CLOSED LOOP CURRENT CONTROLLING TECHNIQUES FOR BLDC MOTOR SPEED CONTROL

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Abstract-- BLDC motors stand for brush less DC motor. These motors are widely used in robotics, computer hard drives, ceiling fans, hybrid electrical vehicles due to its smooth operation. There are several advantages with these motors like torque provided by these motors are very high, smooth vibration less operation, high efficiency and power to weight ratio of BLDC motors is high. There are many current controllers used for speed control of BLDC motors. Even though conventional methods have fast response for load changes, their usage helps only in limiting either of the current or torque ripples and acoustic electromagnetic noise. Also non linearity characteristics of BLDC motor is difficult to operate using conventional methods. Hence many controllers are being designed to overcome the disadvantages of conventional methods for speed control of BLDC motor. The design of PI and fuzzy logic controllers is carried out by using MATLAB/SIMULINK. In this project a comparative simulation analysis will be done on BLDC motor with and without current controllers at fixed and variable speeds.

Index Terms - INTRODUCTION

Electrical motors are used to convert electrical energy to mechanical energy. In industries mostly we use Induction motors and DC motors. Induction motor has the advantages of simple structure, easy fabrication, reliable work and low price, but it is uneconomical to regulate the speed smoothly over a wide range and it is not easy to start up, And in conventional DC motors mechanical commutation is implemented by using brushes, which will result in problems like mechanical friction that would shorten the lifetime, and create noise, electric sparks, and radio interference, etc.., and they also require frequent maintenance of commutator and brushes. When the functions of commutator and brushes were replaced by solid-state switches, maintenance free motor is developed. These types of motors are now known as Brushless DC motors. Brushless DC (BLDC) motors are in fact a type of permanent magnet Synchronous motors. It is driven by DC voltage and the current commutation is done by solid state switches. BLDC motors are mostly used in areas where wide range of speed control isrequired.

BLDC motor speed control plays an important role in modern motor control. The control methods are usually divided into two main types: open-loop and closed-loop ones. Dual closed-loop speed control is common in control systems. The inner loop is the current or torque loop, while the outer loop is the voltage loop. Speed can be varied by varying voltage; mostly industries are using PWM technique for speed control of BLDC motors.

These applications may demand high-speed control accuracy and good dynamicresponses.

- Home appliances: washers, dryers andcompressors.
- In automotive, fuel pump control, electronic steering control, engine control and electric vehiclecontrol.
- In aerospace there are a number of applications like centrifuges,pumps, robotic arm controls, gyroscope controls and soon.

Compared with PMSM, the torque ripples in BLDC motor are much more serious. The pulsation will not only cause acoustics and vibration, but severely limit the performance of the system, especially in high-precision and high-stabilization applications. Minimization of the torque ripples in a BLDC motor drive system has been an important and difficult problem. Generally speaking, the pulsation in a BLDC motor can be divided into two categories: cogging torque and commutation torque. The cogging torque is produced by the different reluctance in the air gap caused by the existing of a stator slot. The back-EMF pulsation caused by cogging torque is a periodic function of rotor position, which will lead to torque ripples. Cogging torqueis reduced by skewing poles or slots, embedding a magnetic slots wedge, placing auxiliary slots and teeth, designing fractional slots. The commutation torque ripple in a BLDC motor,is due to current variation during commutation interval.

The aim of the project is to control the speed and reduce the torque ripple in BLDC motor by using PI and FUZZY controllers. The current control method (hysteresis current controller) is implemented in PIand fuzzy for BLDC motor drive.

This hysteresis current controller has more advantages than sine PWMtechnique,

1. Verysimple
2. Fastresponse
3. It does not need any knowledge of loadparameters.

The simulation of BLDC motor drive system is developed using 'Matlab/Simulink'. The simulation circuit includes all realistic components of the drive system. A comparative study associated without current controller and with current controllers at fixed and variable speeds has been made with PI and FUZZYcontrollers.

2.DESCRIPTION

2.1 BLOCK DIAGRAM:

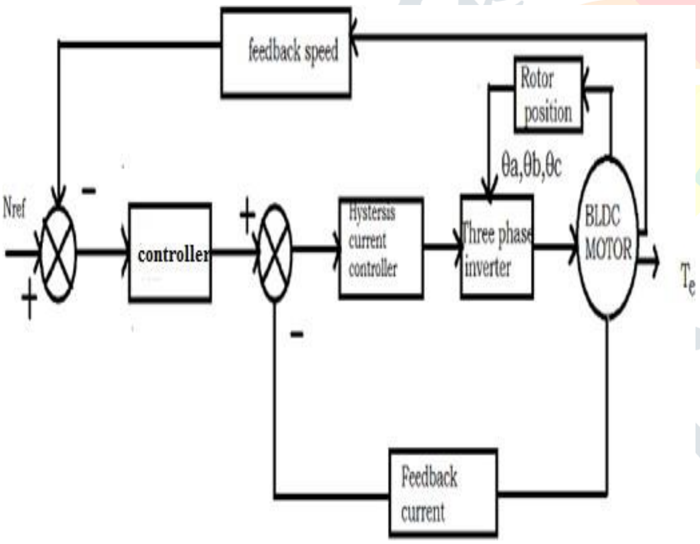


Fig 2.1 Functional Block Diagram of Blind Unit

BLDCMOTOR

Conventional DC Motors are mechanically commutated motors, which consists of commutator and brushes. Due to commutator and brushes mechanical losses are developed, efficiency is reduced and requires frequent maintenance. The functions of commutator and brushes are replaced with electronic switches. This type of motors is called Brushless DC Motors (BLDC). It is type of permanent magnet synchronous motor. So BLDC Motors are called as electronically commutated motors.

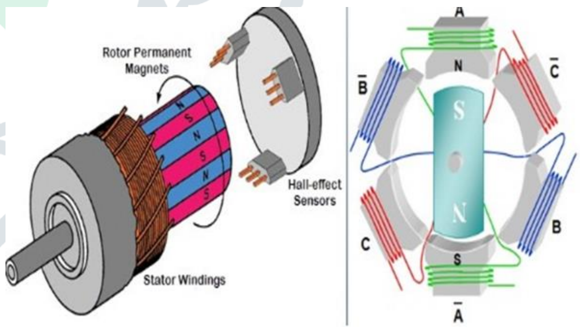
Advantages:

1. Brushless motors are more efficient as its velocity is determined by the frequency at which current is supplied, not thevoltage.
2. As brushes are absent, the mechanical energy loss due to friction is less with enhancedefficiency.
3. BLDC motor can operate at high-speed under anycondition.
4. There is no sparking and much less noise duringoperation.
5. More electromagnets could be used on the stator for more precisecontrol.
6. BLDC motors accelerate and decelerate easily as they are having low rotor inertia.
7. It is high performance motor that provides large torque per cubic inchover a vast speedrange.
8. BLDC motors do not have brushes which make it more reliable, high life expectancies and maintenance freeoperation.
9. There is no ionizing sparks from the commutator, and electromagnetic interference is also getreduced.

Such motors cooled by conduction and no air flow are required forinside cooling.

Disadvantages of Brushless DCMotors:

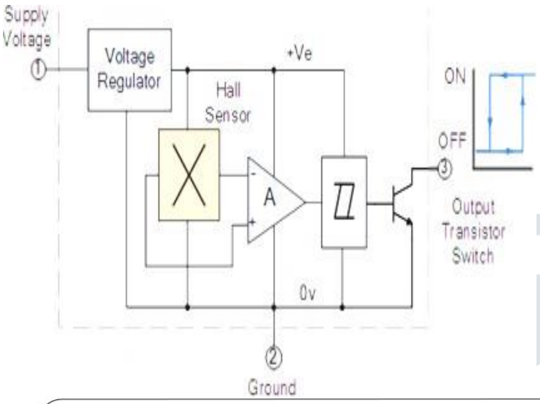
1. BLDC motor cost is more than DCmotor.
2. The limited high power could be supplied to BLDC motor, otherwise too much heat is produced, weakens the magnets and insulation of winding may getdamaged.

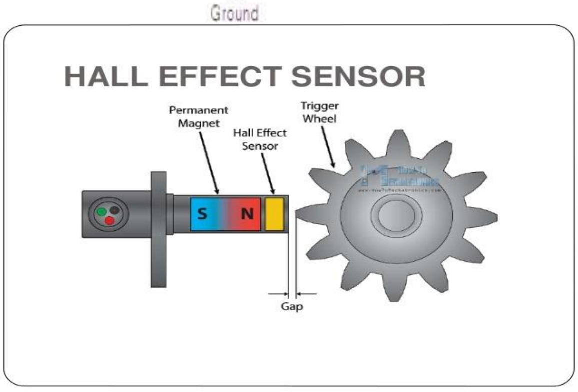


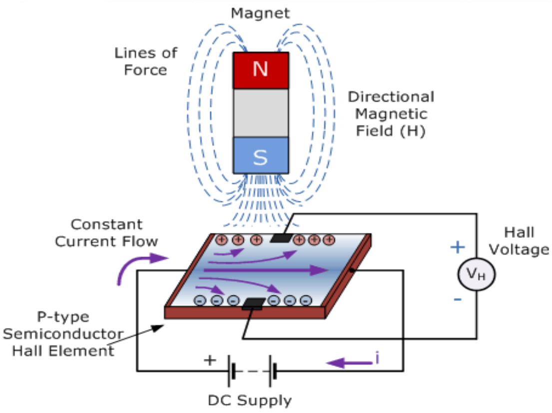
WORKING PRINCIPLE:

The principle for working of BLDC motor are same as for brushed DC motor i.e., internal shaft position feedback. In case of a brushed DC motor, feedback is implemented using a mechanical commutator and brushes butWith a BLDC motor, it is achieved using multiple feedback sensors. The most commonly used feedback sensors are Hall sensors and optical encoders

Hall Effect Sensors are devices which are activated by an external magnetic field. We know that a magnetic field has two important characteristics flux density (B) and polarity (North and South Poles). The output signal from a Hall Effect sensor is the function of magnetic field density around the device. When the magnetic flux density aroundthe sensor exceeds a certain pre-set threshold, the sensor detects it and generates an output voltage called the Hall Voltage V_H. Consider the diagram below.







Hall Effect Sensors consist basically of a thin piece of rectangular p-type semiconductor material such as Gallium Arsenide (GaAs), Indium Antimonite (InSb) or Indium Arsenide (InAs) passing a continuous current through itself. When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes to either side of the semiconductor slab. This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material. As these electrons and holes move side wards, a potential difference is produced between the two sides of the semiconductor material by the build-up of these charge carriers. Then the movement of electrons through the semiconductor material is affected by the presence of an external magnetic field which is at right angles to it and this effect is greater in a flat rectangular shapedmaterial.

The effect of generating a measurable voltage by using a magnetic fieldis called the Hall Effect. After Edwin Hall who discovered it back in the 1870's with the basic physical principle underlying the Hall Effect being Lorentz force. To generate a potential difference across the device the magnetic flux lines must be perpendicular(90^{0}) to the flow of current and be of the correct polarity, generally a southpole.

The output voltage, called the Hall voltage (V_H) of the basic Hall Element is directly proportional to the strength of the magnetic field passing through the semiconductor material (output ∝ H).

Hall sensor working

Hall Effect Sensors are available with either linear or digital outputs. The output signal for linear (analog) sensors is taken directly from the output of the operational amplifier with the output voltage being directly proportional to the magnetic field passing through the Hall sensor. This output Hall voltage is givenas:

$$V_H = R_H *[I * B]$$

V_H is the Hall voltage in volts.

R_H is Hall effect co-efficient.

B is the magnetic flux density in tesla.

ADVANTAGES:

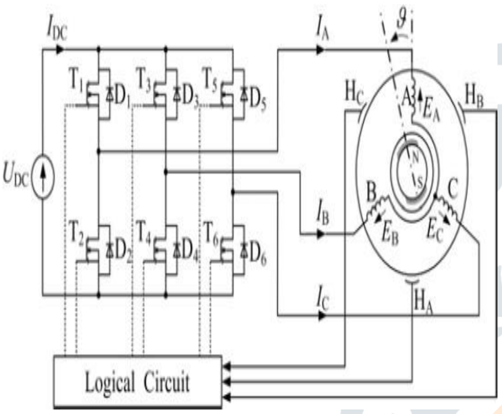
Hall Effect sensors provide a faster response time to change in the magnetic field. Therefore they provide greater efficiency in commutating a BLDCMOTOR.

Due to their accuracy they provide constanttorque.

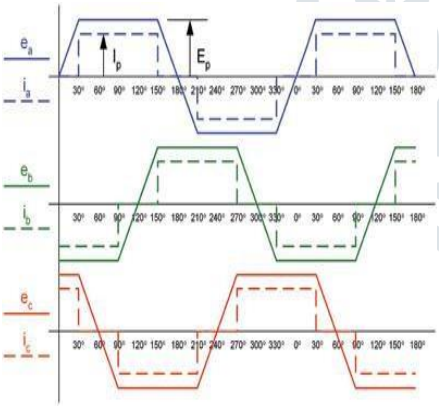
They provide high stability andsensitivity.

OPERATION OFBLDC:

A BLDC motor is a permanent magnet synchronous motor that uses position detectors and an inverter to control the armature currents. There are two main types of BLDC motors: trapezoidal type and sinusoidal type. In the trapezoidal motor the back emf induced in the stator windings has a trapezoidal shape and its phases must be supplied with quasi-square wave currents for ripple free operation. The sinusoidal motor on the other hand has a sinusoidal shaped back emf and requires sinusoidal phase currents for ripple free torque operation. The shape of the back emf is determined bythe shape of rotor magnets and the stator winding distribution. The sinusoidal motor needs high



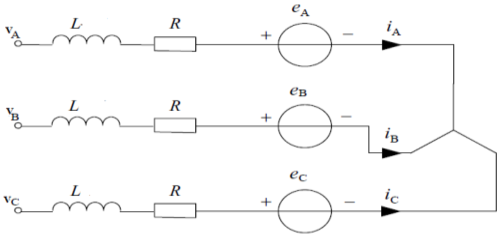
Trapezoidal waveform of BLDC motor.



EQUIVALENT CIRCUIT OF BLDCMOTOR:

CONTROLLER

Introduction:



A controller is one which compares controlled values with the desired values and has a function to correct the deviation produced.

The important uses of the controllers are written below:

- Controllers improve steady state accuracy by decreasing the steady stateerrors.
- As the steady state accuracy improves, the stability alsoimproves.
- They also help in reducing the offsets produced in thesystem.
- Maximum overshoot of the system can be controlled using these controllers.
- They also help in reducing the noise signals produced in thesystem.
- Slow response of the over damped system can be made faster with the help of thesecontrollers.

The purpose of a motor speed controller is to take a signal representing the demand speed and to drive a motor at that speed. Closed loop speed control systems have fast response, but become expensive due to the need of feedback components such as speed sensors. Speed controller calculates the difference between the reference speed and the actual speed producing an error, which is fed to the PI controller.

PI CONTROLLERS:

PI controllers are used widely for motion control systems. They consist of a proportional gain that produces an output an output proportional to the input error an integration to make the steady state error zero for a step change in the input. PI controller is a generic control loop feedback mechanism (controller) widely used in industrial control system a PI isthe most commonly used feedback controller and calculates an "error" value as the difference between a measured process variable and a desiredset point. The controller attempts to minimize the error by adjusting the process control input. The PI controller calculation involves two separate constant parameters, and is accordingly sometimes called two-term control: the proportional, the integral values, denoted *P*, *I*. These values can be interpreted in terms of time: *P* depends on the present error, *I* on the accumulation of past errors, based on current rate of change

BLDC Motor transfer function:

$$G(s) = \frac{6.82092*10^{-3}}{3.31297*10^{-8}s^2+33.617*10^{-6}s+1}$$

Open loop Transfer function:

$$(K_p+\frac{K_I}{s}) *(\frac{6.82092*10^{-3}}{3.31297*10^{-8}s^2+33.617*10^{-6}s+1})$$

$K_I = 1;$

Closed loop transfer function:

$$\frac{\left(K_P+\frac{1}{s}\right)*\frac{6.82092*10^{-3}}{(3.31297*10^{-8}s^2+33.617*10^{-6}s+1)}}{1+\left(K_P+\frac{1}{s}\right)*\frac{6.82092*10^{-3}}{(3.31297*10^{-8}s^2+33.617*10^{-6}s+1)}}$$

Characteristic equation:

$3.3129*10^{-8}s^3+33.617*10^{-6}s^2+K_p*6.82092*10^{-3}s+6.82092*10^{-3}=0$

From R-H criteria:

S3 3.3129*10-8

(Kp*6.82092*10-3)+1

S2 33.617*10-6

6.82092*10-3

S ((K_P*2.292* 〖10〗 ^(-7)-

(33.617* 〖10〗 ^(-6))))/(33.617* 〖10〗 ^(-6))

0

S0 (Kp*6.82092*10-3)+1

0

System to be stable:

((K_P*2.292* 〖10〗 ^(-7)-(33.617* 〖10〗 ^(-6)

)))/(33.617* 〖10〗 ^(-6)) >0

Kp>-0.00146

(Kp * 6.82092* 10-3)+1>0

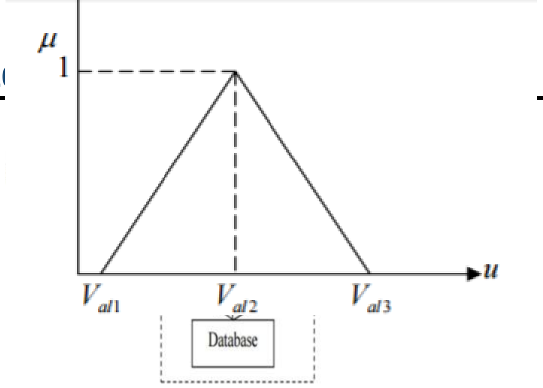
Kp>-146.607

There are several methods for tuning of PI controller. Manual tuning methods can be relatively inefficient, particularly if the loops have response times on the order of minutes or longer. So we prefer many more techniques. Here we proposed one outer speed loop and one inner current loop as the double-loop control system is introduced. In the double-loop control system, a PI controller is adopted in the speed loop and a hysteresis current controller is adopted in the current loop

FUZZYCONTROLLER:

INTRODUCTION:

The idea of fuzzy logic was first advanced by Dr. LotfiZadeh of the University of California at Berkeley in the 1960s. Fuzzy control is an attempt to meet the challenges of increasing complexity of the processes to be controlled and of the tasks to be solved by automatic control systems. The systems involved in practice are, in general, complex and time variant, with delays and nonlinearities, and often with poorly defineddynamics. Consequently, conventional control methodologies based on linear system theory have to simplify the nonlinear systems before they can be used, but without any guarantee of providing good performance. To control nonlinear systems satisfactorily, nonlinear controllers are often developed. The main difficulty in designing nonlinear controllers is the lack of a general structure. In addition, most linear and nonlinear control solutions developed during the last three decades have been based on precise mathematical models of the systems. Most ofthose systems are difficult/impossible to be described by conventional mathematical relations, hence, these model-based design approaches may not provide satisfactory solutions, This motivates the interest in using FLC .FLCs are based on fuzzy logic theory and employ a mode of approximate reasoning that resembles the decision making process of humans. The behavior of a FLC is easily understood by a human expert, as knowledge is expressed by means of intuitive, linguistic rules. In contrast with traditional linear and nonlinear control theory, a FLC is not based on a mathematical model and is widely used to



solve problems under uncertain environments with high non linearity's.

APPLICATIONS:

ENVIRONMENTAL CONTROL:

- Airconditioners
- Humidifiers.

DOMESTIC GOODS:

- Washingmachines
- Dryers
- Vacuumcleaners
- Microovens
- Televisions
- Photocopiers
- Still and videocameras
- Hi-Fisystems.

AUTOMATIC SYSTEMS:

- Vehicle climatecontrol
- Four wheelersteering
- Automatic gearboxes

FUZZY LOGICCONTROLLER:

Fuzzy logic expressed operational laws in linguistics terms instead of mathematical equations. Many systems are too complex to modelaccurately, even with complex mathematical equations. Therefore traditional methods become infeasible in these systems. However fuzzy logics linguistic terms provide a feasible method for defining the operational characteristics of such system. Fuzzy logic controller can be considered as a special class of symboliccontroller.

The fuzzy logic controller has three main components

1. Fuzzification
2. Fuzzyinference
3. Defuzzification

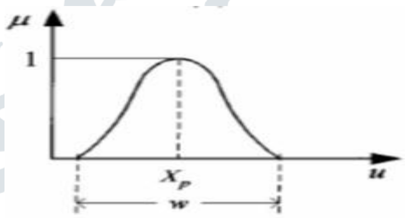
Fuzzification:

Multiple measured crisp inputs first must be mapped into fuzzy membership function this process is called fuzzification. It performs the function of fuzzification that converts input data into suitable linguistic values which may be viewed as labels of fuzzy sets. Fuzzy logic linguistic terms are often expressed in the form of logical implication, such as if-then rules. These rules define a range of values known as fuzzy member ship functions. Fuzzy membership function may be in the form of a triangular, a trapezoidal, a bell or another appropriate form.

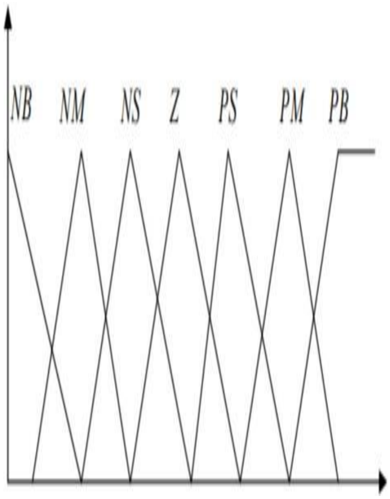
TRIANGULAR FUNCTION:

TRAPEZIOD FUNCTION:

BELL FUNCTION:



The inputs of the fuzzy controller are expressed in several linguist levels. These levels can be described as Positive big (PB), Positive medium (PM), Positive small (PS) Negative small (NS), Negative medium (NM), Negative big (NB) or in other levels. Each level is described by fuzzy set.



FUZZYINFERENCE:

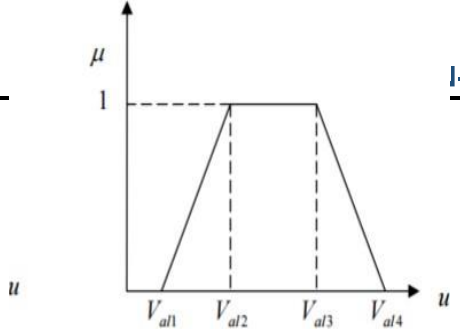
Fuzzy inference is the process of formulating the mapping from a giveninput to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic tool box-mamdani type and Sugeno-type. Thesetwotypesofinferencesystemsvarysomewhatinthe way outputs are determined. Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logiccontrollers.

$$X_{COG}=\frac{\int_a^b x f(x)\,dx}{\int_a^b f(x)\,dx}$$

Mamdani fuzzy inference is the most commonly seen inference method. This method was introduced by Mamdani and Assilian (1975). Another well-known inference method is the so- called Sugeno or Takagi–Sugeno–Kang method of fuzzy inference process. This method was introduced by Sugeno (1985). This method is also called as TS method. The main difference between the two methods lies in the consequent of fuzzy rules.

DEFUZZIFICATION:

The output of the inference mechanism is fuzzy output variables. The fuzzy Logic controller must convert its internal fuzzy output variables into crisp values so that the actual system can use these variables. This conversion is called defuzzification.There are different methods for defuzzification.



- Center of Area(COA).
- Center Of Maximum(COM).
- Mean Of Maximum(MOM).
- Center Of Sums(COS).
- Heightmethod.

Center of Area(COA):

In the Center of Area (COA) defuzzification method, also called the Center of Gravity (COG) method, the fuzzy controller first calculates the area under the scaled membership functions and within the range of the output variable. The fuzzy logic controller then uses the following equation to calculate the geometric center of thisarea.

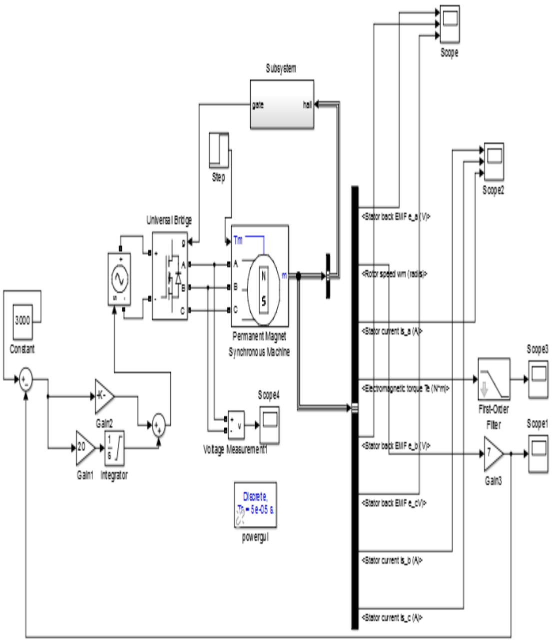
$$COA=\left(\frac{\int_{X_{min}}^{X_{max}} f(x)*x\,dx}{\int_{X_{min}}^{X_{max}} f(x)\,dx}\right)$$

Where COA is the center of area, x is the value of the linguistic variable, and x_{min} and x_{max} represent the range of the linguistic variable. The Center Of Area defuzzification method effectively calculates the best compromise between multiple output linguisticterms.

The type and characteristics of the FLC we have designed are as follows.

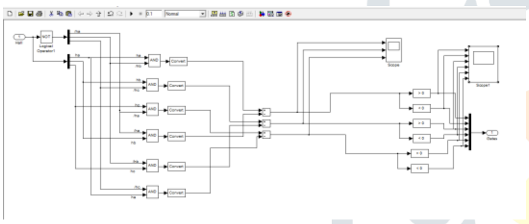
SIMULATION

BLDC Motor drive performance without Current controller at Fixed speed.

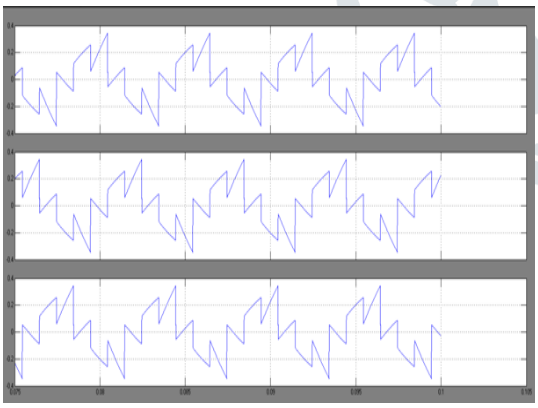


BLDC Motor drive performance without Current controller at Fixed speed.

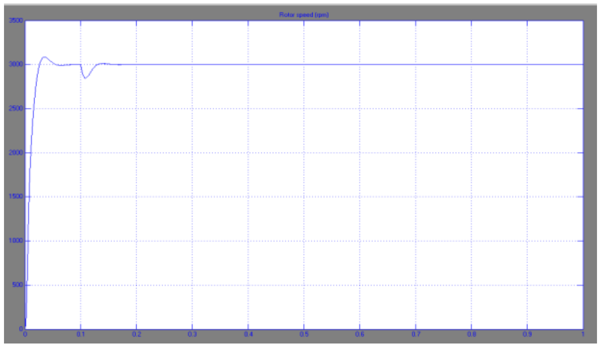
LOGICCIRCUITFORGATETRIGGERING



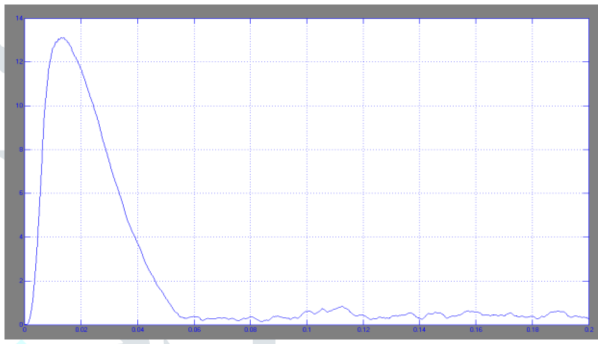
STATOR CURRENTS:



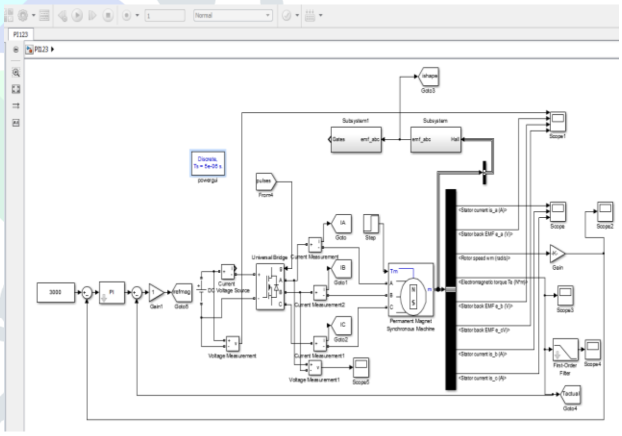
SPEED WAVEFORM:



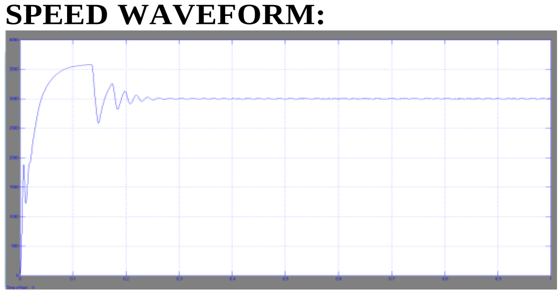
TORQUEWAVEFORM:



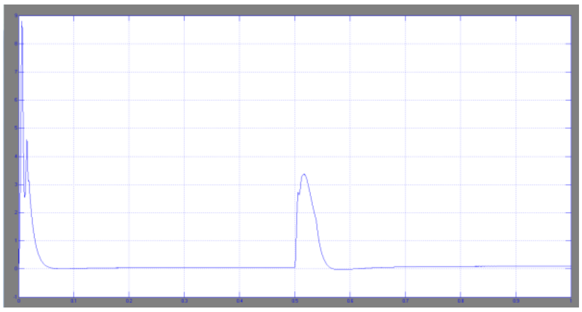
BLDC Motor drive performance with PI based Current Controller at Fixed speed.



SPEED WAVEFORM:



TORQUE WAVEFORM:



CONCLUSION:

A BLDC drive system is controlled with PI and Fuzzy based current controller compared to the conventional motor without current control technique at fixed and variable speeds, the proposed current control system is to increase the speed response of the motor and effective controlling.

Method	Time taken to reach steady state	
	Fixed speed	Variable speed
PI controller	0.3 sec	1500rpm-0.12 sec 3000rpm-0.68 sec
Fuzzy controller	0.2sec	1500rpm- 0.08 sec 3000rpm- 0.64 sec

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