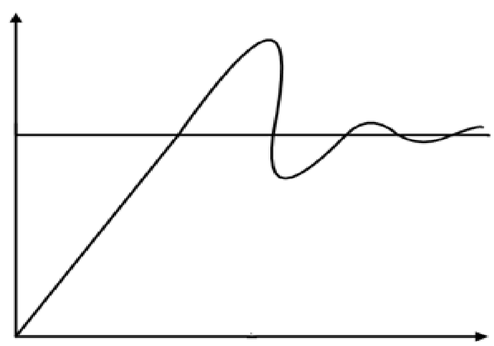


Fig. 3.6 PID controller Integral Response

Derivative (D) response:

Derivative controller is used to with combination of PD or PID. It never used alone, because if error is constant (non-zero), output of the controller will be zero. In this situation, controller behave life zero error, but in actual there are some error (constant). Output of derivative controller is directly proportional to the rate of change of error with respect to time as shown in equation. By removing sign of proportionality, we get derivative gain constant (k_d). Generally, Derivative controller is used when processor variables starts oscillating or changes at a very high rate of speed. D-controller is also used to anticipates the future behavior of the error by error curve. Mathematical equation is as shown below;

$$y(t) \propto de(t)/dt$$

$y(t) = K_d * de(t)/dt$

Where K_d is a Derivative gain factor.

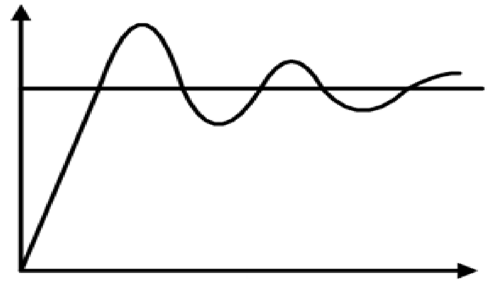


Fig.3.7 PID controller Derivative Response

Proportional, Integral and Derivative controller:

This is a combination of P, I and D controller. Output of controller is summation of proportional, integral and derivative responses. Mathematical equation of PD controller is as shown below;

$y(t) \propto (e(t) + \int e(t)\, dt + de(t)/dt)$

$y(t)=k_p*e(t) + k_i\int e(t)dt + k_d*de(t)/dt$

3.5.2 Tuning Methods for PID Controller:

For desired output, this controller must be properly tuned. The process of getting ideal response from the PID controller by PID setting is called **tuning of controller**. PID setting means set the optimal value of gain of proportional (k_p), derivative (k_d) and integral (k_i) response. **PID controller is tuned for disturbance rejection** means staying at a given setpoint and command tracking, means if setpoint is change, output of controller will follow new setpoint. If controller is properly tuned, output of controller will follow variable setpoint, with less oscillation and less damping.

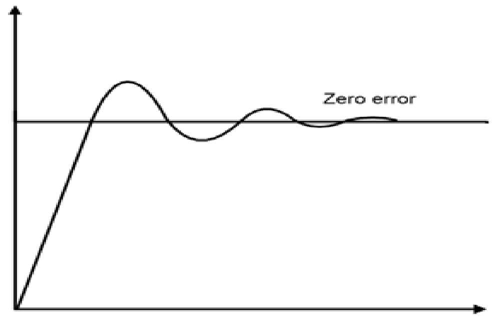


Fig.3.8 Disturbance rejection by PID Controller Tunner

There are **several methods for tuning PID controller** and getting desired response. Methods for tuning controller are as below:

1. Trial and error method
2. Process reaction curve technique
3. Ziegler-Nichols method
4. Relay method
5. Using software

1. Trial and error method:

Trial and error method is also known as manual tuning method and this method is simplest method. In this method, first increase the value of kp until system reaches to oscillating response but system should not make unstable and keep value of kd and ki zero. After that, set value of ki in such a way that, oscillation of system is stops. After that set the value of kd for fast response.

2. Process reaction curve technique:

This method is also known as Cohen-Coon tuning method. In this method first generate a process reaction curve in response to a disturbance. By this curve we can calculate the value of controller gain, integral time and derivative time. This curve is identified by performing manually in open loop step test of the process. Model parameter can find by initial step percentage disturbance. From this curve we have to find slop, dead time and rise time of curve which is nothing but the value of kp, ki and kd.

3. Zeigler-Nichols method:

In this method also first set the value of ki and kd zero. The proportional gain (kp) is increase until it reaches at the ultimate gain (ku). Ultimate gain is nothing but it is a gain at which output of loop starts to oscillate. This ku and the oscillation period Tu are used to derive gain of PID controller from below table.

Type of Controller	kp	k_i	kd
P	$0.5\ k_u$	▪	▪
PI	$0.45\ k_u$	$0.54\ k_u/T_u$	▪
PID	$0.60\ k_u$	$1.2\ k_u/T_u$	$3\ k_uT_u/40$

4. Relay method:

This method is also known as Astrom-Hugglund method. Here output is switched between two values of the control variable but these values are chosen in such a way that process must cross the set point. When process variable is less than set point, the control output is set to the higher value. When process value is greater than set point, the control output is set to the lower value and output waveform is formed. The period and amplitude of this oscillatory waveform is measured and used to determine ultimate gain ku and period Tu which is used in above method.

5. Using software:

For PID tuning and loop optimization, software packages are available. These software packages collect data and make a mathematical model of system. By this model, software finds an optimal tuning parameter from reference changes.

3.5.3 Use of PID as a control scheme for speed and position control

PID controller is its feasibility and easy to be implemented. The PID gains can be designed based upon the system parameters if they can be achieved or estimated precisely.

Moreover, the PID gain can be designed just based on the system tracking error and treats the system to be "black box" if the system parameters are unknown.

However, PID controller generally has to balance all three-gains or else impact to the whole system and may compromise the transient response, such as settling time, overshoots, and oscillations

Generally, PID control algorithms, using in PLC controllers with many analog inputs and outputs, enable control of many control loops. It is a great advantage. In my opinion the only disadvantage it is usually related to the tuning methodology.

Due to above advantages, feasibility and accuracy given by perfectly tuned PID control scheme it is convenient to use PID as a control scheme for speed and position control.

Following are the effects of PID parameters (Kp, Ki, and Kd):

- System Rise time will be reduced by Kp, it provides faster response in variable load condition
- Steady state error will be reduced by Ki, hence the motor speed is pushed near to reference speed
- Settling time and overshoot will be reduced by Kd, hence provides faster response.

CHAPTER 4

Results & discussions

4.1 Model and result

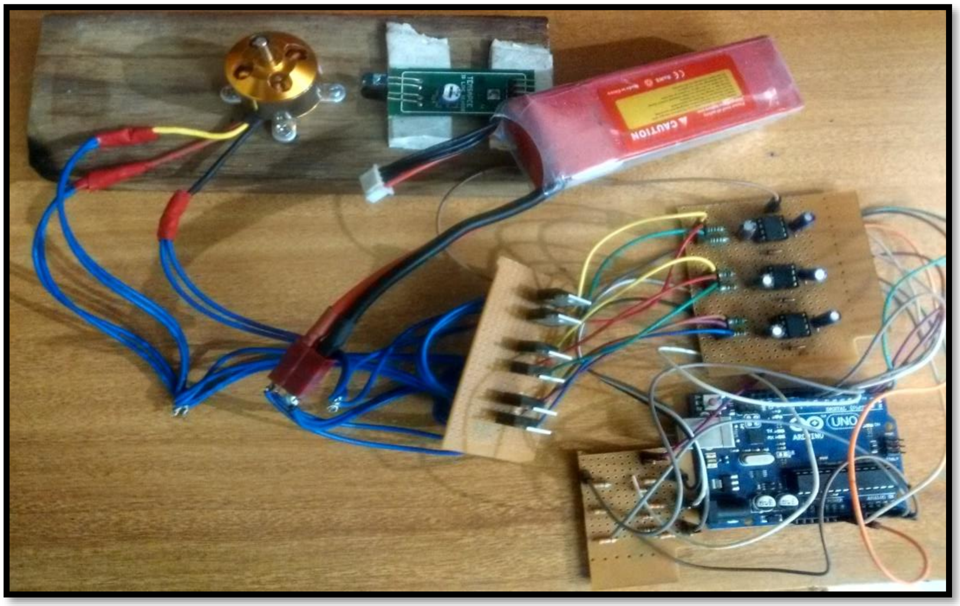


Fig.4.1 Complete actual Circuit model

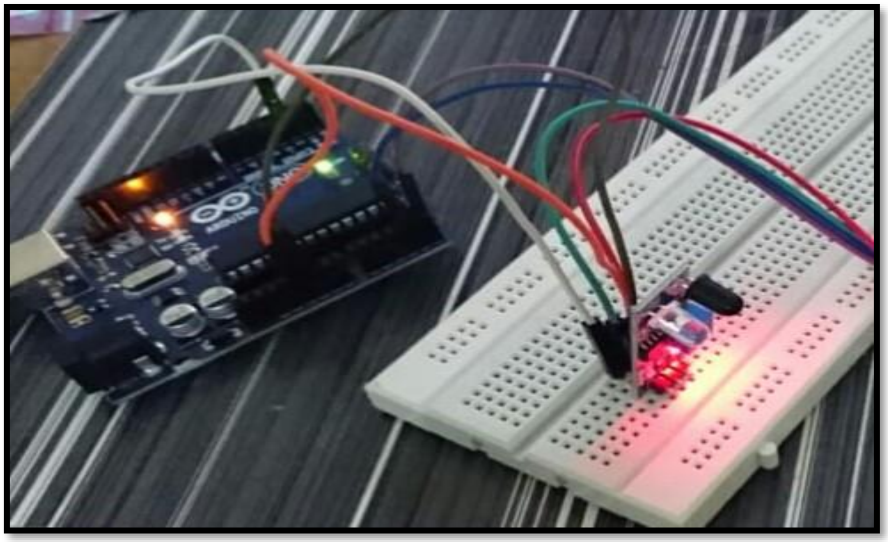


Fig4.2 IR sensor testing model

CHAPTER 5

Conclusion:

The proposed speed control scheme is robust, efficient, and easy to implement in place of sensor applications. Simulation results and operation results of implemented PID based BLDC motor controller shows accurate results. Use of PID in the closed loop implementation adds efficiency and stability to systems. The FPGA based implemented motor controller can be used for system critical applications where the system stability and motor speed accuracy are the determining factors.

FUTURE SCOPE:

1] Proposed control system can be upgraded and further secondary control means for stability operation in order to reduce vibrations of the motor up to certain extent.

2] For remote monitoring & control in industry related applications mentioned below.

Applications:

1] In textile Industry for spinning machine motor control.

2] In Printing Industry, for paper roller tension control mechanism.

3] In Conveyor system for food industry.

4] In PCB engraver for track drilling and carving.

3] We can add internet structure to the system through IOT platform. thus making it operator friendly.

CHAPTER 6

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