Speed Control of DC Motor under Varying Load Using PID Controller

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Abstract

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.

Keywords: Speed Control, DC Motor Model, PID Control, Closed Loop, Load Disturbance.

1. INTRODUCTION

For the last many years, the DC motors are extensively used in the industrial control applications. DC motors are highly versatile and flexible in aspects of speed control. High performance DC motor drives are popular in industrial applications for its enormous good characteristics such as high starting, accelerating and retard torque, high response performance, rapid braking and easier to be linear control etc. DC motor is a highly controllable electrical actuator and is widely used for robotic manipulators, guided vehicles, steel rolling mills, cutting tool, overhead cranes, electrical traction and other application etc. In comparison to AC drive, DC motor drives are simple and less expensive [1].

Mostly, the feedback control loop is indispensable for the desired and better performance of the system. However, this feedback system has slow response. For the fast dynamic response of the system, many control strategies have been deployed in various feedback control systems. The vital role of controls in a drive system include precise and quick tracking for reference speed with minimum overshoot or undershoot and having little or eliminated steady state error. The conventional (*proportional integral- derivative*).PID controllers have become very popular and

widely used in industrial control applications due to their features like simple mathematical modeling, easy to operate, good robustness, high reliability, stabilization and eliminating steady state error [2]. PID controller is used to attain the desired torque-speed characteristics of DC motor. However, the optimization and tuning task of these controllers is very time consuming and challenging, mainly under the varying load conditions, parameter variations, in abnormal operating modes etc.

DC motors are considered as adjustable speed machine. Separately excited DC motor drive is the most suitable configuration used for variable speed applications for a long time due to its accurate speed control, controllable torque, high reliability and simplicity [1]. In Separately excited DC motor, the power supply is directly connected to the field winding of the motor. There are three speed control techniques used commonly; named as field resistance control, armature resistance control and armature voltage control. The field current kept constant & variable voltage applied to the armature in armature voltage control method. The basic working principle of an armature controlled DC drive is that the speed of a separately excited DC motor is directly proportional to the applied armature voltage of the DC motor. DC motor speed is controllable over wide range via the proper proportional adjustment of terminal voltages. There have been so many schemes such as using PI, PID controller, Fuzzy Logic controller, Artificial Intelligence techniques, applied to control the separately excited DC motor through proper tuned regulation of terminal voltages [7-12]. Besides the DC motor speed, its various loading effect is also a focal consideration in the running operation of the DC motor. In this paper, the principle of DC motor speed control under varying load using armature voltage control technique is presented.

In the experiment, the motor speed is kept constant and the load is varying from zero to peak torque. The motor speed keeping constant under varying load condition is an attractive approach to control the motor under varying load condition. By using this approach, PID controller is employed in this system to overcome the unwanted undershoot of motor speed due to varying load impact at certain abnormal conditions. The proposed system model using PID control scheme, is designed on Matlab and simulations performed on Simulink platform.

In this paper, the speed control technique of separately excited DC motor under varying load condition is presented with simulations. The DC motor model is developed and Matlab simulation has been done under disturbing load conditions on Simulink platform. PID controller is employed in this control system in order to get desired response of the system. The operation and tuning rules of PID controller is also discussed. At the end, experimental result is presented and discussed.

2. SYSTEM DESCRIPTION
This In this section, the entire system is described. This section is divided into two sub-parts. In the first part, the dynamic model of DC motor speed control is presented. In the second part, the proposed controlled system is presented and simulations have been done with Matlab on Simulink platform.

2.1 Dynamic Model of DC Motor
This part presents the dynamic model of closed loop armature controlled DC motor speed control system. The simulation of armature controlled DC motor has been performed on Simulink/ Matlab software. The separately excited DC motor dynamic model and its design parameters have been taken from Carnegie Mellon, Control Laboratory of University of Michigan, US [3]. This system model consist of a armature controlled separately excited DC motor in which speed is being controlled by the applied armature voltage Va and the field current If is held constant. The armature controlled DC motor model is depicted in figure 1.

The speed range of separately excited dc motor can be from zero to rated speed. This performance is mostly achieved by the variable armature voltage applied in the constant torque condition. The input voltage is applied to the armature terminals of the motor. The three

parameters of motor are involved in to drive a mechanical load, such as inertia J, friction coefficient T_f, and load torque TL. The dc motor specifications are as follows:
Where;
Shaft power of the motor = 5 hp
Rated voltage of the motor = 240 V
Ra = 0.6, Resistance of armature, (Ohm),
La = 0.012, Inductance of armature winding, (Henry),
Rf = 240 ohm; Field resistance,
Lf = 120 H; Field inductance,
Ia = Armature current of the motor (ampere),
If = Field current of the motor (ampere),
Va = Armature voltage applied to the motor,
T_f = 0 Nm, Coulomb friction torque
e_b = back emf, (volt),
Tm = Torque of the motor (N.m),
θ =Angular displacement of motor shaft, (radian),
ω = Angular Velocity of motor-shaft,
J = 1 Km2, Equivalent moment of inertia of motor and load referred to motor shaft, (Kg.m2),
B = 0.02 Nm, Equivalent viscous-friction coefficient of the motor and load referred to the motor shaft, (N.m / rad / sec).

The transfer function of armature controlled separately excited DC motor with an angular displacement θ(s) to the applied armature voltage Va(s) as an input voltage source without load is given by equation (1).

$$\frac{\theta(s)}{Va(s)} = \frac{Km}{s(Js+B)(Las+Ra)+KmKbs} \tag{1}$$

The transfer function of armature controlled separately Excited DC motor with the speed (an angular velocity i-e ω(s) = s θ(s) to the applied armature voltage Va(s) as an input voltage source without load (Td(s) = 0) is given by equation (2). The block diagram of open loop armature controlled separately excited DC motor without load Torque is shown in Figure 2.

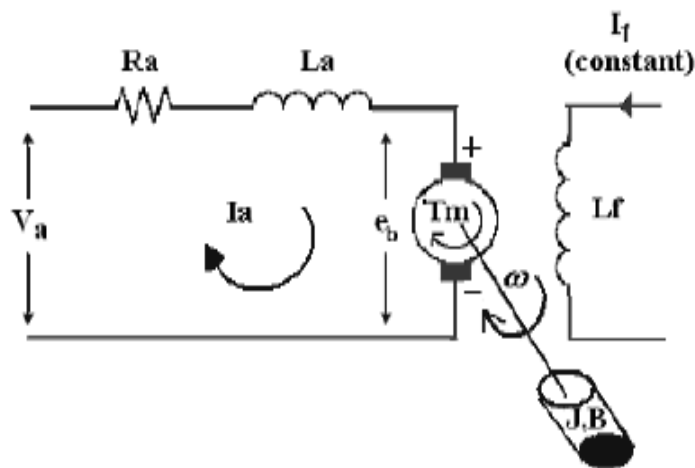$$\frac{\omega(s)}{Va(s)} = \frac{Km}{(Js+B)(Las+Ra)+KmKb} \tag{2}$$

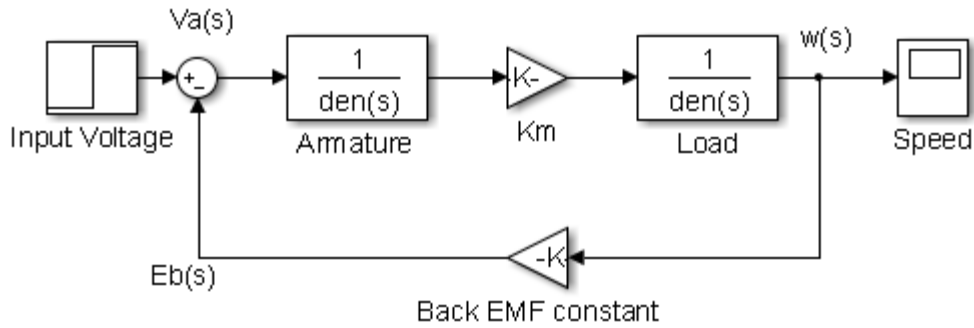**FIGURE 1:** Armature Controlled DC Motor Model.

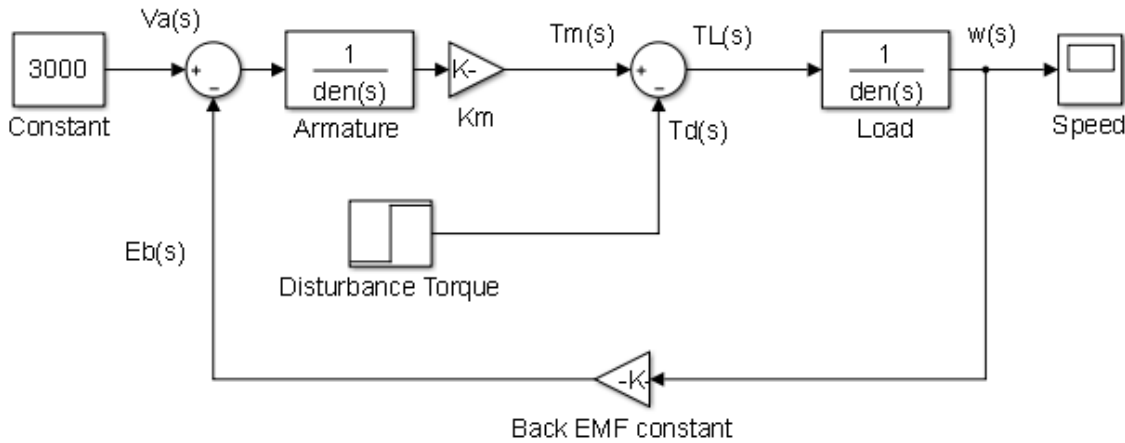**FIGURE 2:** Simulink diagram of armature controlled DC motor without load.

FIGURE 3: Simulink model of armature controlled DC motor with load.

The transfer function block diagram of armature controlled separately Excited DC motor with the speed (an angular velocity ω(s) to the applied armature voltage Va(s) with load (Td(s)) is also depicted in figure 3.

2.2   Proposed System Description

In this part, the proposed model of separately excited DC motor system for speed control under varying load is presented. The proposed control system consists of a control loops for speed and armature current. A proportional-integral, Derivative (PID) controller is employed in this control system in order to get desired response of speed-Torque characteristics and overcome the problems of motor speed control under the effects of varying load.

The actual motor speed is measured by the armature current necessary for the motor. The actual speed of the motor is sensed by the feedback control loop and compares this speed with the preset reference speed in order to determine the required motor's reference armature current. The simulation of proposed system model has been accomplished in two steps. In the first one, actual speed is setup with the reference speed with no-load condition. Next, the speed is setup with the reference speed under varying load and the speed is kept constant.

The PID controller is very popular and common in process control industry. In the PID (proportional-integral-derivative) closed control loop controller, the three controllers P,I and D all have different tuning adjustments which interact all together that's why its tuning is time consuming and challenging task [4]. The effects of all three individual controllers (P-I-D) summed together to produce the output value of the system [2]. Tuning of PID controller is the major task

of this device in order to proper functioning of the PID controller under the given circumstance of the control system [7]. There are different tuning methods used to tune PID controller such as Ziegler-Nichols method, manual tuning method and MATLAB tuning method [5]. PID controller is the best choice for dynamic control system with no-steady state error, fast response, and superior stability without oscillations. The P-I-D controller can be used for processes with higher order.

The variable e(s) stand for the error signal used to track the reference signal. The variable e(s) is the difference between the desired reference input set point value r(s) and the actual output ω(s). This error signal is sent to the PID controller and then controller evaluates the derivative and the integral of the error signal. The output signal (u) of the controller becomes equal to the proportional gain (Kp) times the magnitude of the error plus the integral gain (Ki) times the integral of the error plus the derivative gain (Kd) times the derivative of the error. The signal (u) will now be sent to the plant, and get the new generated output ω(s).This output will be again return back to the sensor in order to determine the new error signal e(s). The new error signal will be again sent to the controller and computes both derivative and integral again. The above process repeats in the same manner. The signal (u) can be represented as follow [2].

$$u = K_p e + K_I \int e \, dt + K_D \frac{de}{dt}$$ (3)

In this paper, Ziegler-Nichols tuning method has been employed in the first step which overcomes the overshoot problem of reference speed with the actual speed under no-load and eliminates the steady state error. By using Ziegler-Nichols tuning method also known as 'ultimate cycle method', determined the parameter values of each controller that is; Kp; proportional gain, Ki; integral gain and Kd; derivative gain[2]. Ziegler Nichols tuning chart is given in Table 1. In the next step, manual tuning is accomplished to overcome the undershoot problem of the motor speed under the loading effect. The Block diagram of armature controlled S.E.DC motor with PID controller under the effect of the load is illustrated in Figure 4. The output of PID controller is applied as an input voltage to the armature terminals of the DC motor. The ultimate parameter values for the 'PID Controller' are KP = 2500, Ki = 3500 and Kd = 1100.

	K_c	T_I	T_D
P	$K_U/2$		
PI	$K_U/2.2$	$P_U/1.2$	
PID	$K_U/1.7$	$P_U/2$	$P_U/8$

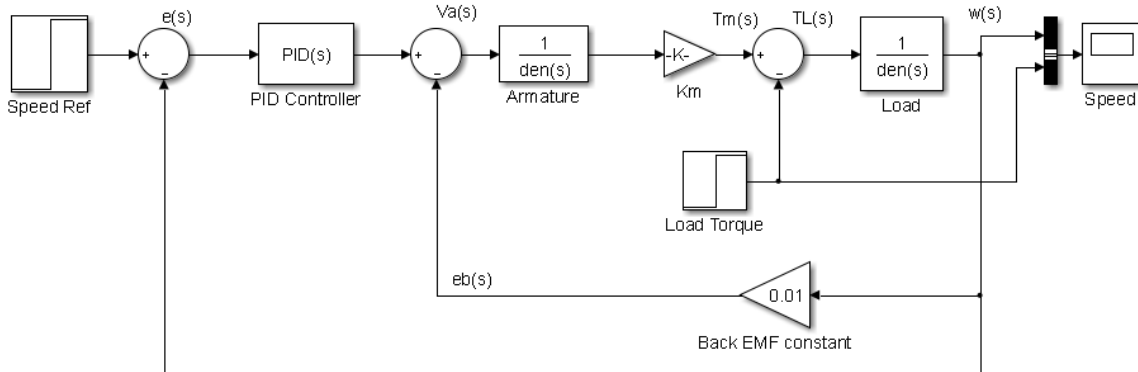**TABLE 1**: ZIEGLER-NICHOLS Tuning Chart.

FIGURE 4: Block diagram of armature controlled SEDC motor with PID controller under the effect of load.

2.3 The Proposed System Comparative to Previous Control System

There has been lot of research work done and published [11-14] on the same topic but the approach of speed control technique presented in this paper is quite unique from all other techniques already presented and published since those are mostly employed with the variation of the control schemes. However, apart from the control schemes such as PI, PID, Fuzzy and Sliding Mode Control etc, an idea is presented in this paper for the speed regulation of DC Motor under varying load condition with the speed kept constant. This idea is experimentally tested on the simulation software. By using this experiment setup, it will be justified whether the speed regulation of the DC motor under varying load can be controlled effectively if the speed kept constant and PID control scheme is employed to achieve this task.

3. RESULTS AND DISCUSSION

This section presents the results of the proposed speed control system model's simulations, which have been performed on the Simulink platform of Matlab software. The complete step by step simulation results of DC motor speed control under the effect of load with speed – Torque characteristic curve have been illustrated in this section.

The block diagram of system model without and with PID controller is developed on the Simulink platform. First of all, the step response of the system model without PID controller is taken and illustrated in figure 5. The output voltage reached up to the 0.1v (10% of the final value) when the 1V unit step volt is applied at the input. The rise time is 1.2 seconds, while the settling time is 1.5 seconds. The steady state error is about 90% of the final value.

In the next step of this experiment, the PID controller has been employed in the existing block diagram of system model in order to attain the desired speed. The step response of PID controlled system model is shown in figure 6. The output voltage reaches up to the desired value of 1V. The rise time has been greatly reduced and is only 0.2 second, while the settling time for PID controlled system is 0.25 second.

After that, the system model has been tested without PID controller with full load condition. The speed – torque step response is also shown in figure 7. It is obvious that the speed is not attained to the desired reference value. It has also been observed from the graph that the speed slows down for about 15000 rpm below the running speed as the load torque changes from 0 to 1500.

Next, once again the PID controller is employed in the existing block diagram of system with load disturbance. PID controller is used to overcome the current problem of speed control under the effect of load. The simulation graph of the system model is demonstrated in the figure 8. By using the same parameter values of PID controller, the response of the system become good with respect to the desired speed sustainability with zero load torque. However, this speed sustainability become drastically demolishes as the load torque changes from zero to 1500Nm. This figure illustrates that the motor speed is tremendously hunted with open loop speed control in full-load condition.
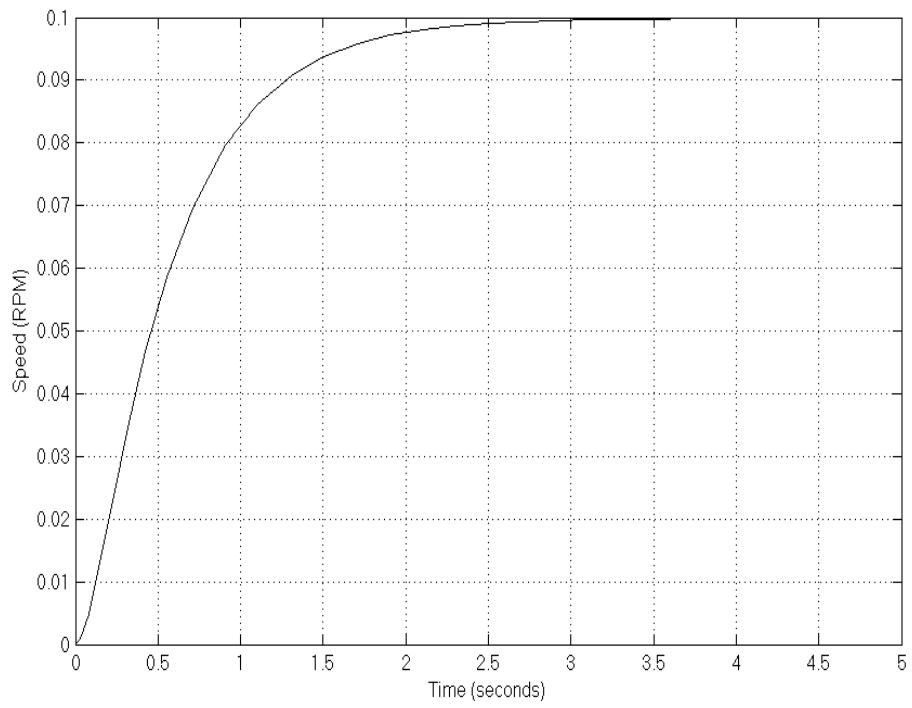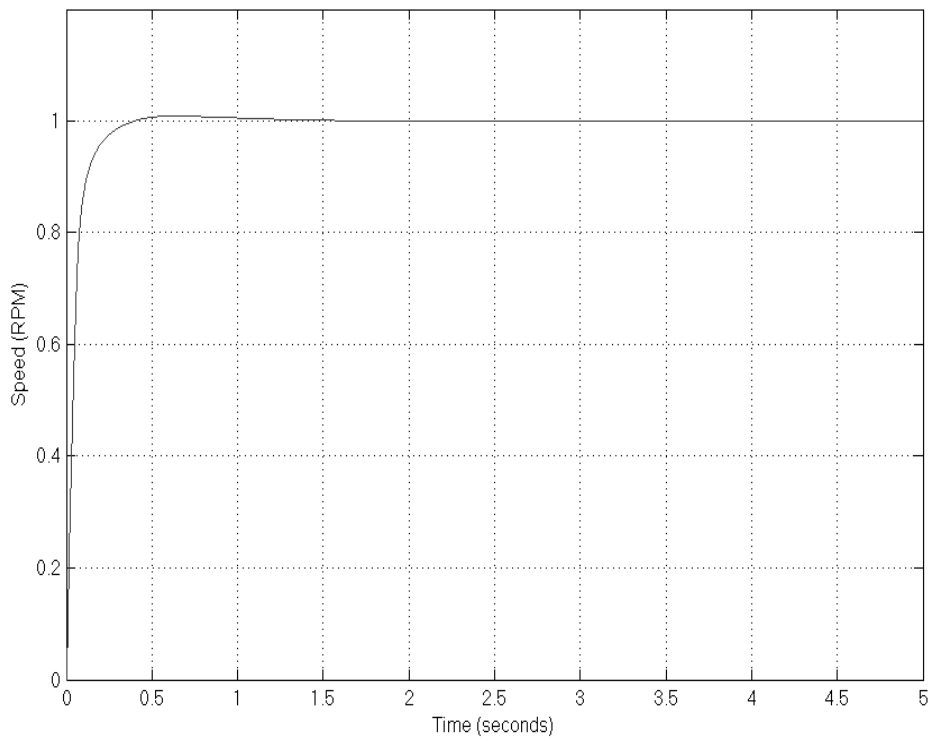
FIGURE 5: Uncontrolled DC Motor Speed Response.

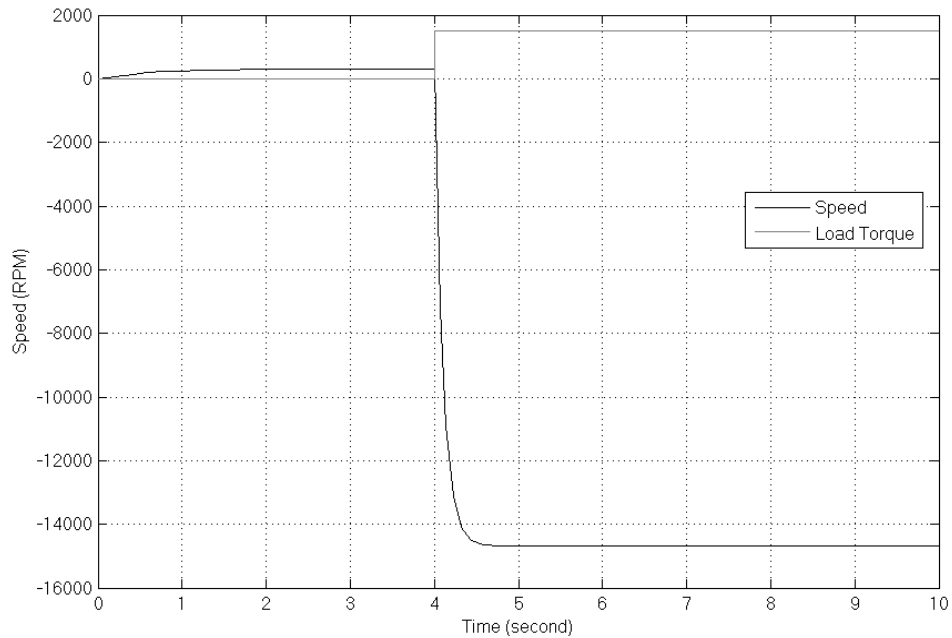**FIGURE 6:** PID Controlled Response of DC Motor.

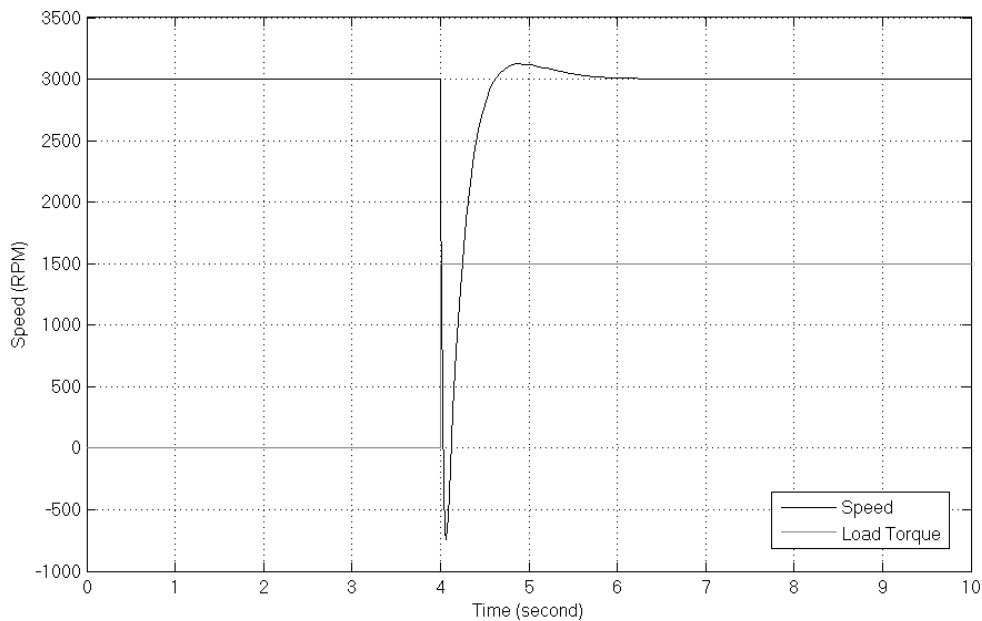**FIGURE 7:** Uncontrolled speed response of DC motor under load disturbance.

FIGURE 8: Partially Tuned PID controlled speed response of DC motor under load disturbance.

Eventually, the manually tuned PID controller has been employed in the system model and tested for a speed control under the effect of the varying load. The step responses of the system with no-load to full-load and unloading conditions are illustrated in Figure 9 and 10.

Figure 9 and Figure 10 show the speed response with no-load to full-load and unloading conditions respectively. It is obvious from these responses 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 speed motor is hunting about 200 rpm (6.66%) in 900 milliseconds on unloading condition.
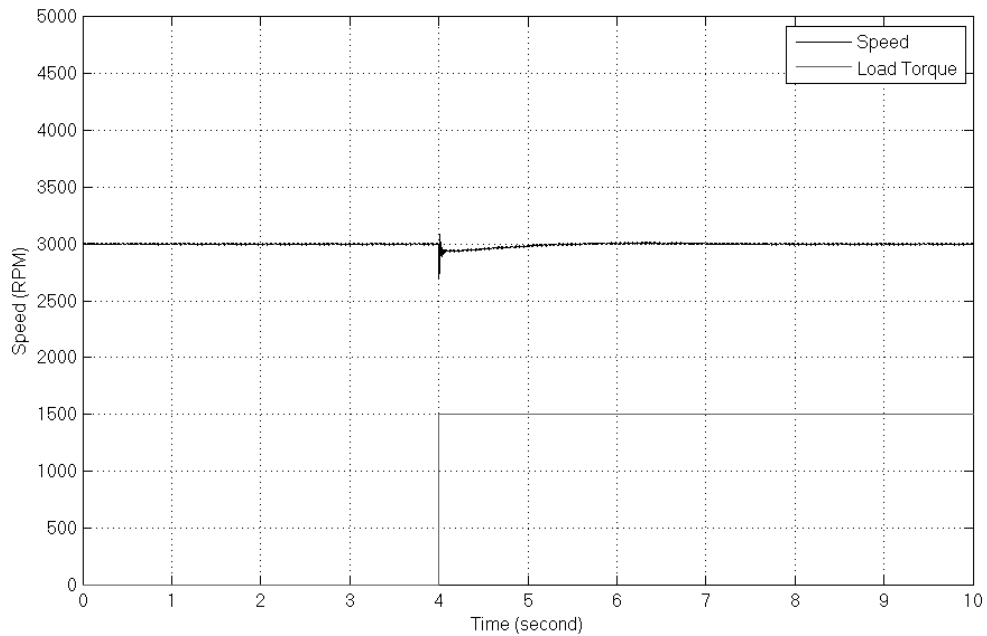
FIGURE 9: Tuned PID controlled DC motor speed response with No-load to Full load condition.
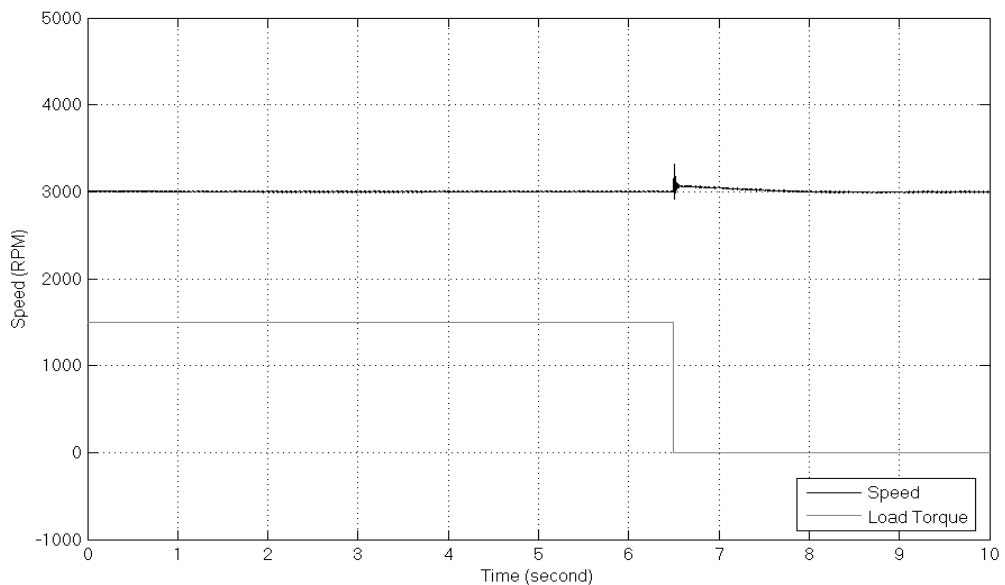

FIGURE 10: Tuned PID controlled DC motor speed response with Unloading condition.

4. CONCLUSION

This paper presented the separately excited DC motor speed control strategy using PID controller under varying load. The DC motor model was designed with PID controller to control the speed of the motor under the effect of load. In this experiment, the speed of the motor is kept constant and the load torque is varying. The proposed system was fruitfully designed and tested. As per results of the experiment, it is obvious from the above results and hence concluded that PID controller is very effective and powerful controller that is capable of controlling the open-loop speed control of DC motor under varying load condition. The ultimate parameter values of PID controller were setup by using Manual Tuning method. Simulation results of the proposed system proved that

PID controller has better control approach in order to control and sustain the speed of the motor under varying load condition. The results also confirmed the validation of the PID based closed loop speed control system under the effects of load disturbance.

5. FUTURE SCOPE

The targeted result is achieved successfully under the given suitable conditions. However, some improvements can be made in the control aspects of the proposed system design. In this experiment, the PID controller is well performed for the motor speed control under the loaded condition while the speed is kept constant. The ultimate parameter values of PID controller were setup by Manual Tuning method. An Adaptive approach of PID controller may be used in the prospective development in order of effectively speed control of the motor with reference to input speed under the effect of load.

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