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A Review of Transient and Steady State Response of DC Motor Position Control

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Abstract— **The goal of this project is to design an electric drive with a dc motor, with the required angular position controlled in two regimes in the given desired reference command signal . In our practical world we have to use a lot of controlling process in industry or any engineering section. So, it does vary initiative attempt to design a control drive in corresponding to our practical field. Modern manufacturing systems are automated machines that perform the required tasks. The electric motors are perhaps the most widely used energy converters in the modern machine-tools and robots. These motors require automatic control of their main parameters (position, speed, acceleration, currents). In this case the project is representation of a work on the control drive design. Here, focusing control based on the position and various method (root locus, state space, PID and frequency control method) was using to designing this position control drive. And all the designing was related with the DC motor .For using in the practical field, this project used the real world catalog value. DC motor system, the use of MATLAB for comprehensive study of analysis, performance and position control design methods has been demonstrated.**

Keywords—Control Theroy;DC motor; Matlalb

I. INTRODUCTION

There are two major divisions in control theory, namely, classical and modern, which have direct implications over the control engineering applications. The scope of classical control theory is limited to single-input and single-output (SISO) system design [1], except when analyzing for disturbance rejection using a second input. The system analysis is carried out in the time domain using differential equations, in the complex-s domain with the Laplace transform, or in the frequency domain by transforming from the complex-s domain. Many systems may be assumed to have a second order and single variable system response in the time domain. A controller designed using classical theory often requires on-site tuning due to incorrect design approximations. Yet, due to the easier physical implementation of classical controller designs as compared to systems designed using modern control theory, these controllers are preferred in most industrial applications.

The most common controllers designed using classical control theories are PID controllers [2]. A less common implementation may include either a Lead or Lag filter and at times both. The ultimate end goal is to meet a requirement set typically provided in the time-domain called the Step response, or at times in the frequency domain called the Open-Loop response.

The step response characteristics applied in a specification are typically percent overshoot, settling time, etc. The open-loop response characteristics applied in a specification are typically Gain and Phase margin and bandwidth. These characteristics may be evaluated through simulation including a dynamic model of the system under control coupled with the compensation model [3].

As the technology is growing the new applications are coming into existence, which needs both speed control as well as position control for better and efficient performance. We have many speed control and position techniques such as armature voltage control, field control etc. In addition to these control techniques for better performance of the systems we need to design an algorithm, which is helpful for DC position control. The advances in the theory and practice of automatic control provide the means for attaining optimal performance of dynamic systems, improving productivity.

This project addresses design, modeling, dynamics analysis and controller selection and design issues of a electric DC motor is used, modeled, simulated and a control system is selected and designed to a desired output position, θ corresponding to applied input voltage, Vin and satisfying all required design specifications, controller was selected and designed to make the system robust, adaptive and improving the system on both dynamic and steady state performances.

The objective of this project is to demonstrate the time specification performance for various controllers in position control system of a DC motor. The scope of this research is to apply direct control technique in position control system. This project was written to reflect on the work done on the implementation of a various controller. Motor parameters were taken from a datasheet with respect to a real motor.

II. LITERATURE REVIEW

Frederick and Taylor (1987) discussed the application of expert system technique to the design of lead-lag compensators for linear SISO systems [4].

D'Azzo et al, (1988), covered how it is possible to improve the system performance, along with various examples of the technique for applying cascade and feedback compensators, using the methods root locus and frequency response [5].

J. Santana, J. L. Naredo, F. Sandoval, I. Grout, and O. J. Argueta, et al successfully designed and implemented an open loop control system to control the speed of a DC motor [6].

Loh, Cai and Tan (2004) studied the auto-tuning of phase lead-lag compensators using the frequency response of the plant using relays with hysteresis [7].

Chang (2004) used phase-lag and phase-lead compensators to control servo control systems [8].

Roubal, Augusta, and Havlena, 2005 present the procedure of the control design, including a description of a system, an identification of its parameters, a simple and an advanced controller design based on optimal control [9]

Wang (2006) developed a non-trial-and-error procedure to design lag-lead compensators based on the idea of Yeung-Wang-Chen's graphical-based non-trial-and –error method for 3-parameters lag-lead compensators and Wang's result on the exact and unique solution for single lag and lead compensator design [10].

Zhang, Liu, Dang, Zhang and Ou (2006) used a lag-lead compensator to control asynchronous linear motors for better performance and application to active mass driver control system for vibration control of civil engineering structures [11].

Panda and Padhy (2007) applied the genetic algorithm optimization technique to design a thyrister controlled series compensator-based controller to enhance the power system stability. They considered two types of controller structure: lead-lag and PID. They used the ISE and ITAE criterion to optimize the controller parameters [12].

Ayasun and Karbyaz, 2007,describe the MATLAB/SIMULINK realization of a DC motor speed control methods, namely field resistance, armature voltage and armature resistance control methods, and feedback control system for DC motor drives. They studied the torque/speed characteristics for different field resistance, armature voltage and different armature resistance, showing how the speed of the motor vary for different PI gain values[13].

Sharaf, Elbakush and Altas, 2007 present a novel PID dual loop controller for a solar photovoltaic (PV) powered industrial permanent magnet DC (PMDC) motor drive. MATLAB /SIMULINK were used in the analysis[14].

Silva, Carvalho, Vasconcelos and Soares, 2007 present a remote experiment for controlling a DC motor. The experiment is controlled using a PID algorithm programmed in LabView environment[15].

Aung, 2007, gave an analyze how to choose DC motor to be balance with their applications of especially for Wheeled Mobile Robots (WMR). Specification of DC Motor that can be used with desire WMR is to be determined by using MATLAB Simulink model[16].

Ayasunand Nwankpa described the MATLAB/Simulink realization of the DC motor speed control methods (field resistance, armature voltage andresistance) and feedback control system for DC motor drives[17].

M. S. Rusu et al 2008, Mechatronics robot systems and low-to-medium power machine-tools often use DC motors to drive their work loads. These motors are commonly used to provide rotary (or linear) motion to a variety of electromechanical devices and servo systems. There are several well known methods to control DC motors such as: Proportional-Integral PI, Proportional-Integral-Derivative PID or bi-positional [18].

M. S. RUSU, and L. Grama 2008, A simple technique for designing a DC motor speed controller with continuous time based on system theory concepts was presented in[19].

Nassirharand (2008) developed an educational software for designing linear compensators based on the Youla parameterization technique and an exact model matching criterion [20].

Cao, Watkins and O'Brien (2008) studied the use of the graphical user interface (GUS) in designing continuous time compensators using MATLAB. Their work was based on using the root-locus plot and the Bode plot [21].

S. Othman ,Othman successfully designed a speed controller for closed loop operation of the BLDC motor[22].

Allaoua, et al presented a new design method to determine optimal PID controller parameters using the Particle Swarm Optimization method[23].

Wang (2009) provided a new approach for phase-lead/lag compensators to achieve the desired specifications of gain and phase margins, for all-pole stable plants with time-delay [24].

Sawhney (2010) used lag-compensators to improve the response of DC motors using settling time, peak overshoot and steady state error [25].

Li, Sheng and Chen (2010) derived the impulse response of the distributed order lead-lag compensator and used it to compute the distributed order lead-lag compensator in MATLAB [26].

Setiawan (2010) presented the evaluation of closed-loop controller responses of a TiNi SMA gripper using lag, lead and lag-lead compensators. He discussed the tuning of the used compensators [27].

Zhang and Messner (2011) studied the design of the complex proportional-integral-lead (CPIL) compensator using the root-locus plot. They used 2 design strategies for a double integrator and a second order system with a very lightly damped resonance [28].

Zanasi, Cuoghi and Ntogramatzidis (2011) presented the dynamic structure of a new form of lead-lag compensator with complex zeros and poles. They used Nyquist and Nichols planes in the design of the lead-lag compensator satisfying design specifications on gain margin, phase margin and crossover frequency [29].

Zanasi and Cuoghi (2011) presented 3 different methods for the synthesis of lead-lag compensators meeting the specification of phase margin and gain crossover frequency, plus satisfying an additional specification for robust control [30].

Eslami, Shareef, Mohamed and Khajehzadeh (2011) studied the simultaneous coordinated designing of power system stabilizer and static VAR compensator damping controller. They used a lead-lag compensator structure with gain and wash-out. They used the particle swam optimization to search for the optimal controller parameters [31].
Guzman and Hagglund (2011) described simple tuning rules for the design of feed forward compensators based on IAE minimization with restriction on the process output overshoot and high frequency gain of the compensator. They considered lead-lag and lead-lag with delay compensators [32].

Saha, Chatterjee and Dutta (2011) used a lead-lag compensator to control the motion of a snake robot using the frequency domain approach. The compensator concentrated on controlling the steady-state errors and transient response of the actuators [33].

Hedaya Alasooly, 2011 It also covered some methods of optimal linear system design and presentation of eigenvalues assignments for MIMO system by state feedback [34].

Nandar (2012) proposed a design of a robust power system stabilizer (PSS) considering less control energy using a genetic algorithm. He used a first order lead-lag compensator as a PSS and showed that with less control energy, the robustness and damping effect was guaranteed [35].

Goswami, Sanyal and Sanyal (2012) studied the control of a hydrofoil ship using a compensator to match the desired control specifications. They used a second order lead-lag compensator of two pole-zero pairs [36].

Ntogramatzitis, Zanasi and Cuoghi (2012) presented a comprehensive range of design techniques for the synthesis of lead, lag and PID compensators. They presented a closed-form formulae for the compensator parameters [37].

Prakash, R. Srinu Naik (2013), discuss the adjusting gain constants of PID (Proportional-Integral-Derivative) control with Ziegler-Nichols (ZN) based algorithm probably a stochastic method of approach of genetic algorithm was implemented which will give more optimal results when compared with the results obtained with untuned PID controller. This tuned PID controller is used for position control of DC motor for better performance. This work is carried through MATLAB/SIMULINK environment [38].

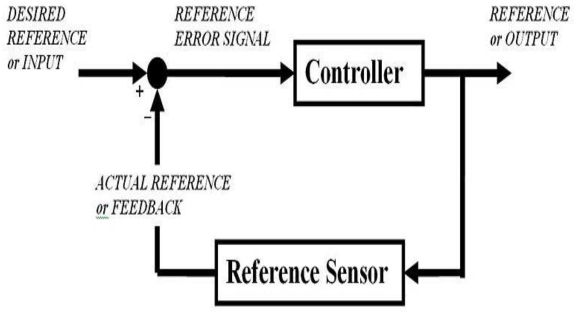
Tajrin Ishrat, Hasib Bin Liakat 2014, proposed inour paper is representation of a work on the control drive design. Here, focusing control based on the position and state space method was using to designing this position control drive. And all the designing was related with the DC motor .For using in the practical field, this project used the real world catalog value [39]

Dr. Kais S. Ismail Dr. Firas Mohammed Tuaimah Ruba Al-Mulla Hummadi 2014,described our paper DC motor speed control based on pole assignment feedback control technique. The present pole assignment technique specifies all closed-loop poles. Such a system where the reference input always zero is called a regulator system. The problem of shifting the regulator poles (closed-loop poles) at the desired location is called pole assignment problem, and this can be done if and only if the system is completely state controllable. Controller's objective is to maintain the speed of rotation of the motor shaft with a particular step response [40].

III. CONTROL THEROY

A. *Control System*

Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems. The desired output of a system is called the *reference*. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system [41].

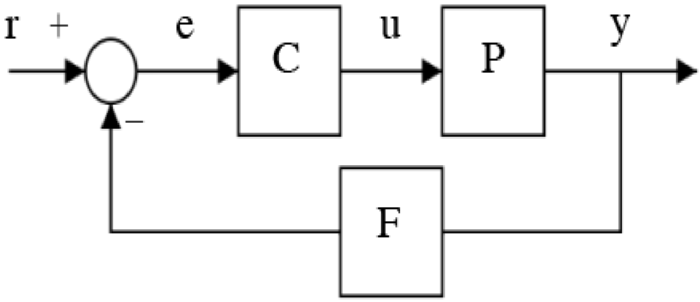


“Fig. 1, “Block Diagram of Control System”

Concept of the Feedback Loop to Control the Dynamic Behavior of the Reference If we consider an automobile cruise control, it is design to maintain the speed of the vehicle at a constant speed set by the driver. In this case the system is the vehicle. The vehicle speed is the output and the control is the vehicle throttle which influences the engine torque output. One way to implement cruise control is by locking the throttle at the desired speed but when encounter a hill the vehicle will slow down going up and accelerate going down. In fact, any parameter different than what was assumed at design time will translate into a proportional error in the output velocity, including exact mass of the vehicle, wind resistance, and tire pressure. This type of controller is called an open-loop controller because there is no direct connection between the output of the system (the engine torque) and the actual conditions encountered; that is to say, the system does not and cannot compensate for unexpected forces. For a closed-loop control system, a sensor will monitor the vehicle speed and feedback the data to its computer and continuously adjusting its control input or the throttle as needed to ensure the control error to a minimum therefore maintaining the desired speed of the vehicle. Feedback on how the system is actually performing allows the controller (vehicle's on board computer) to dynamically compensate for disturbances to the system, such as changes in slope of the ground or wind speed . An ideal feedback control system cancels out all errors, effectively mitigating the effects of any forces that may or may not arise during operation and producing a response in the system that perfectly matches the user's wishes.

B. Closed Loop Transfer Function

The output of the system *y(t)* is fed back through a sensor measurement *F* to the reference value *r(t)*. The controller *C* then takes the error *e* (difference) between the reference and the output to change the inputs *u* to the system under control *P*. This is shown in the figure. This kind of controller is a closed-loop controller or feedback controller. This is called a single-input-single-output (*SISO*) control system; *MIMO* (i.e. Multi-Input-Multi-Output) systems, with more than one input/output, are common. In such cases variables are represented through vectors instead of simple scalar values [42]



“Fig.2 Closed-loop controller or feedback controller”

If we assume the controller *C*, the plant *P*, and the sensor *F* are linear and time invariant (i.e.: elements of their transfer function *C(s)*, *P(s)*, and *F(s)* do not depend on time), the systems above can be analyzed using the Laplace transform on the variables. This gives the following relations:

$$Y(s) = P(s)U(s)$$

$$U(s) = C(s)E(s)$$

$$E(s) = R(s) - F(s)Y(s)$$

Solving for *Y*(*s*) in terms of *R*(*s*) gives:

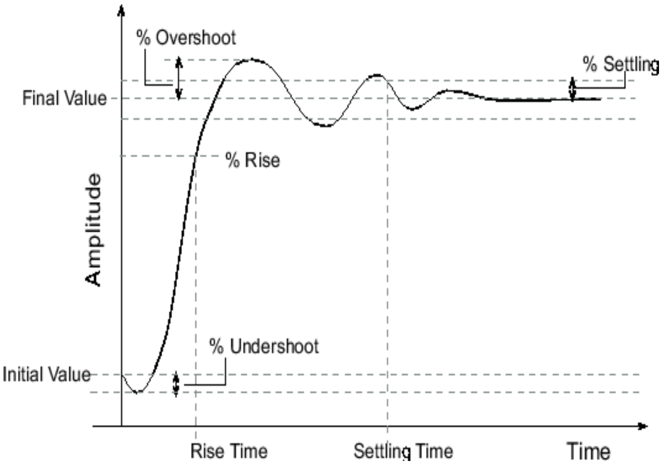
$$Y(s) = \left(\frac{P(s)C(s)}{1 + F(s)P(s)C(s)}\right) R(s) = H(s)R(s)$$

$$H(s) = \left(\frac{P(s)C(s)}{1 + F(s)P(s)C(s)}\right)$$

The expression $H(s) = \left(\frac{P(s)C(s)}{1 + F(s)P(s)C(s)}\right)$ is referred to as the closed-loop transfer function of the system. The numerator is the forward (open loop) gain from *r* to *y*, and the denominator is one plus the gain in going around the feedback loop, the so-called loop gain. If $|P(s)C(s)| >> 1$, i.e. it has a large norm with each value of *s*, and if $|F(s)| \approx 1$, then *Y(s)* is approximately equal to *R(s)*. This means simply setting the reference controls the output.

C. Time Response Characteristic

- Rise time: The time taken for the response signal to reach a specified percentage of the step’s range. The step’s range is the difference between the final and initial values.
- % Rise: The percentage used in the rise time.
- Settling time: The time taken until the response signal settles within a specified region around the final value. This settling region is defined as the final step value plus or minus the specified percentage of the final value.
- % Settling: The percentage used in the settling time.
- % Overshoot: The amount by which the response signal can exceed the final value. This amount is specified as a percentage of the step’s range. The step’s range is the difference between the final and initial values.
- % Undershoot: The amount by which the response signal can undershoot the initial value. This amount is specified as a percentage of the step’s range. The step’s range is the difference between the final and initial values.



“Fig. 3 Time Response Characteristic”

IV. PROPOSED WORK

A. *Proposed Work*

DC motors are designed for use in industrial and commercial applications such as the pump and blowers, material handling, system and gear drives, and adjustable speed drives. These motors are used to give rotary speed and position to a various electromechanical system. Now a days many applications find the usage of DC motors as it provides excellent speed control for both acceleration and deceleration with effective and simple torque control. They are portable and well suited to special applications, such as industrial tools and machinery that is not easily run from remote power places.

An electric motor is an electric machine that converts electrical energy into mechanical energy. Electric motor can be powered by Direct Current (DC) sources such as batteries, motor vehicles or rectifiers, or by and Alternating Current (AC) sources, such as from power grid, inverters, or generators.

In this thesis, DC motor has been selected because it is widely used in industrial applications, robot manipulators and home appliances where speed and position control are required. The dc motors can comes in many shapes and sizes, makes the development of dc motor application quite easy and flexible. It is also has high reliabilities and low cost [43].

Development of high performance motor drives is very essential for industrial applications. DC drives, because of their simplicity, ease of application, reliability and favorable cost have long been a backbone of industrial applications. DC drives are less complex as compared to AC drives system. DC drives are normally less expensive for low horsepower ratings. DC motors have a long tradition of being used as adjustable speed machines and a wide range of options have evolved for this purpose. D.C motors have long been the primary means of electric traction. They are also used for mobile equipment such as golf carts, quarry and mining applications. DC motors are conveniently portable and well fit to special applications, like industrial equipments and machineries that are not easily run from remote power sources.

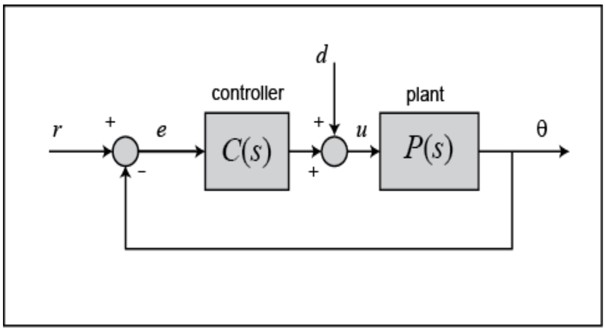
The purpose of this work is to provide control theory that is relevant to the analysis and design.

- The term control system design refers to the process of selecting feedback gains that meet design specifications in a closed-loop control system. Most design methods are iterative, combining parameter selection with analysis, performance, and insight into the dynamics of the plant.
- With the growing technology, the new applications find the use of both speed control as well as position control for better and efficient performance. In addition to the existing control techniques, we introduce a various control technique, which helps in the position control of DC motor.
- The purpose of developing a control system is to enable stable control since it has parameters tuning difficulties, non-linear, poor stability and imprecise control.
- For this we make use of control techniques and designed by root locus and PID controller techniques. This will lead to automatic control of position of the DC motor without manual interference.
- The mathematical model of the basic open loop system, to be derived and analyzed, this will be followed by designing the closed loop system, controller models added, different control strategies will be applied with the closed loop, tested, analyzed and finally, based on system controller selection and design, overall controller effect, system performance and analysis, the control strategy will be selected, design and dynamic analysis will be verified by MATLAB/Simulink.

The project intends presenting comprehensive study for all the techniques of study, analyzing, and designing a DC motor position controller based on system theory concepts. The position control design methods used are studied under MATLAB and Simulink in the following sections.

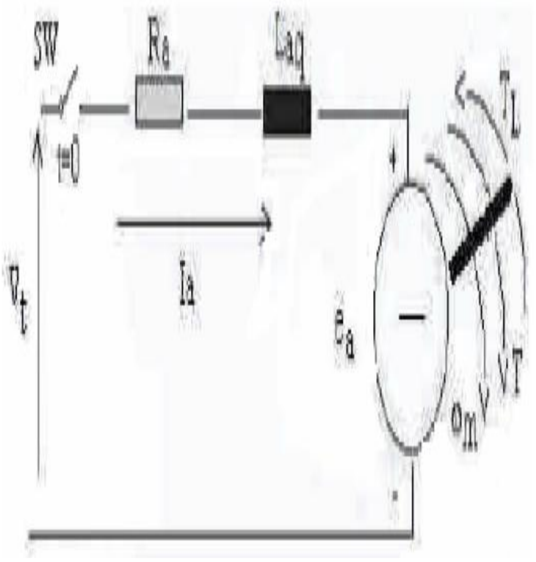
V. *DESIGN NEEDS AND SYSTEM PERFORMANCE, OBJECTIVE*

A. *BLOCK DIAGRAM*



"Fig.4 Block Diagram of Closed Loop System"

Closed-Loop System Consideration To perform the simulation of the system, an appropriate model needs to be established. Therefore, a model based on the motor specifications needs to be obtained. Figure 5 shows the DC motor circuit with Torque and Rotor Angle consideration.



"Fig. 5 Schematic diagram of a DC Motor"

System Equation The motor torque T is related to the armature current, i , by a torque constant K;

T = K i (1)

The generated voltage, ea, is relative to angular velocity by;

ea = K wm = K dθ/dt (2)

From Figure 5.1 we can write the following equations based on the Newton"s law combined with the Kirchhoff"s law:

J d2θ/dt2 + b dθ/dt = K i (3)

L di/dt + Ri = V- K dθ/dt (4)

Transfer Function Using the Laplace transform, equations (3) and (4) can be written as: J s2 θ(s) + b s θ(s) = K I(s) (5)

L s I(s) + R I(s) = V(s) – K s θ(s) (6)

Where *s* denotes the Laplace operator. From (6) we can express I(*s*):

$$I(s)=\frac{V(S)-Ks\theta(s)}{R+Ls} \tag{7}$$

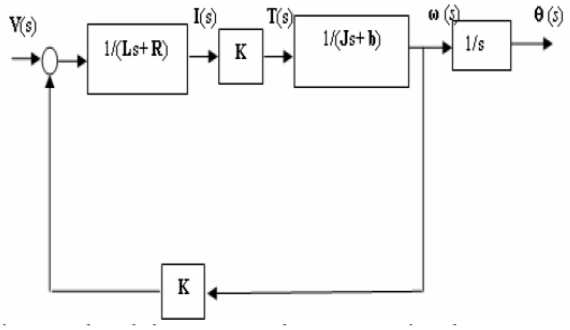
and substitute it in (5) to obtain:

$$Js^2\theta(s)+bs\theta(s)=\frac{K(V(s)-Ks\theta(s))}{R+Ls} \tag{8}$$

This equation for the DC motor is shown in the block diagram in Fig.5. 2, From equation (8), the transfer function from the input voltage, V (*s*), to the output angle, θ, directly follows:

$$G(s)=\frac{\theta(s)}{V(s)}=\frac{K}{\left[s\{(R+sL)(Js+b)+K^2\}\right]}$$

Before any consideration of the above equations, we must know the constant values of data, K, J, b, V, L and R. This is very important to the application of DC motor which we will be used.



"Fig.6 A Closed- Loop System that Representing the DC Motor"

B. OBJECT

The purpose of developing a control system is to enable stable and reliable control. Once the control system has been specified and the type of control has been decided, then the design and analysis are done.

There are three major objectives of system analysis and design: producing the desired transient response, reducing steady-state error, and achieving stability.

The objective of project is to design a DC Motor position controller using Root Locus Method and PID controller considering disturbance in the system and reduce the effect of the disturbance to zero.

- ➢ The uncompensated motor may only rotate at 0.1 rad/sec with an input voltage of 1 V. Since the most basic requirement of a motor is that it should rotate at the desired speed, the steady-state error of the motor speed should be less than 1%.
- ➢ The other performance requirement is that the motor must accelerate to its steady-state speed as soon as it turns on. In this case, we want it to have a settling time of 2 seconds for example. Since a speed faster than the reference may damage the equipment, we want to have an overshoot of less than 16.

There are many motor control system design strategies that may be more or less appropriate to a specific type of application each has its advantages and disadvantages. The designer must select the best one for specific application. In this project, we are to design, apply, verify and performance of different control strategies in order to improve the desired transient response, reducing steady state errors and achieving stability to control the output angular position, θ of a given DC motor, corresponding to applied input voltage Vin. If simulation was done with the reference input r(t) by a unit step input, then the motor speed output should have

- ➢ Settling time less than 40 milliseconds
- ➢ Overshoot less than 16%
- ➢ No steady state error
- ➢ No steady state error due to a disturbance

Finally it has been observed that the values of peak overshoot, settling time and other parameters, attain values which improve the stability of the

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