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Speed Control of DC Motor using PID Controller FED H-Bridge

Niharika Mishra, Sameer Bajpai, Esh Narayan

***Abstract:** In the present scenario, DC motor is widely used in industries. So, if DC motor is used for industrial purpose, the controlling is necessary. But there are various methods to control any system or plant such as via Proportional controller (P), Integral controller (I), Derivative controller (D), PI controller, PD controller, PID controller. Each controller is used on the basis of requirement. Proportional controller reduces the rise time, improves the steady state accuracy, and reduces the steady state error. But Integral controllers eliminate the steady state error but the process is too slow so it produces the worse transient response. Derivative controller improves the transient response, reduces the overshoots and improves the stability. So, for obtaining the accurate output of any plant, PID controller is best for many others. And for operating the DC motor in forward and backward both, H-bridge MOSFET is also used in this dissertation. Any other power electronics device is not suitable.*

***Keywords:** Proportional controller (P), Integral controller (I), MOSFET, Derivative controller (D), Matlab etc.*

I.INTRODUCTION

An electrical drive consists of various types of electric motors: AC as well as DC, its power controller and energy transmitting shaft. Power electronic converters are the part of power electronics. In industries and domestic application they are used as power controller. In the form of drives, these converters are mainly of two types:

DC drives are useful for various purposes like speed control etc. There are various important applications of DC drives. In industries for growth purpose, high performance motor drives are very crucial. DC drives are much better than AC drives. They are less costly and less complex than AC drives. DC motors are essentially utilized in the form of speed drives and position control system. Their speed can be modified by below or above rated speed. Their speed below rated speed is controlled through armature voltage and above rated speed is controlled by field flux control. The cost of DC motors are low and they have less complex control structure and de range of speed and torque so due to their features DC motors are mostly used in industry.

For controlling the current and speed of DC motor, current-speed controllers are used. The main operation of these controllers is to reduce the error and the error is calculated by comparing output value with set point (SP). This composition mainly assign with controlling speed of DC motor using H-bridge MOSFET and using PID as speed and current controller.

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II.DESCRIPTION OF COMPONENTS

2.1 DC Motor

At present time, the DC motors are very popular in industries, on the basis of their high performance which required for high regulation, speed controlling of drives. They have variable characteristics. This type of motors are used to provide reversing, good speed regulation, breaking and frequent starting. The speed control methods of these motors are less complex than the AC motors and also they are simple. These motors play a special job in modern industrial drives. At present, the AC motor drives are becoming high competitive with DC motor drives, on the basis of microcomputers, control technique, power conversion. On the basis of advancement and performance of DC drives, they can replace the AC drives. In other way rectifier is also used as a controller and when there is requirement to convert the fixed DC supply to variable DC supply, a power electronic device Chopper is used. Separately excited DC motors and another series excited DC motors, both are essential for variable speed drives. The operating principle of DC motor can be explained with the help of Fleming's left-hand rule.

2.1.1 Classification of DC motor :

Today, in the field of engineering there are various applications of dc motor. On the basis of requirement in industries and others there are various type of dc motors designed.

This classification of DC motor is explained in the tree formation as shown in fig.2.1

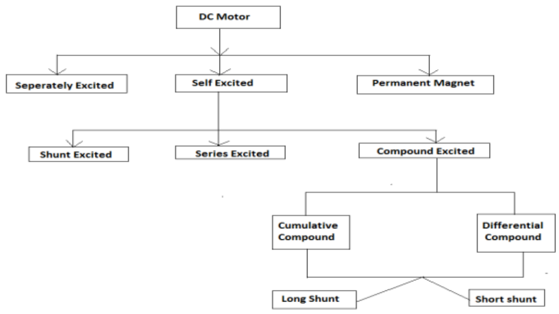

Fig 2.1: Classification of DC motor

2.2 separately excited dc motor:

This type of dc motor has two windings, one is field winding and another is armature winding. These windings are individually connected with supply voltages. Field winding supplies field flux to armature. When DC voltage is provided to motor, current is carrying the path of the armature winding via brushes and commutator.

Rotor is situated in a magnetic field and carries current also. So motor will develop a torque and back emf to balance the load torque at specific speed.

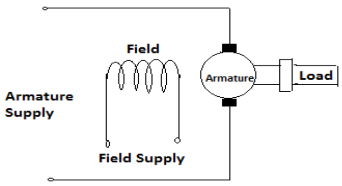

Fig 2.2: Circuit diagram of separately excited dc motor

Mathematical analysis:

When the excitation is provided in this motor, by a field current I_f and an armature current I_a, a torque and back emf is developed to balance the load torque at a specific speed. And the field current is not dependent to armature current Ia. The supply is applied to the each winding is separately. Field current is not affected by any change in armature current. Generally the field current is much less then armature current. . Let,

Armature voltage = V_a in volt,
Armature current = I_a in ampere,
Motor back emf = E_g in volt,
Armature inductance = L_a in Henry,
Armature resistance = R_a in ohm.

The equation of armature is shown below:

$$V_a = E_g + I_aR_a + L_a\frac{dIa}{dt} \quad \text{...........} (1)$$

Now the torque equation:

$$T_d = J\frac{d\omega}{dt} + B\omega + T_l \quad \text{.........} (2)$$

Where,
T_l = load torque in Nm,
T_d = torque developed in Nm,
J = moment of inertia in kg/m²,
B = friction coefficient of the motor
ω = angular velocity in rad/sec.

Assuming friction in rotor of motor is negligible, it will B=0.

Therefore, new torque equation will be given by:

$$T_d = J\frac{d\omega}{dt} + T_l \quad \text{....................} (3)$$

Equation for back emf of motor will be:

$E_g = K\Phi I_a$ .... (4)
Also, $T_d = K\Phi I_a$ .... (5)
$W = (V_a - I_aR_a) / K\Phi$ ....(6)

Now, from equations 4,5,6 it is clear that speed of DC motor depends on four parameters.

III.REVIEW OF LITRATURE

This chapter deals with the survey of various research papers that have contributed the ideas of speed controlling of DC motor with the help of different type controllers. **Saman Javed, Sumit Jha, Hasan Sajid, Vishu Kumar** Gives the effective and provide precise output so application of DC motor is large for commercial purpose. **D.K Yadav, S. M. Tripathi, S.K. Sinha DC** motor drive has been presented in this paper. The performances of the drive employing PI controller are evaluated analytically for different speed variations and changes in load torque using MATLAB/SIMULINK. The performance of drive system has been found satisfactory. [13]

3.1 CONTROLLER

Various control systems in industries are based on conventional PID (Proportional Integral-Derivative) regulators. PID controllers are estimated the accuracy between 90% and 99%.

The reasons are following:

1. PID controllers are simple in construction basis and they also are robust.

2. It has a strong relationship between system response parameters and PID. PID controller has three parameters, and plant operators have knowledge about the controlling of the parameters and defined response characteristics.

3. Various techniques for tuning of PID have been complex during fresh decades.

4. Because of its nature of flexibility, PID controller could convenience from the modern in technology. Many controllers used in industry have been given with unique process to

Types of controllers:- There are three individual controllers which are given below:

But in industries on requirement basis these controller may combined with each other and behaves like as PI, PID, PD controllers.

The individual description of all three controllers is given below:

a) Proportional Controllers :-

A proportional controller Kp is processed to the control mechanism which is directly proportional to the error between set point SP (desired value) and process value PV (measured value).It will reduce rise time and also improve the steady state accuracy by decreasing Steady State Error but it will never eliminate Steady State Error. $\mathbf{P = K_P\, e(t)}$. The block diagram of proportional controller is shown in figure, consists simple gain value. Where u represents the reference input, y represents the output and K is the proportional gain.

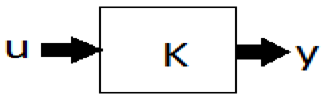

Fig 3.1: Block diagram

b) Derivative Controllers :-

A derivative controller Kd is processed to the control mechanism which is directly proportional to the derivative of error signal (SP-PV). It will increase the stability of any control system and reduce the overshoot and improve the transient response

$$D = K_d\frac{de(t)}{dt}$$

When Laplace is implemented in the derivative controller then the derivative gain is represented in block diagram.

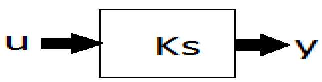

Fig 3.2: Block diagram

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c) Integral Controllers :

An integral controller Ki is processed to the control mechanism which is directly proportional to the integral of error signal (SP-PV). It will eliminate steady state error but due to slowly processing it will produce the worse transient response.

$$I = K_i \int_0^t e(t)dt$$

When Laplace is implemented in the integral controller then the integral gain is represented in block diagram

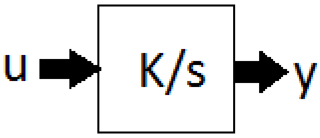

Fig 3.3: Block diagram

3.2 Types of Feedback Control Loops:

A system in which controlling is provided by maintain the relationship of one variable to another with the help of comparing the function.

Feedback control loops are basically two:

4. Open loop feedback control system:

In this system, the controlling of the controller is not dependent to the process variable" (PV).When we discuss about Central heating boiler, it is only controlled by timer, so heat provides for a continuously over a period of time. So the boiler can be controlled by switch on or switch off.

5. Closed loop feedback control system:

In this control system, the controlling operation of the controller is dependent on feedback. When we discuss about boiler, a closed loop is used in a thermostat to differentiate the temperature which is build (PV) with set point (SP) of the temperature on the thermostat. By this a controller output is generated to maintain the process variable at the required temperature with the help of boiler on and off. This control system consists a feedback loop

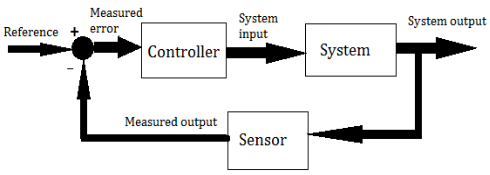

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Fig 3.4: Block diagram of feedback control system

In the theory of control system the main uses of the controllers are given below:

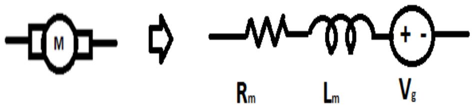
- Controllers enhance the accuracy of steady state and the steady state errors decrease.
- The stability improves with improving the steady state accuracy.
- It helps to reduce the offsets in the system.
- This controller can control the maximum overshoot.
- This controller can also reduce the noise signals.
- By these controllers worse transient feedback of the system can become faster.

IV.PRASENT WORK

This section discusses the foundational basics of controlling the speed of DC motor. It also contains a brief overview of H-Bridge MOSFET Fed chopper using PID controller.

4.1 H-Bridge formation

This type of circuit is basically used in various applications where requirement of Direct Current motors to run backward direction and forward direction. On the basis of its graphical representation this circuit is called the H-bridge because of this circuit all four switching components are connected in H pattern. We can say, an electronic revolution that provides a voltage to apply over the load in opposite way is called H-Bridge. H-bridge circuits are used to control the both speed of motor and direction of motor. In other words, H-Bridge contains four switching segments and also loads at centre as showing fig 4.1.



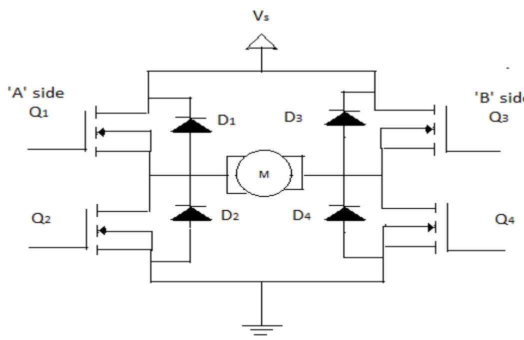


Fig 4.2: H-bridge using MOSFET

Fig.:4.1 Motor elements

In the above figure Q_1, Q_2, Q_3, Q_4 are basically switching devices behave like as bi-polor or FET transistors. Diodes D_1, D_2, D_3, D_4 are the catch diodes which behave like as schottky diodes. When **Insulated Gate Field Effect Transistor** is used in different type of electronic circuit is called **MOSFET**. The top end of the circuit is connected to source V_s it can be battery and the bottom end of the circuit is connected to ground. **Working Of H-bridge**

The working of H-bridge consists mainly two modes. The discussions of these modes are given below:

MODE 1:- When Q_1 & Q_4 are turned on:- Firstly the two elements Q_1 & Q_4 are turned on then the direction of current flow from V_s to Q_1 to Motor to Q_4 to Ground. The circuit is completed from source to ground. In this way during Q_1 & Q_4 turned on, the motor will energized.

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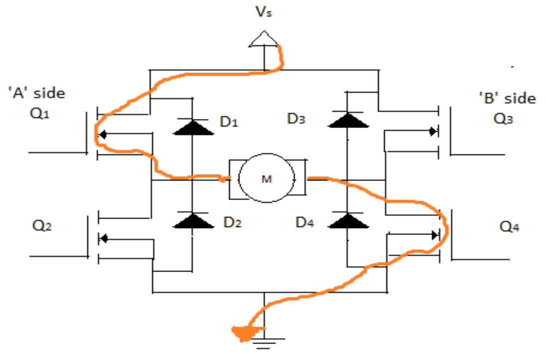

Fig 4.3: Operation of Q_1 & Q_4

MODE 2:- When Q_2 & Q_3 are turned on :- Now the next two elements Q_2 & Q_3 are turned on then the direction of current flow from V_s to Q_3 to Motor to Q_2 to Ground. The circuit is completed from source to ground. In this way during Q_3 & Q_2 turned on, the motor will energize in reverse direction.

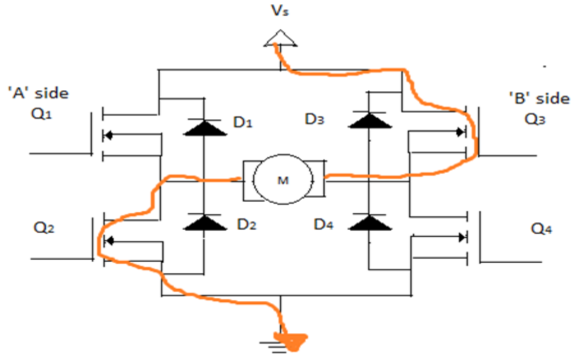

Fig 4.4: Operation of Q_2 & Q_3

In this H-bridge operation , we should never operate two elements ' Q_1 & Q_2' OR 'Q_3 & Q_4' at the same time. If we close the 'Q_1 & Q_2' OR 'Q_3 & Q_4' at the same time then there is very low resistance path will created between power and ground and due to this short circuitry will be created and whole H-bridge will destroy.

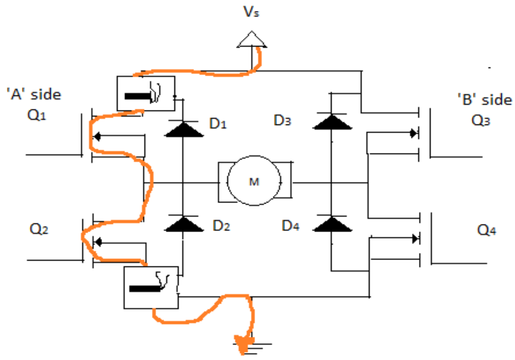

Fig 4.5: Operation of Q_1 & Q_2

4.2 Description of MOSFET

MOSFET is a class of semiconductor and differ from all other semiconducting devices. The full name of MOSFET is METAL OXIDE FIELD EFFECT TRANSISTOR which amplifies the input signal. It also produce an output current and voltage gain into an external load that overreach the input current and voltage. The fabrication of MOSFET is processed by controlling of oxidation of silicon. Basically the meaning of oxidation is to assemble the oxide on the surface of semiconductor in MOSFET which is called the substrate. Basically MOSFETs are used in H-Bridge on the basis of their advantage over the BJT. MOSFET requires almost zero current in input to control the load current, where as BJT requires base current flow the collector. At present time MOSFET is most preferred switching device which is used in the chopper circuits. MOSFET has zero storage time and it is also voltage controlled device. Generally MOSFET is used in various applications because of no any storage time for minority carrier and it is also suitable for switching of high recurrence (frequency).

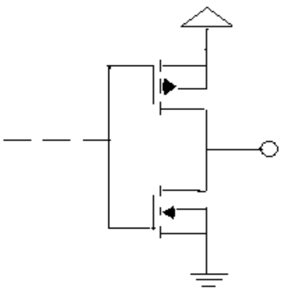

Fig 4.6: Symbol of MOSFET

4.3 Key parameters of MOSFET:

- Source drain resistance: A device is on over the drain and load, and then the measured resistance is source drain resistance.
- Drain source voltage: Drain source voltage is also represented by V_{DS} which is applied over drain and source points of MOSFET.
- Drain current: It is also represented by I_D .It is a maximum current which the drain can contain to protect the device from hazards.
- Gate charge: It is an amount of charge which required to switch the gate from ON to OFF, and OFF to ON.

S. No.	Title	Switching Device	Supply Voltage (V)	RPM range (rpm)
1.	Speed control of DC motor using IGBT	IGBT	220-440V AC supply	Induction motor(4 pole) (2500rpm)
2.	Speed control of DC motor using Thyristor	Thyristor	AC 240	Induction motor(4 pole) (2050rpm)
3.	Speed control of DC motor using BJT	BJT	220V AC supply	5000rpm
4.	Speed control of DC motor using MOSFET	MOSFET	220V AC supply	40 to 2500rpm

Fig 4.7: Comparison table of switching devices

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This above table gives the proper comparison among various switching devices like IGBT, Thyristor, BJT, and MOSFET. These all devices are differing to each other on the basis of their supply voltage and RPM range. From the above table it is clear that MOSFET is more and more efficient for speed control system of DC motor because the RPM range of MOSFET can be varied from 40-2500 rpm and it can be perfectly control the speed of motor.

4.4 Research Method:

MATLAB executes powerful graphics capability, simulink module library and computing power which execute results in most of the electrical engineering programme. For example, in circuit analysis, electronics control systems such experiment. During the preparation process firstly set up a simulink model then obtain simulation experimental data and its analysis. Thus makes better composite of theoretical and practical analysis, further inspire students to think-solving skills, problem-solving ability and greater interest in students learning. If any circuit designed using this software, it will have high accuracy and easy computation.

4.5 Objectives:

The major objectives of this research are given below:-

- The main motive of this research is to maintain the performance of DC motor using a Bridge which consist four MOSFETs.
- For achieving the desired speed of motor, the firing circuit of H-bridge receives signal from PID controller and then supply the variable voltage to motor armature.
- Using MOSFET based circuit, the entire speed range of the motor can control smoothly as compared to other switching devices.
- With the help of PID controller, it may be possible to control a plant satisfactorily without full information about the transfer functions and characteristics of that plant. This is usually achieved by tuning which could be done automatically or manually via a tuning/optimization algorithm.

4.6 Methodology

Accurate performance of a motor is desired feature for any industrial application. Generally the performance of any motor decreases, as their duration of installation increases, so it is necessary to evaluate the performance of motor from time to time for efficient operation, The conventional method for calculating output performance indices are quite time consuming. An approach based on PID controller, system worked satisfactorily. The main methodology during this analysis is given below:-

1) In the test system PID controller is used, for more and better performance over other controller

2) A proportional controller Kp is processed to the control mechanism which is directly proportional to the error between set point SP (desired value) and process value PV (measured value).It will reduce rise time and also improve the steady state accuracy by decreasing Steady State Error but it will never eliminate Steady State Error.

$$P = K_P\, e(t)$$

1) An integral controller Ki is processed to the control mechanism which is directly proportional to the integral of error signal (SP-PV). It will eliminate steady state error but due to slowly processing it will produce the worse transient response.

$$I = K_i \int_0^t e(t)dt$$

2) A derivative controller Kd is processed to the control mechanism which is directly proportional to the derivative of error signal (SP-PV). It will increase the stability of any control system and reduce the overshoot and improve the transient response.

$$D = K_d \frac{de(t)}{dt}$$

3) With the help of PID controller, the output performance of the system is very near to accuracy.

4) For the simulation of project, MATLAB is very sophisticated and convenient software.

The close loop response of all controllers on behalf of rise time, overshoots, settling time and steady state error are given below:-

Close loop response	Rise Time (sec)	Maximum overshoots (%)	Settling time (sec)	Steady state error
As increase of K_P	Decrease	Increase	Small change	Decrease
As increase of K_i	Decrease	Increase	Increase	Eliminate
As increase of K_D	Small change	Decrease	Decrease	Small change

4.7 Simulation Circuit

Simulation Circuit of H-BRIDGE The H-Bridge block represents an H-bridge motor driver. The block has the following two Simulation mode options:

Repeating Sequence - The H-Bridge output is a controlled voltage that depends on the input signal at the repeating sequence port.

Averaged — this mode has two Load current characteristics options.

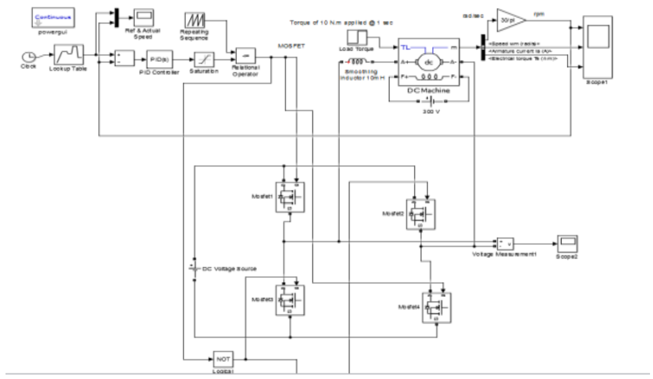

Fig 4.9: Simulation Circuit of Speed control of DC motor using PID controller Fed H-Brig

The simulation circuit of H-Bridge is shown in the given Fig consisting the various blocks:-

H-bridge using MOSFET

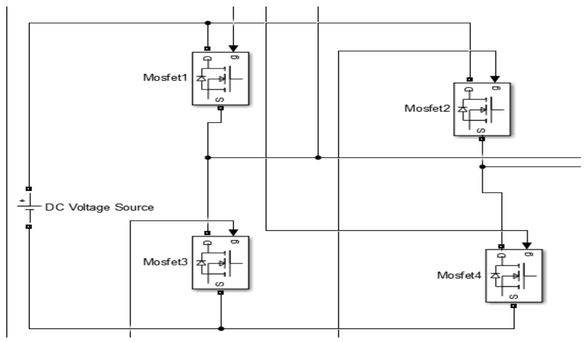

Fig 4.10 H-Bridge circuit

4.8 Parameters used in H-BRIDGE with Table

MOSFET and internal diode in parallel with a series RC snobbier circuit, When a Gate signal is applied the MOSFET conduct and act as a resistance (Ron) in both directions. If the gate signal falls to zero when circuit is negative, current is transferred to the anti parallel diode.

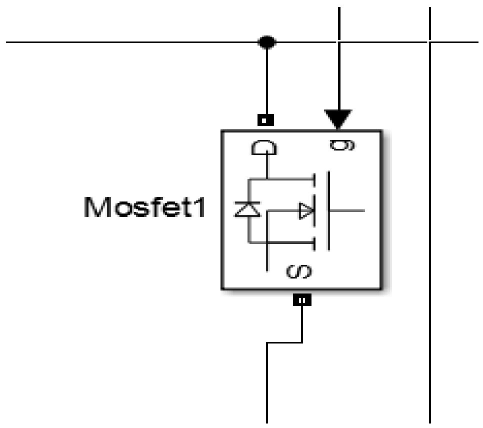

Fig 4.11: Representation of MOSFET in Matlab simulink

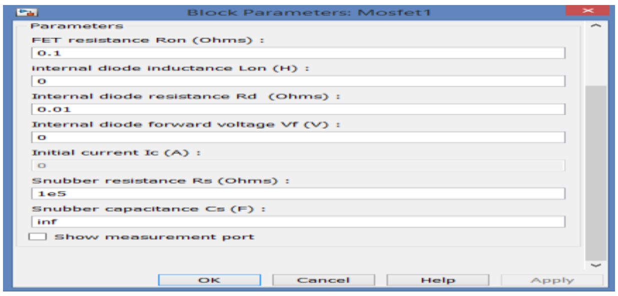

Fig 4.12: Block Parameter of MOSFET1

Above figure represents the actual parameters of MOSFET1 used in H-bridge. It shows all values of MOFET like internal diode resistance, internal diode forward voltage etc. There are four MOSFETs are connected in the form of proper pattern, they behave like as switches in the H-bridge. The switching of these four MOSFETs is maintained with the help of NOT GATE.

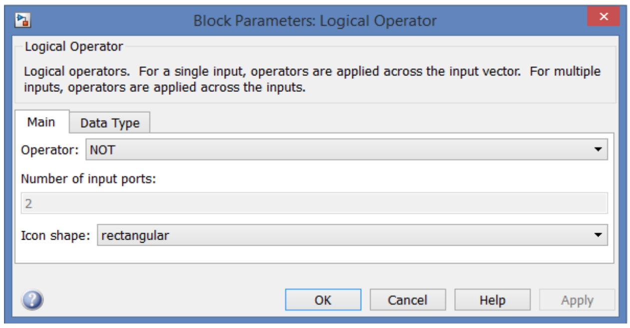

Fig 4.13: Block Parameter of NOT GATE

- **DC MACHINE:** For the wound field DC machine, access is provided to the field connections. So that the machine can be used as separately excited, shunt-connected or series connected DC machine

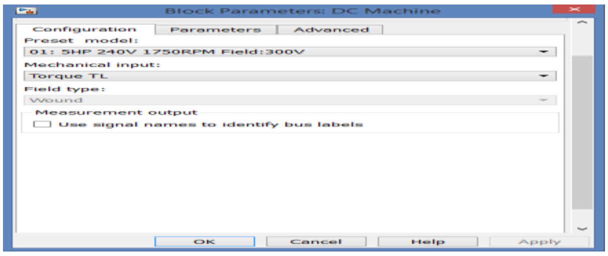

Fig 4.14: Block Parameter of DC machine

V.RESULTS AND DISCUSSION

Since the data analysis we are using MATLAB software. The MATLAB software is used to give actual graphical analysis of the whole circuit. Through the MATLAB we can analyze the graphical performance with change in type of controllers (PI & PID controller).

By MATLAB software it is clarify that how PID controller is better than PI controller.

Using PI controller: A proportional controller Kp is processed to the control mechanism which is directly proportional to the error between set point SP (desired value) and process value PV (measured value).It will reduce rise time and also improve the steady state accuracy by decreasing Steady State Error but it will never eliminate Steady State Error.

$$P = K_P\, e(t)$$

An integral controller Ki is processed to the control mechanism which is directly proportional to the integral of error signal (SP-PV). It will eliminate steady state error but due to slowly processing it will produce the worse transient response.

$$I = K_i \int_0^t e(t)dt$$

So that, when proportional controller and integral controller both are processed together, they formed as PI controller. Basically PI controller reduce the rise time, remove the steady state error but transient response is worse. In MATLAB simulink, the block parameter representation of PI controller is shown in Fig. 5.1

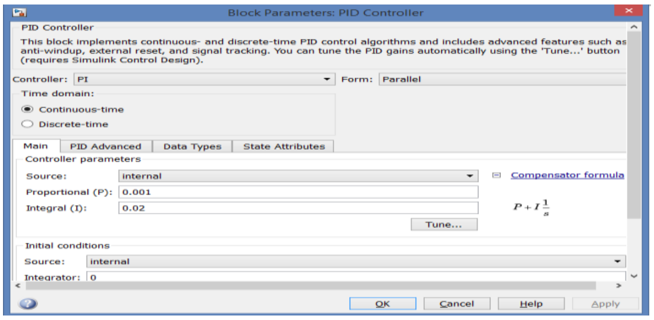

Fig 5.1 Block representation of PI controller

PI controller always eliminates the steady state error but the slowly process and transient response is also worse. It is representing with the help of Reference & Actual Speed graph as shown below.

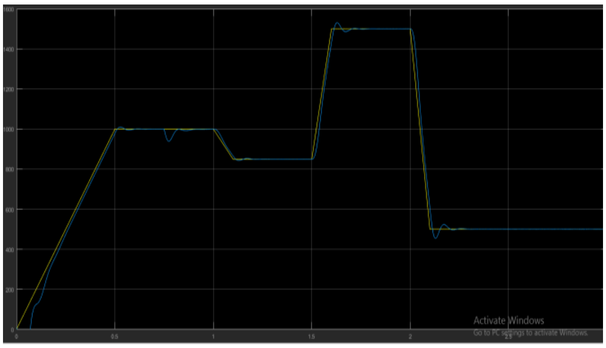

Fig 5.2 Reference & actual Speed graph

In the above reference & actual speed graph, YELLOW line represents REFERENCE value and BLUE line represents ACTUAL value. So this blue line clears the slow processing and worse transient response. Fig 5.3 represents the final output of DC motor using PI controller with armature current and electric torque.

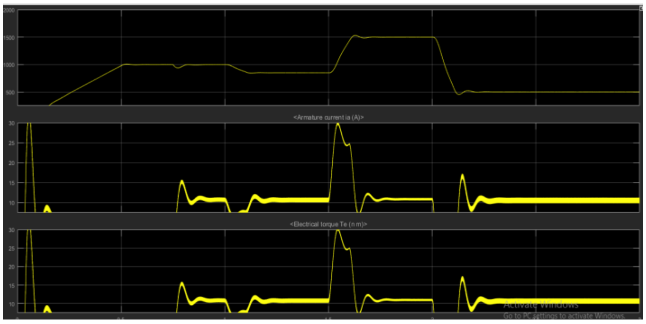

Fig 5.3 Graph of Scope1

Using PID Controller

When derivative controller is processed with PI controller then this controller behaves as PID controller. A derivative controller Kd is processed to the control mechanism which is directly proportional to the derivative of error signal (SP-PV). It will increase the stability of any control system and reduce the overshoot and improve the transient response. So it can say that, PID controller consists the whole features of P,I,D controllers.

With the help of PID controller the stability of the system is improved, transient response is improved and overshoots are reduced. The response of the DC motor using PID controller in Matlab simulink is shown by the given parameter and graph.

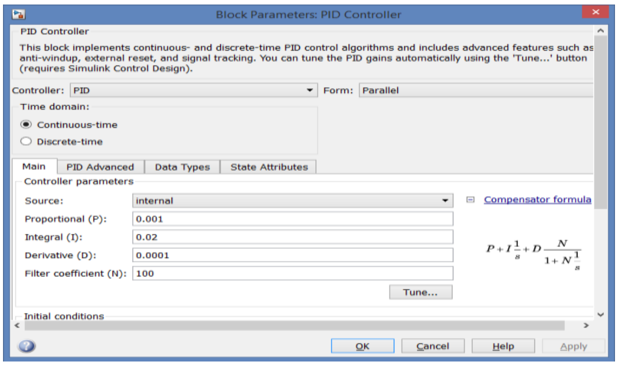

Fig 5.4 Block representation of PID controller

PID controller is best for stability but it also has some specific range or value of P, I, D. In fig 5.4 values of P,I,D are mentioned. But when we run the model then the reference and actual speed graph is not in favor, as shown in fig5.5. When we apply the value of P = 0.001, I = 0.02, D = 0.0001 then the graph of actual and reference speed is given below:

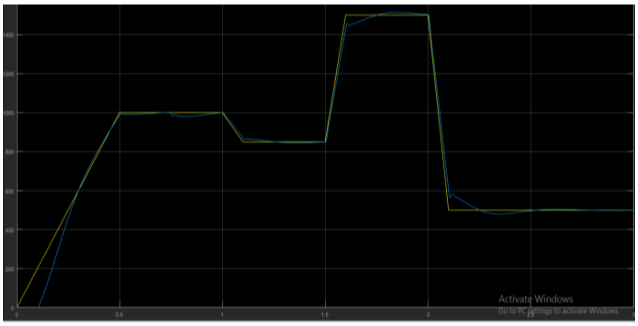

Fig 5.5 Reference & actual Speed graph

And the output response of Dc motor measured by scope1 is given below:

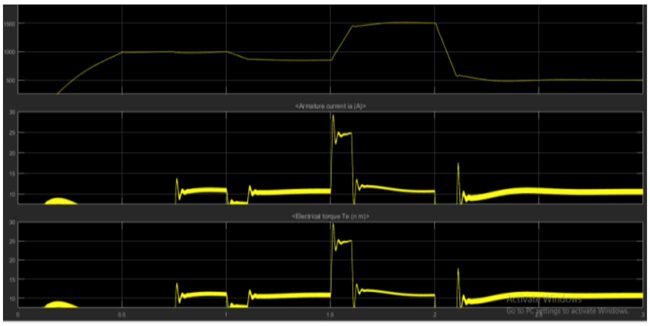

Fig 5.6 Graph of Scope1

In this way at different values of P, I, D in block parameter the graph of reference and actual speed are differ. After applying many values it is find that for some specific range of P, I, D the output become stable. The range of P, I, D between which the graph will accurate, given below:

P = 1-50, I = 5-15, D = 0.01 – 1 Approx.

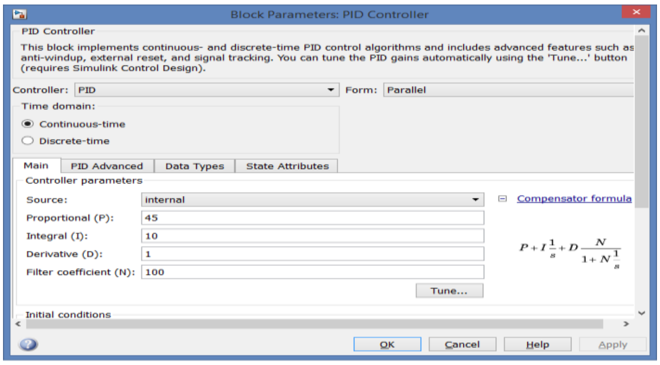

Fig 5.7 Block representation of PID controller

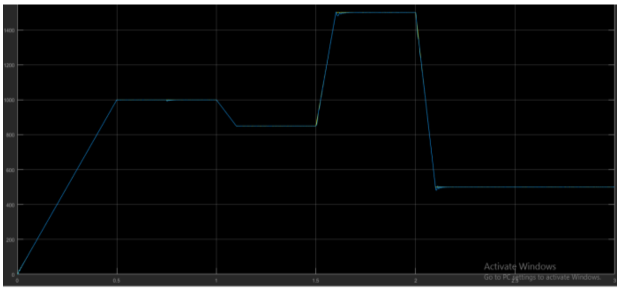

Fig 5.8 Reference & actual Speed graph

And the response of DC motor from scope1 is given below:

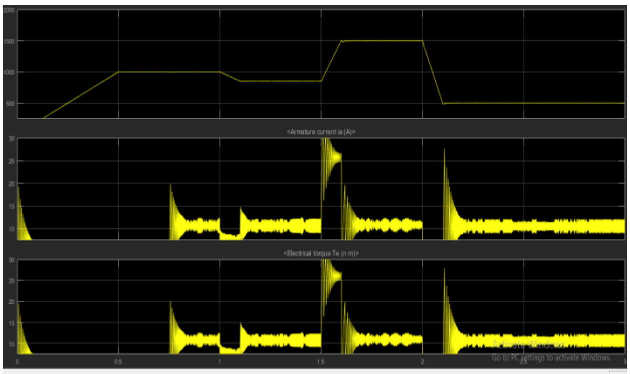

Fig 5.9 Graph of Scope1

VI.CONCLUSION AND FUTURE SCOPE

In this research, the main aim to review various literatures for the classical controller techniques introduced by the different researchers for controlling with PID controller to control the motor speed to optimize the best result. This review article is also presenting the Armature current status and Electric Torque which control motor speed with the help of classical PID controller technique.

6.1 Conclusion

The speed of DC motor has been successfully controlled with the help of MOSFET fed H-Bridge circuit. In H-Bridge the four quadrants operation is done in MATLAB Simulink. The results also similar to the identical, The various operations of motor like Start, Stop, Reverse Braking, Forward braking, Increasing the speed and also Decreasing the speed of motor is also achieved. From the results we know that the proportional controller (k_p) is processed to reduce the rise time; but never reduce steady-state error and an integral controller (k_i) is processed to eliminate steady-state error, but it produces the transient response worse and derivative controller (k_d) is also processed to control the mechanism. It will amplify the stability of any control system and reduce the overshoot and make batter the transient response.

6.2 Future Scopes

The above described model has been run and tested successfully in MATLAB simulation, so there lays the opportunity to implement the above described model in industry and study the impact of the approach taken in this thesis report.
Moreover in this report we have analyzed only the impact of the approach on separately excited dc motor so there lies the scope to extend the study to various other kind of motors. Also here we have done to control the speed of motor below its rated speed so analysis can also be extended to study the dynamics for above the rated speed using field flux control. The industrial application needs high performance motor drives. Generally the highly efficient motor drive is a type of motor drive in which a drive system should have the capability to track the dynamic speed and good load regulating response. Therefore in future acceleration of the dc motor provides outstanding control in speed and deceleration also.

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