Modeling and simulation of P, PI and PID controller for speed control of DC Motor Drive

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Abstract**—**The thyristor d.c. drive remains an important speed-controlled industrial drive, especially where the higher maintenance cost associated with the d.c. motor brushes compared with induction motor is tolerable. The controlled rectifier provides a low-impedance adjustable 'd.c.' voltage for the motor armature, thereby providing speed control. The DC Motor Drives are increasingly applied in many recent industrial applications that require excellent transient performance of drives. In general the role of controller is very crucial in the control of drive for transient and dynamic conditions. This paper has been attempted to presents the Comparative study of Proportional (P), Proportional Integral (PI), and Proportional Integral Derivative (PID) controller for speed control of DC Motor Drive. The performance of P, PI and PID controller is studied and compared. A proposed DC Motor Drive have a precise speed control, stable operation in complete range of speed and good transient behavior with smooth and step less control.

Keywords—DC Motor Drive, Speed Control, P , PI , PID Controller.

I. INTRODUCTION

Until the 1960s, the way of obtaining the variable-voltage d.c. supply needed for speed control of an industrial d.c. motor was to generate it with a d.c. generator. The generator [1] was driven at fixed speed by an induction motor, and the field of the generator was varied in order to vary the generated voltage.

The motor/generator (MG) set could be sited remote from the d.c. motor, and multi-drive sites (e.g. steel works) would have large rooms full of MG sets, one for each variable-speed motor on the plant. Three machines (all of the same power rating) were required for each of these 'Ward Leonard' drives [2], which was good business for the motor manufacturer. For a brief period in the 1960s they were superseded by grid-controlled mercury arc rectifiers, but these were soon replaced by thyristor converters having low cost, higher efficiency (typically over 95%), smaller size, reduced maintenance, and faster response to changes in set speed.[3]

The disadvantages of rectified supplies are that the waveforms are not pure d.c. which limits the overload capacity of the converter and that a single converter is not capable of regeneration[4]. Though no longer pre-eminent, study of the d.c. drive is valuable for several reasons:

- The structure and operation of the d.c. drive are reflected in almost all other drives, and lessons learned from the study of the d.c. drive therefore have close parallels to other types.[5]
- The d.c. drive tends to remain the yardstick by which other drives are judged.
- Under constant-flux conditions [6] the behaviour is governed by a relatively simple set of linear equations, so predicting both steady-state and transient behaviour is not difficult. When we turn to the successors of the d.c. drive, notably the induction motor drive, we will find that things are much more complex, and that in order to overcome the poor transient behaviour, the strategies adopted are based on emulating the d.c. drive.

II. DC MOTOR DRIVE

Direct current (DC) motor has already become an important drive configuration for many applications across a wide range of powers and speeds. The ease of control and excellent performance of the DC motors will ensure that the number of applications using them will continue to grow for the foreseeable future.

An Electrical Motor Drive is defined as a form of machine equipment consist of Electric Motor together with its electronic control equipment & energy transmitting links design to convert electrical energy into mechanical energy and provide electronics control of this process.[7].

The arrangement shown in Fig.1 is typical of the majority of d.c. drives and provides for closed-loop speed control.

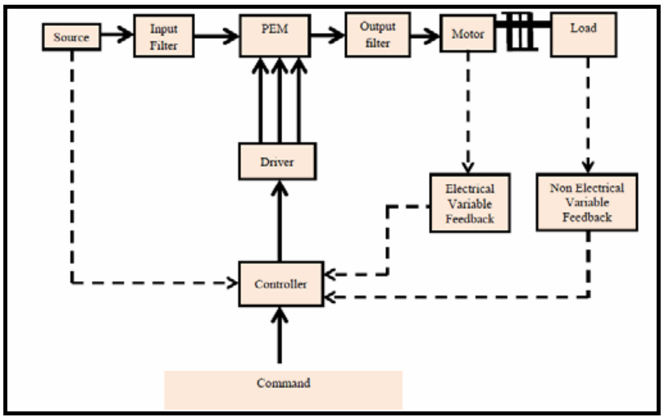

Fig. 1. Block Diagram of DC Motor Drives

The main power circuit consists of a six-thyristor bridge circuit which rectifies the incoming a.c. supply to produce a d.c. supply to the motor armature. The assembly of thyristors, mounted on a heat sink, is usually referred to as the 'stack'. By altering the firing angle of the thyristors the mean value of the rectified voltage can be varied, thereby allowing the motor speed to be controlled.

The controlled rectifier produces a crude form of d.c. with a pronounced ripple in the output voltage. This ripple component gives rise to pulsating currents and fluxes in the motor, and in order to avoid excessive eddy-current losses and commutation problems, the poles and frame should be of laminated construction [8].

We know that motors supplied through thyristor drives have laminated construction, but older motors often have solid poles and/or frames, and these will not always work satisfactorily with a rectifier supply. It is also the norm for drive motors to be supplied with an attached 'blower' motor as standard. This provides continuous through ventilation and allows the motor to operate continuously at full torque even down to the lowest speeds without overheating.

Low power control circuits are used to monitor the principal variables of interest (usually motor current and speed), and to generate appropriate firing pulses so that the motor maintains constant speed despite variations in the load. The 'speed reference' is typically an analogue voltage varying from 0 to 10 V, and obtained from a manual speed-setting potentiometer or from elsewhere in the plant.

The combination of power, control, and protective circuits constitutes the converter. Standard modular converters are available as off-the-shelf items in sizes from 0.5 kW up to several hundred kW, while larger drives will be tailored to individual requirements. Individual converters may be mounted in enclosures with isolators, fuses etc., or groups of converters may be mounted together to form a multi-motor drive.

A. Parts of DC Motor Drives

1) Input source:

For motors up to a few kilowatts the armature converter can be supplied from either single-phase or three-phase mains, but for larger motors three-phase is always used. A separate thyristor or diode rectifier is used to supply the field of the motor: the power is much less than the armature power, so the supply is often single-phase is used.

Very low power drives are generally fed from single-phase sources; low and medium power motors are fed from three-phase 400 V supply, large motors may be rated at 3.3 KV, 6.6 KV and 11 KV.

Some drives are powered from a battery voltage may be 24 V, 48 V or 110 V dc. For the aircraft and space application 115 V, 400 HZ supply is used. For line traction application 65 KV, 50 HZ supply used and for underground traction application 500 To 759 KV DC supply is utilized.[9]

2) Input and Output filters:

The electronic filters are circuits which perform signal processing functions, specifically to remove unwanted frequency component from the signal, A power supply must provide ripple free source of power from an A.C. line. But the output of a rectifier circuit contains ripple components in addition to a D.C. term.

It is necessary to include a filter between the rectifier and the loads in order to eliminate these ripple components. Ripple components are high frequency A.C. Signals in the D.C output of the rectifier. These are not desirable, so they must be filtered. So filter circuits are used.

3) Power Electronics Modulators (PEM):

A Power Electronics Modulator (PEM)[10] is a heart of Power Electronics System which modulates the power available from the source as required by the load with the command input given by controller.

The power modulator performs the following functions:

i. It modulates the flow of power from the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load.
ii. It restricts source and motor current to permissible limits during transient operations, such as starting, braking and speed reversal.
iii. It converts the electrical energy of the source in the from suitable to the motor. Example, if the source is dc and an induction motor is to be employed, then the power modulator is required to convert dc in to a variable frequency ac.
iv. It selects the mode of operation of the motor i.e. motoring and braking.

4) Controller:

The controls for a power modulator are provides in the control unit. The nature of the control unit for a particular drive depends on the power modulator that used.

When semiconductor converters are used, the control unit consists of firing circuits which employ linear and Digital Integrated Circuits, transistors and microprocessor are used when sophisticated control is required.

Control for power electronics modulator is built in control unit which usually operates at much lower voltage and power levels. In addition to operating the power electronics modulator it may also generate commands for the protection of power electronic modulators and motors. Input command signal which adjusting the operating point of the drive by analyzing the feedback signal in the controller.

The controller is realized with analog and integrated circuits. The present trend is to use microprocessors, single chip modulators, Digital Signal Processors (DSP), VLSI and special custom chips known as Application Specifics ICs (ASIC) to embody a set of functions in the controller [11].

5) Sensors:

Speed sensing is required for implementation of closed loop speed control schemes. Speed is usually sensed by using tachometers.

Two commonly used methods of sensing the current are: (i) using current sensors employing Hall Effect, and (ii) Using a non-inductive resistance shunt in conjunction with an isolation amplifier, which has an arrangement for amplification and isolation between the power and control circuits.

6) Energy transmitting link:

The energy transmitting link is placed between motor / equipment and load. It provides speed and torque conversions from a rotating power source to another device.

There are basically four different methods for energy transmitting links like:

i. Direct coupling method
ii. Using chain
iii. Using belt coupling
iv. Gear Drives

II. CONTROL SYSTEM DESIGN

Control for power electronics modulator is built in control unit which usually operates at much lower voltage and power levels. In addition to operating the power electronics modulator it may also generate commands for the protection of power electronic modulators and motors. Input command signal which adjusting the operating point of the drive by analyzing the feedback signal in the controller [12].

PID controllers use three basic behavior types of modes:

P-proportional, I- integral and D- derivative. While Proportional and integrative modes are also used as signal control modes a derivative mode is rarely used on it's own in control systems. Combinations such as PI and PID controller are very often used in practical systems [13].

A. Proportional (P) Controller

A Proportional controller [14] system is a type of linear feedback control system. The P controller system is more complex than on-off control systems like a bi-metallic domestic thermostat, but simpler than a PID control system used in something like an automobile cruise control. In general it can be said that P controller cannot stabilize higher order processes.

For the 1st order processes, meaning the processes with one energy storage, a large increase in gain can be tolerated.

Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics. A large controller gain will result in control system with:

a) Smaller steady state error, i.e. better reference follower
b) Faster dynamics, i.e. broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise
c) Smaller amplitude and phase margin.

In the P controller algorithm [15], the controller output is proportional to the error signal, which is the difference between the set point and the process variable. In P controller the actuating signal for the control action in a control system is proportional to the error signal. The error signal being the difference between the reference input signal and feedback signal obtained from the output.

For the system considered as shown in the Fig. 2. The actuating signal is proportional to the error signal therefore; the system is called P controller system.

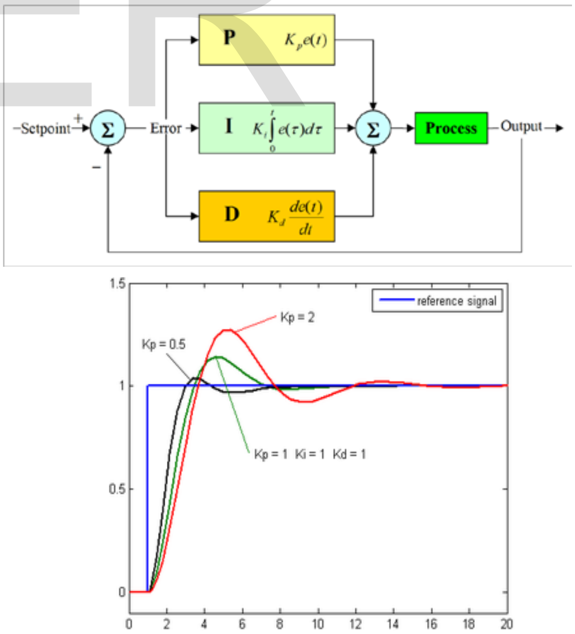

Fig. 2. Block Diagram and Response of P Controller

The error of signal given as follows:

$$e(t) = k[r(t) - h(t)] \quad (1)$$

It is desirable that the control system be under damped for the point of view of quick response. An under damped control system exhibits exponentially decaying in the output time response during the transient period.

B. *Proportional Integral (PI) Controller*

At present, the PI controller [16] is most widely adopted in industrial application due to its simple structure, easy to design and low cost. Despite these advantages, the PI controller fails when the controlled object is highly nonlinear and uncertain. PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller. PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when [17] [18],

1. Fast response of the system is not required
2. Large disturbances and noise are present during operation of the process
3. There is only one energy storage in process (capacitive or inductive)
4. There are large transport delays in the system.

Therefore, we would like to keep the advantages of the PI controller. This leads to propose a PI controller shown in Fig. 3. This controller uses of the proportional term while the integral term is kept, unchanged.

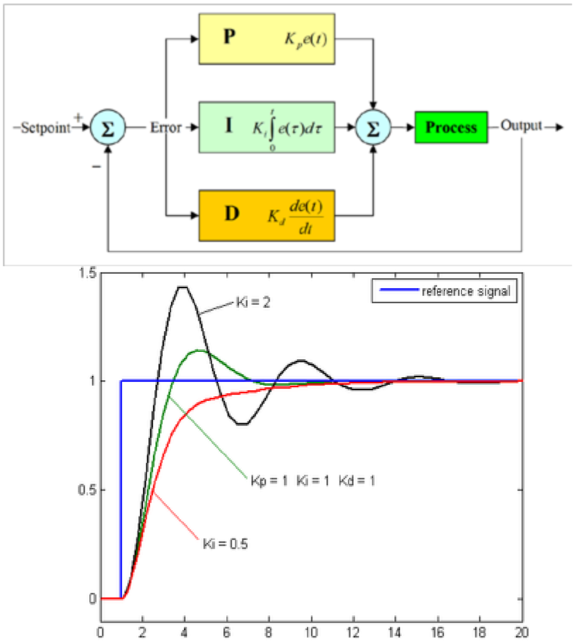

Fig. 3. Block Diagram and Response of PI Controller

The controller output in this case is

$$u(t) = K_p \, . \, e(t) + K_i \int e(t)\, dt \qquad (2)$$

Fig. 3.block diagram PI controller an integral error compensation scheme, the output response depends in some manner upon the integral of the actuating signal. This type of compensation is introduced by a using controller which produces an output signal consisting of two terms, one proportional to the actuating signal and the other proportional to its integral. Such a controller is called proportional plus integral controller or PI controller[19].

C. *Proportional Integral Derivative (PID) Controller*.

Many industrial controllers employ a proportional, integral plus differential PID regulator arrangement that can be tailored to optimize a particular control system. PID controller [20] is most commonly used algorithm for controller design and it is most widely used controller in industry. The controllers used in industry are either PID controller or its improved version. The basic types of PID controller are parallel controller, serial controller, and mixed controller. The PID controller algorithm utilized for is design velocity algorithm, it is also called incremental algorithm. In the industry, PID controllers are the most common control methodology to use in real applications.

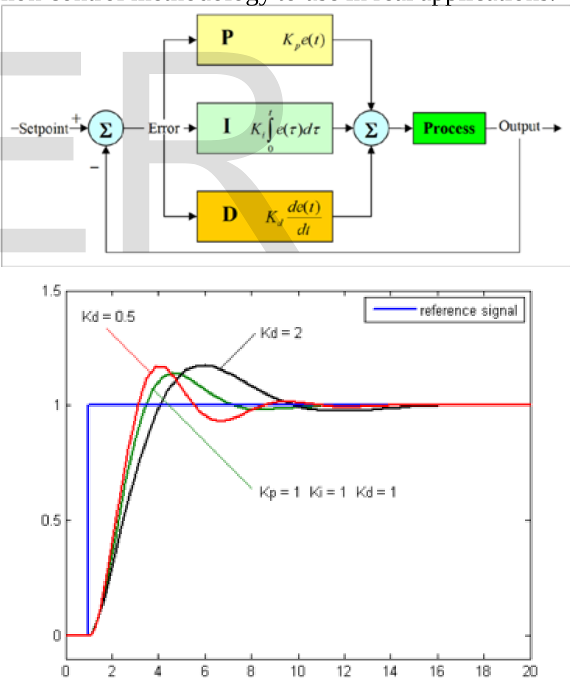

Fig. 4. Block Diagram and Response of PID Controller

PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode).Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant Ti, which increases speed of the controller response.PID controllers are the most often used controllers in the process industry. The majority of control systems in the world are operated PID controllers. It has been reported [21] that 98% of the control loops in the pulp and paper industries are controlled by single-input single output PI controllers and that in process control applications, more than 95% of the controllers [22] are of the PID type controller. PID controller combines the advantage of proportional, derivative and integral control action.

The control signal is proportional to the error signal and the proportional gain K_p. A proportional controller will have the effect of reducing the rise time and will reduce, but never eliminate. If an integrator is added, the control signal is proportional to the integral of error and the integral gain K_i. Integral control will have the effect of reduced the error, in principle, to zero value. The in principle must be added, because there are always limits on accuracy in any system. Derivative control is used to anticipate the future behavior of the error signal by using corrective actions based on the rate of change in the error signal. The control signal is proportional to the derivative of the error and K_d is the derivative gain.

$$u(t)=K_p.e(t)+K_i\int e(t)\,dt+K_d\frac{de(t)}{dt} \qquad (3)$$

Derivative control will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Derivative control action can never be used alone because this control action is effective only during transient periods. The PID controller makes a control loop respond faster with less overshoot and most popular method of control by a great margin. The combined action has the advantages of each of the three individual control actions.

D. *Selection of Controller:*

The control system should be analyzed and suitable controller should be selected and designed [23]. Few important properties of the widely used P, PI, and PID controllers are:

a) Mode of Action
b) Process lag.
c) Speed of the error correction.
d) Acceptability of steady-state error.

According to the above information controllers and systems can be assigned to each other as:

- For easy-to-control systems where steady-state errors are acceptable, P controllers are used.
- In systems with great lag where offset is tolerable PD controllers are used
- For applications with low requirement to control dynamics and where the system does not exhibits great lags, I controllers are used
- For a dynamic control response without exhibiting the steady state error, PI controllers are used
- If it is required that the speed of the response is as high as possible, regardless of the Greater lag, PID controllers are used.

III. DC MOTOR DRIVE COMBINED WITH CONTROLLER

Fig. 5 shows a closed loop speed control scheme which is widely used in electrical drives. It employs an inner current loop within an outer speed loop. Inner current control loop is provided to limit the converter and motor current or motor torque below a safe limit. In some schemes the current is controlled directly.

Inner current loop [24] is also beneficial in reducing the effect on drive performance of any non linearity present in converter-motor system.

An increase in reference speed ω_m^* produces a positive error $\Delta\omega_m$, speed error is processed through a speed controller and applied to a current limiter which saturates even for a small speed error. Consequently, limiter sets current reference for inner current control loop at a value corresponding to the maximum allowable current. Drive accelerates at maximum allowable current.

When close to the desired speed, limiter desaturates. Steady state is reached at the desired speed and at current for which motor toque is equal to the load torque.

A decrease in reference speed ωm^* produces a negative speed error. Current limiter saturates and sets current reference for inner current loop at a value corresponding to the maximum allowable current. When close to the required speed, current limiter desaturates [25].

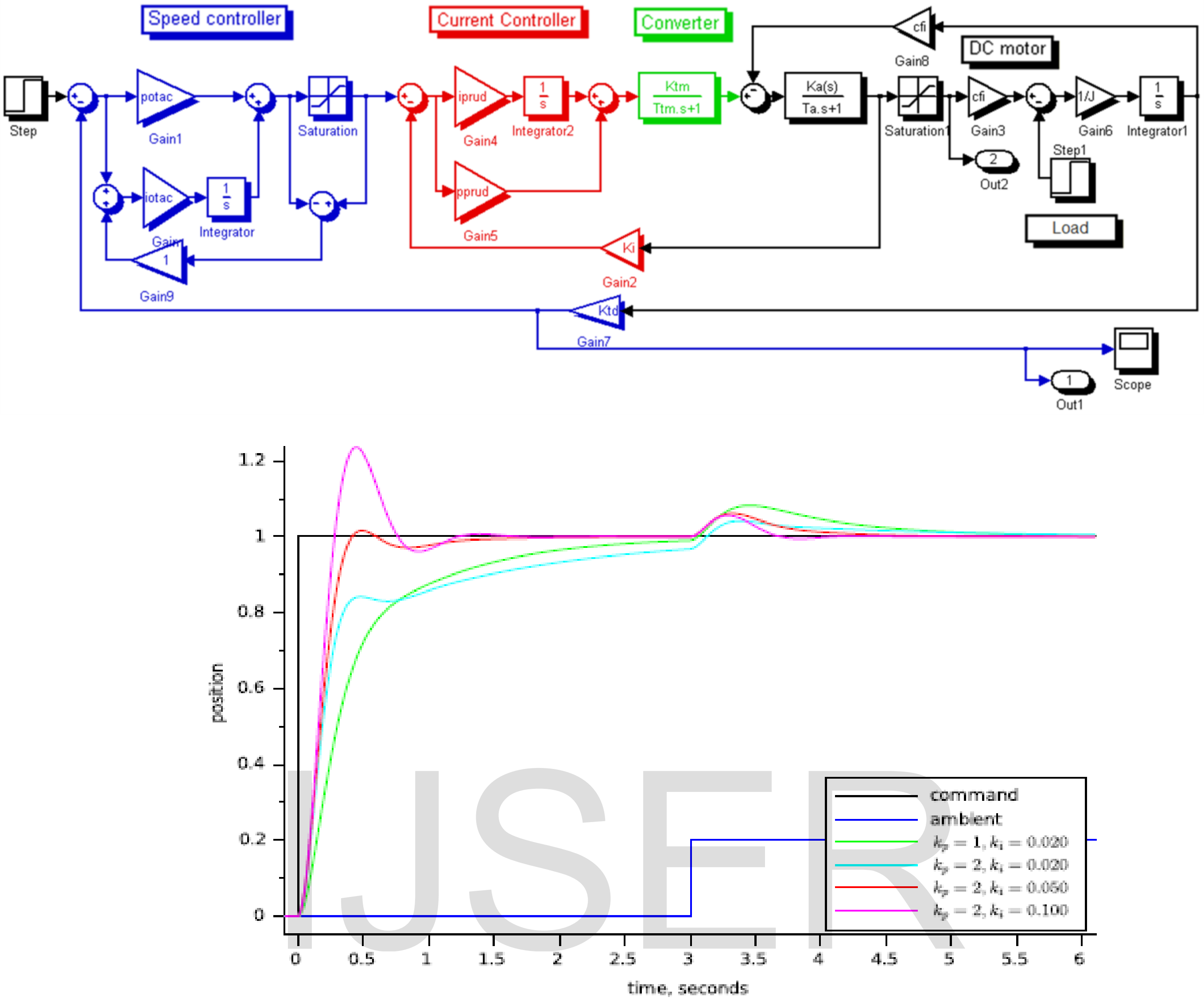

Fig. 5. Closed loop control and response of DC Motor Drives

The operation is transferred from braking to motoring. Drives then settles at a desired speed and at current for which motor torque equals load torque. In those drives where the current I does not have to reverse for braking operation, current limiter will have input output characteristics is normal. In those drive applications where the load torque is able to provide enough decelerating torque; electric braking need not be used.

Table 1 and 2 shows the effects of coefficients and effects of changing control parameters respectively.

TABLE 1. COMPARASION OF GAIN RESPONSE OF P, PI AND PID CONTROLLERS.

Parameter	**Speed of Response**	**Stability**	**Accuracy**
Increasing k_p	Increase	Deteriorates	Improves
Increasing k_i	Decrease	Deteriorates	Improves
Increasing k_d	Increase	Improves	No

TABLE 2. EFFECTS ON VARIOUS O/P PARAMETER OF P, PI AND PID CONTROLLER W.R.T TO VARIATION IN RISE TIME.

Parameter	**P**	**PI Controller**	**PID**
Rise time	Decrease	Decrease	Minor
Overshoot	Increase	Increase	Minor
Settling time	Small	Increase	Minor
Steady state	Decrease	Significant	No change
Stability	Worse	Worse	If Kd Small

IV. CONCLUSION

P controller can stabilize only 1st order unstable process. PI controller can be used to avoid large disturbances and noise presents during operation process. Whereas PID controller can be used when dealing with higher order capacitive processes. The comparative study of P, PI and PID Controller is carried out, in which PID controller gives good response than any other controller. Further output response of DC Motor Drive will be evaluated by using different controller i.e P, PI and PID controller. Based on different industrial application of DC motor, an appropriate controller can be chosen.

DC motors are used extensively in industrial variable speed applications because of most demanding speed-torque characteristics and are simple in controlling aspects. This paper presents a DC motor speed controlling technique under varying load condition. The linear system model of separately excited DC motor with Torque-variation is designed using PID controller. A MATLAB simulation of proposed system with no-Load and full-load condition is performed on Simulink platform to observe the system response. The motor speed is kept constant in this experiment. The simulation result of the experiment shows that a motor is running approximately at a constant speed regardless of a motor load. The Simulink results show that the speed of the motor is slow down only for about 270 rpm (9%) in 980 milliseconds under the effect of full load. However, the motor speed is hunting about 200 rpm (6.66%) in 900 milliseconds on unloading condition. It is concluded that a PID controller is successful tool for controlling the motor speed in presence of load disturbances.

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