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Speed control of Separately Excited DC Motor using various Conventional Controllers

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ABSTRACT
This paper presents comparative study of various conventional controllers such as Proportional (P), Proportional Derivative (PD), Proportional integral (PI) and Proportional Integral Derivative (PID) controller for a speed control of a Separately Excited Direct Current (SEDC) motor by using MATLAB / SIMULINK. All controllers have their specific function for a particular task. The speed control normally done by feedback loop or closed loop. The aim of development of this paper is towards providing efficient and simple method for controlling the speed. The auto - tuning method are used to for this paper to control the speed. Among all this controllers PI controller are frequently utilized in industries as compared to PID because Derivative action are sensitive to noise, though PID controller will improve the steady state error. Additionally it produces less overshoot, decreasing rise time and settling time. The MATLAB simulation are analysed and compared by using the auto tuning method.
***Keywords* -** Proportional (P), Proportional – Derivative (PD), Proportional - Integral (PI), Proportional – Integral – Derivative (PID), Separately Excited Direct Current (SEDC).

I. INTRODUCTION

The development of high performance motor drives is very important in industries. DC motor is used extensively in adjustable speed drives and position control applications due to their simplicity; ease of applications, reliability and favourable cost has been a backbone of industrial applications. The beauty of this motor is, it provide high torque load sustainable property. It is widely used in applications such as railway engine, electric cars, elevator, robotic application, and lifting and transportation purposes. It also designed to use with battery, solar cells energy sources which we can used when it is required and so it provide cost effective solution because it is not possible to have an AC supply in everywhere. DC motor shows its replication for both voltage and current, as speed of motor shown by applied voltage while torque shown by current in armature winding. The main purpose of speed control is, there are many applications such as robotics in which there is need to change the speed of motor because it can work properly until its speed is controlled in precise way. In DC motor, we can control the speed below and above the rated speed by using various methods such as field current control method and armature voltage control method.

Many varieties of control techniques are used such as P, PD, PI, PID, Fuzzy Logic Controller (FLCs) and Fuzzy Neural Network etc. for controlling the speed of DC motors. It has been reported that more than 95% of the controllers in the industrial process control applications are PID type due to their simplicity, clear functionality, applicability and ease of use. This paper mainly focuses on the performance evaluation of SEDC motor using conventional controllers. The simulation results are presented to demonstrate the effectiveness of this controller and compared with each other using MATLAB / SIMULINK.

II. MATHEMATICAL MODEL OF SEDC MOTOR

When a Separately Excited DC motor is exhilarated by a field current of I_f and armature current of I_a flows in a circuit, the motor develops a back EMF and a torque to balance the load torque at a particular speed. The I_f is independent of I_a. Each winding are supplied separately. The interaction of field flux and armature current in the rotor produces torque.

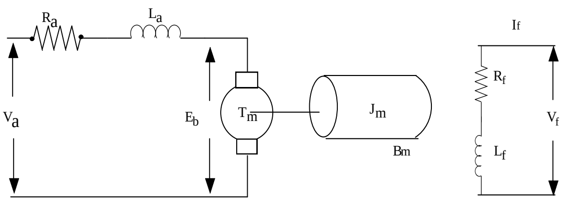

Fig. 1 Separately Excited DC Motor model

When an input voltage is applied to the field winding, the equation will becomes,

$$V_f = R_f * I_f + L_f \, (dI_f / dt)$$

And field flux Φ is proportional to field current I_f

$$\Phi \; \alpha \; I_f$$

We know that,

$$\omega_m \ \alpha \ (V_a - I_a R_a) / \varphi$$

$$\omega_m = (V_a - I_a R_a) / \varphi \qquad (1)$$

Where,
ω_m = Angular Velocity (rad/sec)
V_a = Armature Voltage (in Volt)
I_a = Armature Current (in Ampere)
R_a = Armature Resistance (in ohm)
Armature Voltage equation is,

$$V_a = E_b + I_a R_a + L_a(dI_a/dt) \qquad (2)$$

Torque balance equation is,

$$T_m = J_m (d\omega/dt) + B_m * \omega_m + T_L \qquad (3)$$

Where,
T_m = Motor torque
T_L = Load toque
J_m = Mechanical inertia
B_m = Friction constant

By taking field flux as φ and back emf constant as K. The equation for back emf of motor will be,

$$E_b = K \varphi \omega_m \qquad (4)$$

$$T_m = K \varphi I_a \qquad (5)$$

By taking Laplace transform to equation 2,

$$I_a(s) = (V_a - E_b) / (R_a + L_a (s))$$

$$I_a(s) = (V_a - K \varphi \omega_m) / [R_a (1+ L_a s / R_a)] \qquad (6)$$

Similarly by taking Laplace transform to equation 3,

$$\omega_m(s) = (T_m - T_L) / (J_m s + B_m) \qquad (7)$$

By using equation [1] to [7] we will drawn a block diagram of SEDC motor are as shown in below.

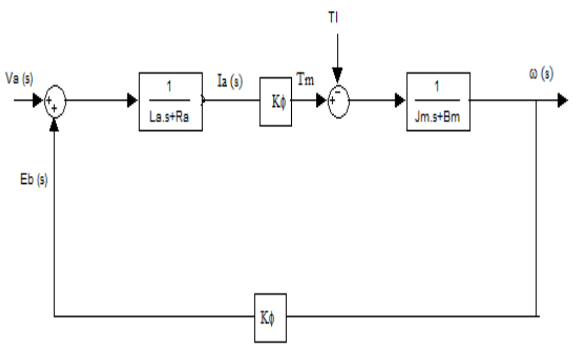

Fig. 2 Block model of SEDC motor

So, after obtaining the block model, we will solve the equation further, so that we can find the transfer function i.e.

$$\omega_m (s) / V_a (s) = [K\varphi] / [L_a J_m s^2 + (R_a + J_m + L_a B_m)s + (B_m R_a + (K\varphi)^2)] \qquad (8)$$

Hence DC motor can be replaced by transfer function obtaining in equation 8. The specification of DC motor model parameter is shown in table 1.

TABLE I
SPECIFICATION OF SEDC MOTOR

Parameters	Value
Armature Resistance (R_a)	1Ω
Armature Inductance (L_a)	0.01 H
Mechanical Inertia (J_m)	0.01 Kg.m^2
Friction Constant (B_m)	0.1 N.m/rad/sec
Back EMF constant (K)	0.01 V/rad/sec
Rated speed in rpm	1450/sec

III. CONVENTIONAL CONTROLLERS

Conventional controllers are typically used control loop feedback in industrial and control system applications. It is simply an equation that the controller used to evaluate the controlled variables which is measures and feedback to the controller. The controller then compares the feedback to the set point and generates an error. It then tries to minimize the error by incrementing or decrementing the control inputs to the process, so that process variable moves closer to the set point. The value is examined by one or more of three proportional, integral and derivative methodologies. Each controller has their specific functions. To improve the performance, PID controller must be adjusted according to the specific applications.

1. Proportional (P) Controller

P controller is mostly used in first order processes with single energy storage to stabilize the unstable process. The main purpose of the P controller is to decrease the steady state error of the system. However, despite the reduction, P control cannot manage to eliminate the steady state error of the system. In addition, it decreases the rise time and after a certain value of reduction on the steady state error, increasing K only leads to overshoot of the system replication.

2. Proportional Integral (PI) Controller

PI controller is mainly used to eliminate the steady state error resulting from P controller. Integral is equal to error multiplied by the time error has persisted. In this manner, integral increases the response of the system to a given error over time until it is corrected. Mostly PI controllers are used in industries because; the noise producing derivative action is neglected.

3. Proportional Derivative (PD) controller

PD control combines proportional and derivative control in parallel. Proportional action provides an instantaneous response to the control error which is useful for improving the response of a stable system. Derivative action is useful for fast system response to a rapid rate of change than to a small rate of change since it has an ability to predict the future error of the system response. Also D action directly amplifies process noise.

4. Proportional Integral and Derivative (PID) controller

A Proportional Integral Derivative controller is a generic controller widely used in industrial control system. The Proportional term responds instantaneously to the current error. The integral term responds to the accumulation of error providing a slow response that drives the steady state error towards zero. And derivative term responds to the rate at which the error is changing.

The PID controllers can use in continuous or discrete form. Also for tunning of such a controller various methods are implied which are given below.

1) Manual tunning method
2) Ziegler – Nichols method
3) Auto tunning method.

In this paper Auto tunning method is preferred. This method has a consistent tunning. In case of speed controlling of DC motor, we does not require to calculate the value of constants such as K_P, K_I, K_D, as we do in Ziegler – Nichols method. The feedback loop easily calculated the constant value with the help of PID controllers and we get the smooth response of a system by using the Auto tunning method.

IV. CONVENTIONAL CONTROLLER DESIGN USING MATLAB / SIMULINK

The system designed in MATLAB simulink environment is used to investigate the performance of a Separately Excited DC motor using all conventional controllers. The MATLAB Simulink model for speed control using P, PI, PD, and PID control are as shown in fig.

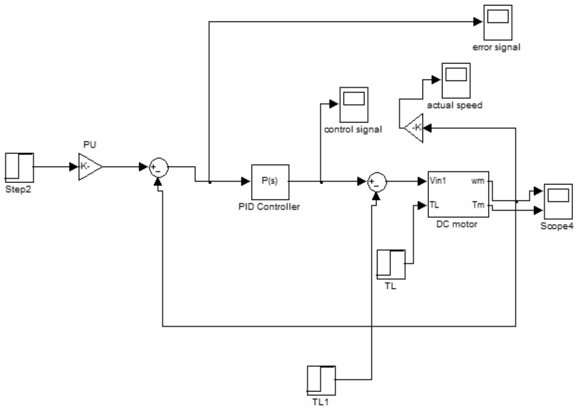

Fig. 3 Simulink model of speed control of SEDC model for P – controller

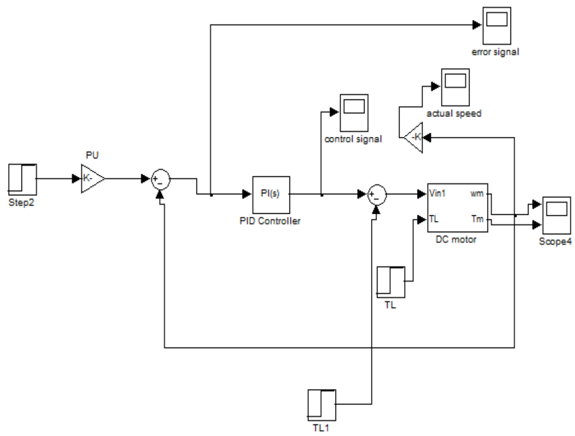

Fig. 4 Simulink model of speed control of SEDC model for PI – controller

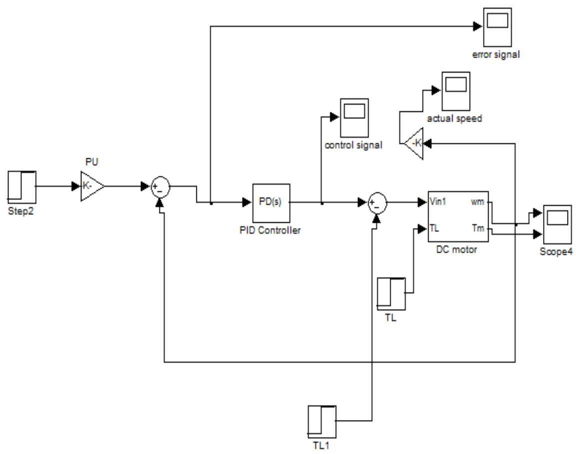

Fig. 5 Simulink model of speed control of SEDC model for PD – controller.

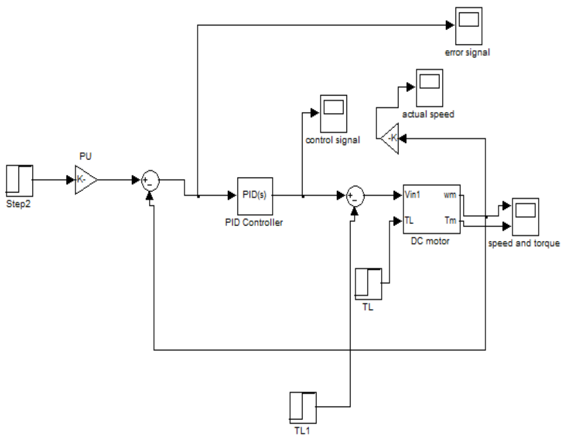

Fig. 6 Simulink model of speed control of SEDC model for PID – controller.

The required speed is controlled by these conventional controllers. The initial speed is input to the any PID type controller. Now this speed and feedback loop value is calculated as a difference which produces an error. This error will minimize to zero, so that speed can be controlled precisely. This PID type controller we have to tune so that the constant value such as K_P, K_I, K_D will get automatically because of Auto tunning method so that trial and error method will skip.

V. SIMULATION RESULT AND DISCUSSION

The MATLAB simulation results for all conventional controllers are given below. Fig. 7, 9, 11, 13 shows Actual speed Vs time for P, PI, PD, and PID respectively. And fig. 8, 10, 12 and 14 shows Actual speed and torque Vs time for P, PI, PD and PID respectively.

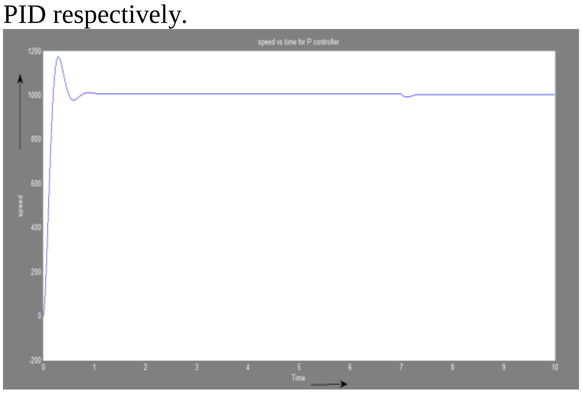

Fig. 7 Actual Speed Vs time for P controller

Fig 7 represents the response of speed with respect to time by using P controller. It has a rise time 0.0164 sec and it settles down at 0.0558 sec with a overshoot 13.9%.

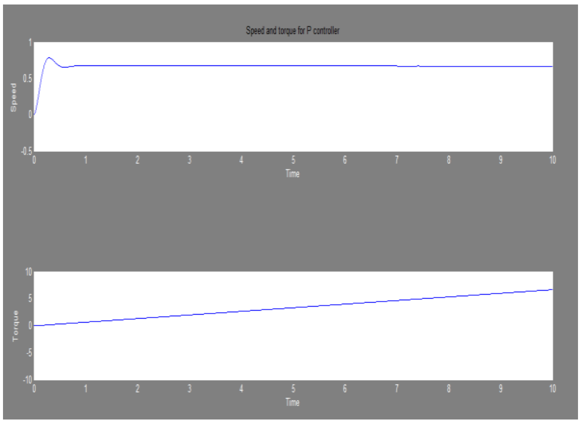

Fig. 8 Actual Speed and Torque Vs time for P controller

Figure 8 represents Speed vs time and torque Vs time. Here torque is increases with respect to time.

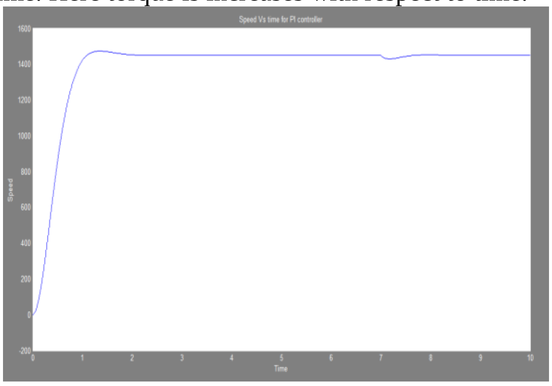

Fig. 9 Actual Speed Vs time for PI controller

Figure 9 shows the Actual speed Vs time for PI controller. After adding the Integral action the overshoot decreases upto 10.7% and it settles down 0.447sec.

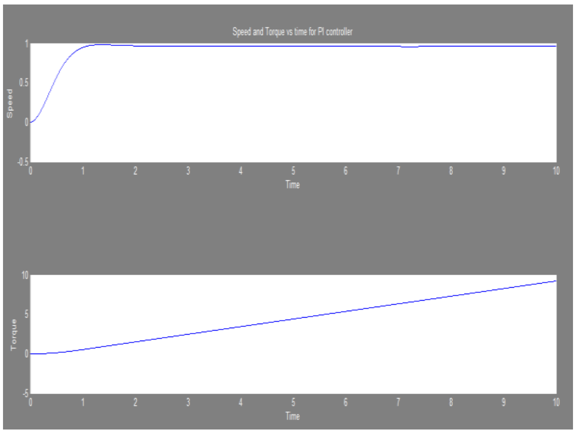

Fig. 10 Actual Speed and Torque Vs time for PI controller

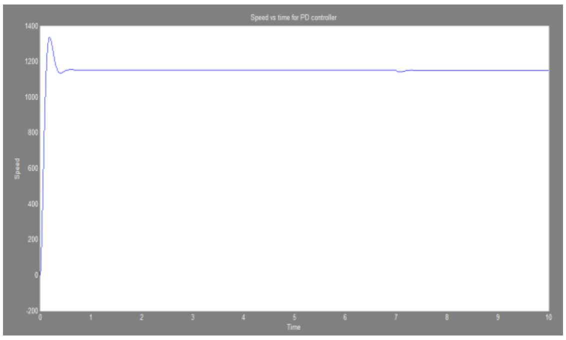

Fig. 11 Actual Speed Vs time for PD controller

The graphical representations of speed Vs time for PD controller are shown in fig. 11. By using the PD controller, it takes 0.0387 sec for settling the output with 12.5% overshoot. It has less overshoot as compared to P controller but greater than PD controller.

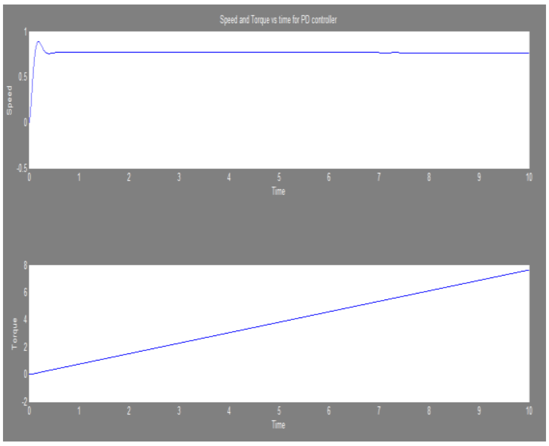

Fig. 12 Actual speed and Torque Vs time for PD controller

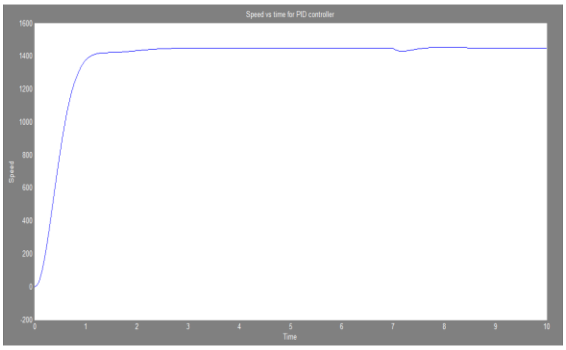

Fig. 13 Actual Speed Vs time for PID controller

PID controller is very efficient as compared to other one though PID controller produces noise due to Derivative action. . It has less overshoot as compared to PI controller.

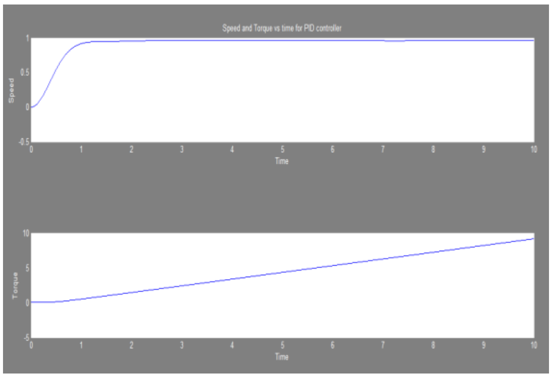

Fig. 14 Actual Speed and Torque Vs time for PID Controller

A comparative simulation result is presented for this PID type controller. The graphical result shows speed and torque versus time with different controller. And error signal results are also shown in following figure.

The comparative analysing value for rise time, settling time, peak, and percent overshoots for all these conventional controllers are shown in table 2 as follows.

TABLE III
CHARACTERISTIC OF SPEED RESPONSE

Controllers	**Rise time (t_r)**	**Settling time (t_s)**	**Peak time (t_p)**	**Overs-Hoot ($\%m_p$)**
P	0.0164	0.0558	1.03	13.9
PI	0.13	0.447	1.11	10.7
PD	0.0114	0.0387	1.05	12.5
PID	0.0785	0.245	1.09	8.91

From the above table we can observe that, the value of rise time and pick time of PID controller is small as compared to other. But PD controller has less settling time i.e. 0.0387sec. By using the PID controller the % overshoot is only 8.91 with a rise time 0.0785sec and it settled at a point 0.245sec.

VI. CONCLUSION

The auto-tuning method used in this paper is very efficient as compared to Ziegler Nichols method, as we do not need to calculate the values of constants and it reduces the time and complexity. The speed can be controlled of SEDC motor using all conventional controller, but as compared to other one the Proportional Integral Controller is mainly intended to control and maintain the constant speed with a less % overshoot and rise time. After using the PID controller it fails to make a zero overshoot value. This conventional controller also fails to provide the speed controlling for a non-linear load. The above problems can be overcome by Fuzzy logic controller (FLC).

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