[Akem, 7(4): April 2020]
DOI- 10.5281/zenodo.3771604

ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

DYNAMIC MODELLING AND CONTROL OF A DIRECT CURRENT (DC) MOTOR USING PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER

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ABSTRACT

The main objective of this project is to develop a home automation system using an *arduino* board with Bluetooth being remotely controlled by any android OS smart phone. As technology is advancing so houses are also getting smarter. Modern houses are gradually shifting from conventional switches to centralized control system, involving remote controlled switches. Presently, conventional wall switches located n different parts of the house makes it difficult for the user to go near them to operate. Even more it becomes more difficult for the elderly or physically handicapped people to do so.

Remote controlled *home automation* system provides a most modern solution with smart phones. In order to achieve this, a *Bluetooth module* is interfaced to the Arduino board at the receiver end while on the transmitter end, a GUI application on the cell phone sends ON/OFF remotely through this technology. The loads are operated by Arduino board up to – isolators and thyristors using triacs.

USAGE: The home automation systems are used for controlling the indoor& outdoor lights, heat ventilation, air conditioning in the house to lock or open the doors &gates to control electrical &electronic appliances and so on using various control systems with appropriate sensors. This paper presents the dynamic modeling and control of a direct current motor using proportional integral derivative controller. This controller helps to supervise the speed response of the DC motor. This propsed control method is widely used in industrial plants because of their simplicity and robustness. Industrial processes are subjected to variation in parameters and parameter perturbations. The parameters were used for speed control of the motor. Tuning PID parameters has a great effect on the stability and performance of the motor. Software called MATLAB/SIMULINK is used for simulation. The test for controllability and observability were carried out in the rank of matrix two to test for stability. When PID was tuned, it was observed that, plots of speed against time at open loop with unity value of 1Volt and 1Ω,the DC motor without the PID control did not stabilize fast. The motor rather stabilizes at a speed of 41rad/sec after about 80seconds which is too long. The PID gives a rise time of 0.0404seconds, settling time of 2.76seconds, overshoot of 84.8%, steady state of 1 and peak amplitude of 1.85 when a controller was introduced. This has also proven the superiority of the PID controller over other controllers.

Keywords: *DC motor, PID controller, modeling, speed control, state space analysis, matlab/simulink*.

I. INTRODUCTION

DC (Direct Current) motor is an electromechanical device that converts electrical energy into mechanical energy DC motor used in industry. The DC motor.(Muaz Abdel Rahman Ismailet al, 2016). This presentation describes the MATLAB/SIMULINK of the DC motor speed control method namely field resistance, armature voltage, armature resistance control method and feedback control system for DC motor drives. (Bimbhra, P.S 2011). The speed of the motor is a function of the applied voltage. A reversal in the applied voltage changes the direction of the motor. In reality however, constant voltage – DC supplies are utilized. Thus, there is a need for the fixed voltage to be converted to a variable voltage source. When speed control over a wide range is required, combination of armature voltage control and field flux control is used. This combination permits the ratio of maximum to minimum speed to be 20 to 40. With closed loop control, this range can be extended up to 200 (Brown et al 2009).Proportional integral derivative controller is a control loop feedback mechanism widely used in industrial control system and a variety of other application requiring continuously modulated control. PID controller is one of the best advantage methods for solving problems raised due to variation in parameter of system and environmental condition, PID controller are simply, quickly and more reliable. In this work proposed a PID controller and it tested for various types of PID controllers. The design Simulink model of PID controller for speed control of dynamic modelling of DC motor tested for various types of PID controllers, and found that for all types of PID the PI operate efficiently and gives better result to improve the speed control of dynamic modelling of dc motor in best time (Muaz Abdel Rahman Ismailet al, 2016). Here, PID controller is employed to control D.C motor speed and mat lab program, it is used for calculation and stimulation. The D.C motor whose speed is to be controlled using PID controller in the plant; the controller regulates the motor of either the supply voltage to the motor (MeghaJaiswal, 2013). Speed control of D.C motor using genetic swarm optimization technique has been compared. The performance was done in MATLAB. They compared two different methods of determining the PID controller parameters using fuzzy genetic algorithm. They compared with both the result and genetic algorithm method and shown better output as compared to simple PID controller (Pratap et al, 2015). Speed control of D.C motor can be controlled by using a PID controller in lab view D.C motor was interfaced with lab VIEW using microcontroller. The speed of D.C motor was sensed by using the IR sensor. The founded PID controller give minimize the error and bring the motor to the set point value (Rekhakushwah, 2013). Speed control of separately excited D.C motor with PID and fuzzy controller. The performance was done in MATLAB. They fuzzy controller is better to replace conventional PID controller to improve the system characteristics(Pooja et al, 2016) Speed control of a motor using PID controller was generated by an arduino program. Arduino is an open source electronic prototyping platform based on flexible easy to use hardware and software. The arduino language program is dumped into the microcontroller and it is given to the analog input of microcontroller and the analog outputs are connected to PID controller. The speed of the motor will be controlled based on the PID controller and the speed sensed through encoder would be compared with the reference value and obtained error is projected over PID controller and the process continues till we get minimum errors.(Nikunj, et al, 2009) Speed control of D.C. motor using conventional PID controller and sliding mode control (SMC) technique. The performance of the SMC is judged via MATLAB simulations using linear model of the D.C motor and known disturbance. They founded that the sliding mode controller (SMCR) is superior controller than PID for the speed control of D.C motor.(Chengaiah, et al, 2014) Comparative study on D.C motor speed control using various controllers. Electrical machines like D.C motors, permanent magnet D.C motors are being controlled with power electronics converters. The control has become precise with invention of micro controllers and power devices like IGBT, power MOSFET. The attempt is made to simulate a speed control of separately excited D.C motor with PID and fuzz controller. With the availability of MATLAB/SIMDUNK, for comprehensive study of modeling analysis and speed control design methods. Basilio (2002) developed the Proportional-Integral-Derivative (PID) controller; he discovered that the controller is better used due to its simplicity, stability, and robustness, which makes it a more widely used controller. He used this controller because its mathematical models are easily analyzed although; it was perceived that it has some level of errors, transients, low rising time and settling time. Singh et al (2012), proposed an efficient method for speed control of a DC servo motor using PI controller. The concept of their approach is used to obtain the transfer function of the motor to design the Pl controller. The design is validated and made simple by using MATLAB/Simulink software. The idea behind the design of the PI controller requires minimizing the error. First, the PI controller is used to control the speed of the motor, then it is used to control the armature current of the motor. The speed responses for different reference inputs between 110V to 220V were executed. In addition, their speed error responses for the same reference input intervals were equally executed. The conclusion is that the performance of the PI controller was evaluated and the controller gain was adjusted to obtain minimized error responses. The results showed significant improvement in maintaining performance of approximately zero overshoot and minimum stabilizing time but could not give the stability time completely and could not deal with the error completely. Bhagat (2009), proposed a DC motor control scheme titled “DC motor control using PID Controllers”. Their model consists of an armature controlled permanent magnet DC motor modeled as a first order system. A pulse width modulator (PWM) generator was used to control the average voltage supplied to the DC motor. The speed control of the motor using PI and PID control modes was incorporated using operational amplifier - TL084 for its implementation with the response of the controller to load variations being observed. The DC motor control system was tested with PI and PID controllers tuned using Zeigler-Nichols tuning method. The response of the PI controller was found to be as desired. When subjected to load variations, the controller output would quickly set to the reference point with a steady state error of less than 2%. However, the response of the system with PID controller was not as desired. Even though the response was found to be fast with steady state error of less than 2%, the system demonstrated oscillations. The PWM generated was not steady and oscillated around the set point. Singh et al (2012), proposed an Intelligent Proportional ~ Integral controller for speed control of a DC motor. Their basic aim was to convert the systems non-linearity into linear dynamics by cancelling out the none — linearity. Their control model used Artificial Neural Networks (ANNs). A Proportional ~ Integral (PI) controller incorporating a NARMA L-2 controller to make the PI controller intelligent was used to enhance the performance of the DC motor. The ANN for the system control uses two controllers; one for speed and the other for current. The authors also used one controller for both current and speed. Simulations are made at different situations and at different reference speeds to check controller performance. A comparison is made with the use of a single ANN controller for current control and with another controller for speed. He observed that by using an ANN controller, when the torque load is constant, the controller shows the ability of the drive to instantly reject perturbation. They further reported that the design of the controller was simple for independent control of torque and flux if it uses a cascaded structure. The authors concluded that the ANN not only controls the speed but also controls the current through the controller thereby reducing the steady state error and settling time, thus making it suitable for industrial operations. It was perceived that it failed to completely eliminate the steady state error. VandanaJha (2013) proposed a model of speed controller for a separately excited DC motor. The controller has two control loops, one for controlling the motor angular speed and the other for controlling the motor armature current. The controller implemented is Proportional-Integral (PI) type, which minimizes the delay and provides fast control. The optimization of the speed controller is done by using modulus-hugging approach; which provides stable and fast control of the DC motor. Simulation results under varying speed and varying load torque conditions are presented. Here, the separately excited DC motor produces two input voltages (armature voltage and the field voltage) which also produce two separate outputs. This control strategy provides good control but failed in some areas like low settling time and high overshoot. George (2008), proposed the speed control of a separately excited DC motor by varying armature voltage. The author applied a nonlinear autoregressive-moving average L2 controller for the speed control of the separately excited DC motor. He also discussed the speed control of a separately excited DC motor using chopper circuit. The author modeled the proposed system using MATLAB 7.0 toolbox and there after compared the performance of the developed system with the traditional ones using two conventional controllers; one with Simplorer Power Systems based chopper controlled DC motor model and the other one using Simulink model. He opined that in the chopper-controlled circuit, a Proportional Integral (PI) controller is used to generate the reference current and a Hysteresis Current Controller (HCC) is used to generate the switching patterns required by the chopper circuit. The PI controlled speed control loop senses in the actual speed of the motor and compares it with the reference speed to determine the reference armature current required by the motor. The current loop consists of a Hysteresis current controller (HCC). The HCC is used to generate switching patterns required for the chopper circuit by comparing the actual current being drawn by the motor with the reference current. A positive pulse is generated if the actual current is less than the reference armature current. Ismail et al (2011) proposed the control of DC motor speed control system by the method of pole assignment feedback technique, where all the closed-loop poles are specified. The primary objective of the control system is to regulate the motor angular speed. Results obtained were compared with another controller applied to the DC motor based on Proportional Integral Derivative (PID) control. It was discovered that the control method of the first results gives better output results than the proportional derivative controller. It was also discovered that the pole assignment feedback techniques could not give the complete overall results as desired. Amongst all the scholars that have researched on the PID controllers that I have reviewed. I am now modifying based on the limitations I have observed on the reviewed works.

II. MATERIALS AND METHODS

The dynamic modeling and control of a direct current motor using PID controller cannot be completed without mentioning the materials and methods used in actualization. Theproposed tools and materials used for this paper are as follows:

- Direct Current (DC) Motor Model of 1.5KW, 2HP, 220V DC Motor.
- MATLAB/SIMULINK R2013b softwareapplication package
- A HP Window10 laptop for implementation
- Textbooks and Journals on DC Machines, DC Machines Control and Instrumentation.

Methods of modeling and Control

The direct current motor is the system under consideration. The schematic diagram of the direct current motor is presented in figure 1.

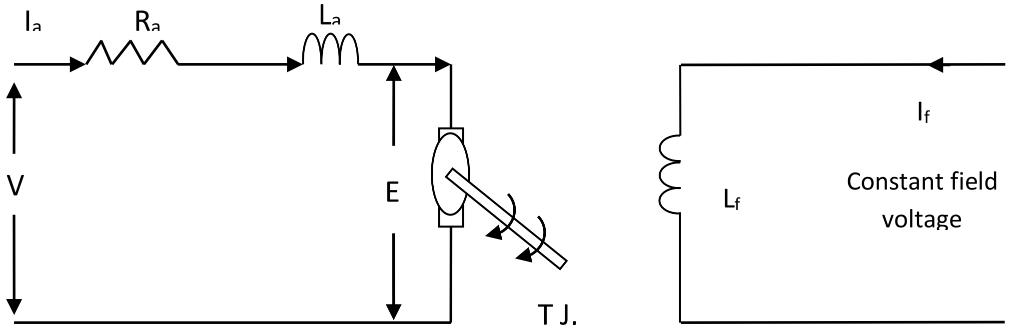

Figure 1:The schematic diagram of a DC motor.

Where;

R_a = armature resistance (Ω)
L_a = armature inductance (H)
I_a = armature current (A)
E_b = back emf (V)
V_a = armature voltage (V)
T_m = motor torque (Nm)
J = rotor inertia (kgm^2)
B = friction constant (Nms/rad)
K_b = back emf constant (Vs/rad)
K_t= torque constant (Nm/A)

Dynamic equations of the direct current motor

The armature circuit consists of the Armature resistance,R_a, the Armature Inductance L_a, a voltage source E_a and the back electromotive force (emf) E_b which is induced in the armature during rotation of the mechanical part. Using Kirchhoff's voltage law on the electrical part, the following equations are obtained,

$$E_\mathrm{a} = i_a R_a + L_a \frac{di_a}{dt} + E_b \tag{1}$$

The back emf, E_b is related to the angular velocity by,

$$E_b = K_b \omega_m = K_b \frac{d\theta}{dt} \tag{2}$$

Where, K_b is the back emf constant, ω_m is the motor angular velocity and θ is the angular speed. Hence, equation (1) can be written as,

$$E_\mathrm{a} = i_a R_a + L_a \frac{di_a}{dt} + K_b \frac{d\theta}{dt} \tag{3}$$

The above equations can be represented in block diagram form as shown in figure 3.2
Similarly, from Newton's laws, the mechanical part can be described by the following equation,

$$T_m = J_m \frac{d^2\theta}{dt} + B_m \frac{d\theta}{dt} \tag{4}$$

Where, $T_m = K_t i_a$ is the motor Torque, K_t is the torque constant, J_m is the motor moment of inertia and B_m is the motor damping coefficient. But the Torque T_m is given as,

$$T_m = K_t i_a \tag{5}$$

Thus, equation (4) can be written as,

$$K_t i_a = J_m \frac{d^2\theta}{dt^2} + B_m \frac{d\theta}{dt} \tag{6}$$

Equations (3) and (6) together make up the model of the DC motor on the electrical and mechanical part.

Equation 1 to equation 6 together makes up the dynamic equations of the direct current motor used for the simulations.

III. THE CONTROL DESIGN BASED ON STATE-SPACE REPRESENTATION

There are several ways of describing or modeling systems, which are:

Transfer function and State space representation among others. The control to be implemented in this paper is a Proportional Integral Derivative Controller, which is a state space controller. Hence, the model of the direct current motor will be presented in State space form. The general state-space representation of a linear system with m inputs, p outputs and n state variables is written as,

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{7}$$

$$y(t) = Cx(t) + Du(t) \tag{8}$$

Where, $x \in \mathbb{R}^n$ is the state vector, $y \in \mathbb{R}^p$ is the output vector, $u \in \mathbb{R}^m$ is the input vector, $A \in \mathbb{R}^{n\times n}$ is the state or system matrix, $B \in \mathbb{R}^{n\times m}$ is the input matrix, $C \in \mathbb{R}^{p\times n}$ is the output matrix and $D \in \mathbb{R}^{p\times m}$ is the feedforward matrix. Hence, rearranging equation (3.3), we obtain,

$$\frac{di_a}{dt} = \frac{1}{L_a}E_a - \frac{R_a}{L_a}i_a - \frac{K_b}{L_a}\frac{d\theta}{dt} \tag{9}$$

Equation (8) can also be written as,

$$\boldsymbol{\frac{di_a}{dt} = \frac{1}{L_a}E_a - \frac{R_a}{L_a}i_a - \frac{K_b}{L_a}\omega_m} \tag{10}$$

Similarly, rearranging equation (3.6), we obtain,

$$\frac{d^2\theta}{dt^2} = \frac{K_t}{J_m}i_a - \frac{B_m}{J_m}\frac{d\theta}{dt} \tag{11}$$

Equation (10) can also be written as,

$$\boldsymbol{\frac{d^2\theta}{dt^2} = \frac{K_t}{J_m}i_a - \frac{B_m}{J_m}\omega_m} \tag{12}$$

Assigning state variables, let $x_1 = \frac{d\theta}{dt} = \omega_m$, $x_2 = i_a$ and$u = E_a$, then,

$$\dot{x_1} = \frac{d^2\theta}{dt^2} = \frac{K_t}{J_m}i_a - \frac{B_m}{J_m}\omega_m, \tag{13}$$

Thus,

$$\dot{x_1} = \frac{K_t}{J_m}x_2 - \frac{B_m}{J_m}x_1 \tag{14}$$

$$\dot{x_2} = \frac{di_a}{dt} = \frac{1}{L_a}E_a - \frac{R_a}{L_a}i_a - \frac{K_b}{L_a}\omega_m$$

Thus,

$$\dot{x_2} = \frac{1}{L_a}u - \frac{R_a}{L_a}x_2 - \frac{K_b}{L_a}x_1 \tag{15}$$

Equations (13) and (14) can be put in matrix form as,

$$\frac{d}{dt}\begin{bmatrix}\omega_m \\ i\end{bmatrix} = \begin{bmatrix} -\frac{B_m}{J_m} & \frac{K_t}{J_m} \\ -\frac{K_b}{L_a} & -\frac{R_a}{L_a}\end{bmatrix}\begin{bmatrix}\omega_m \\ i\end{bmatrix} + \begin{bmatrix}0 \\ \frac{1}{L_a}\end{bmatrix}E_a \tag{16}$$

$$y = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}\omega_m \\ i\end{bmatrix} + [0]E_a \tag{17}$$

Equation (15), (16) and (17) make up the state-space representation of the DC motor system.

Table 1: Parameters for the control simulation

Parameter	**Value and Unit**
E_a	12 volts
J_m	0.01kg.m^2
B_m	0.00003kg.m^2/s
K_t	0.023Nm/A
K_b	0.023V/rad/s
R_a	1Ω
L_a	0.5H

(Nguyen, 2006).

Test for controllability and observability

In order to ensure that there exists an optimal performance, the pair (A, B) must be stabilizable and the pair (A, C) must be observable. To check for these conditions, the controllability and observability matrices have to be computed and analysed as follows:

The controllability matrix of a system represented by equation (7) is given as,

$Ctrb = [B\,AB\,A^2B\,A^3B \ldots A^{n-1}B]$(17)

In the case of the SEDM, *n* = 2, hence, the controllability matrix is,

$Ctrb = [B\,AB]$(18)

$$B = \begin{bmatrix} 0 \\ 2 \end{bmatrix} \text{and} AB = \begin{bmatrix} -0.003 & 2.3 \\ -0.046 & -2 \end{bmatrix} \begin{bmatrix} 0 \\ 2 \end{bmatrix} = \begin{bmatrix} 4.6 \\ -4.6 \end{bmatrix}$$

Thus, $Ctrb = [B\,AB] = \begin{bmatrix} 0 & 4.6 \\ 2 & -4.6 \end{bmatrix}$this has a full rank of 2. Hence, the pair (A, B) is controllable and hence stabilizable.

Similarly, the Observability matrix of a system represented by equation (7) is given as,

$$Obsv = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{bmatrix}$$

In the case of the SEDM, *n* = 2, hence, the observability matrix is,

$$Obsv = \begin{bmatrix} C \\ CA \end{bmatrix}$$

$C = [1 \;\; 0]$and

$$CA = [1 \;\; 0] \begin{bmatrix} -0.003 & 2.3 \\ -0.046 & -2 \end{bmatrix} = [-0.003 \;\; 2.3]$$

Thus, $Obsv = \begin{bmatrix} C \\ CA \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -0.003 & 2.3 \end{bmatrix}$

this has a full rank of 2. Hence, the pair (A, C) is observable.

Thus, it is certain that we can find an optimal gain *K* which can stabilize the DC motor using PID controller.

Model of PID Controller

The PID control is most widely used in industrial applications. It is implemented to control the speed of DC motor. The error between the reference speed and the actual speed is given as input to a PID controller. The PID controller depending on the error changes its output, to control the process input such that the error is minimized. Detailed information about the theory and tuning of PID controllers is given in [4][5]. The Transfer function of a PID controller is given as;

$$c(s) = K_p(1 + \frac{1}{TI*s} + T_D *S) \qquad (18)$$

The proportional control (K_p) is used so that the control signal u(t) responds to the error immediately. But the error is never reduced to zero and an offset error is inherently present. To remove the offset error the integral control action (T_I) is used. The Derivative control (T_P) is used to damped out oscillations in the process response. By tuning the gains of the PID controller and producing the optimum response using trial and error method. With the help of MATLAB/Simulink environment, the performance of separately excited DC motor with simulinkmodel and it is tested with MATLAB/ SIMULINK.

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DOI- 10.5281/zenodo.3771604

ISSN 2348 – 8034
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IV. RESULTS AND DISCUSSION

Simulation Results ofthe System

In order to dynamically predict the control topology, simulink toolbox in matlab is applied. The matlab/simulink program used for the simulations produced a number of results with respect to important variables of the DC motor. Figure 2 shows the SIMULINK representation of the DC motor model

Simulink Model of the System

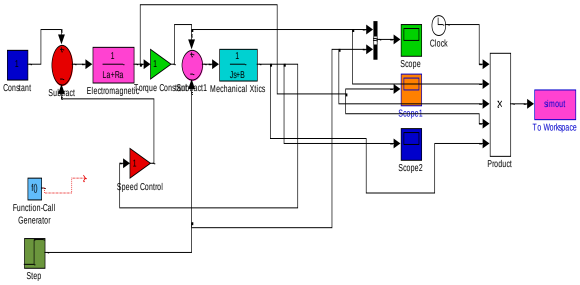

Figure 2: Simulink model of a DC machine

The dynamic equations shown above wereimplemented in Matlab/Simulink. An open-loop step response of the direct current motor was obtained using a step input *u* of IV, and measuring the output *y*. The result obtained is shown in figure 3,

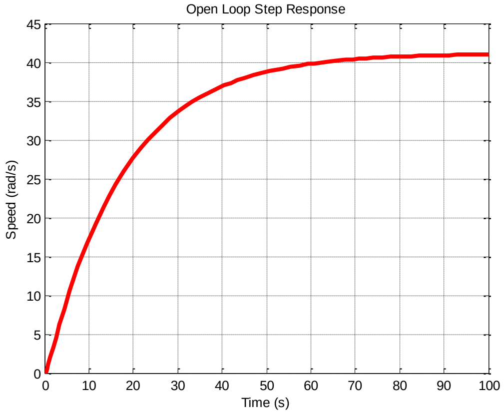

Figure3: Open-loop step response of the motor system

It could be seen from figure 2 that the system gained stable in open loop. The stability is achieved because of the unity voltage (1V) input to the system, the speed increases continuously as time increases, until it stabilizes at a speed of 41rad/s after about 80 seconds. This stability is further confirmed by the poles of the DC motor system using MATLAB/SIMULINK.

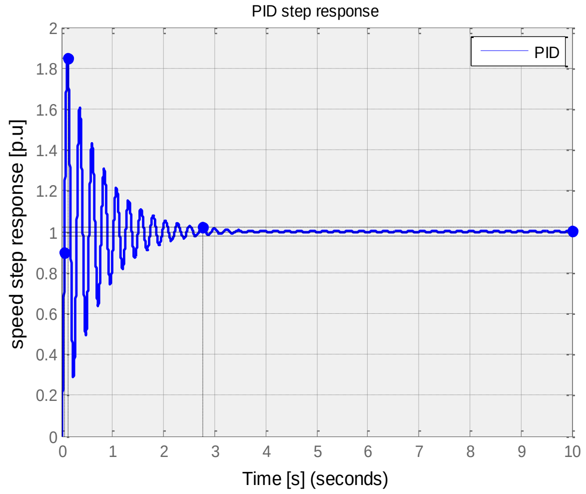

Figure 4: PID step response with control introduction

It could be perceived from figure 4 (speed against time) that the DC motor speed with the introduction of the PID controller stabilizes much faster than the open loop response of figure 3 (speed against time). The output results also shows that there is little or zero over shoot with a very good stability margin and the PID controller was able to achieve reference tracking or point.

Table 2: Speed and characteristics Response for PID

Time Response Specifications	Rise Time (Sec)	Settling Time (Sec)	Peak Amplitude	Steady State	Overshoot (%)
PID	0.0404.	2.76	1.85	1.000	84.8%

Table 2 shows the summary results of the PID controller obtained from figure 4.

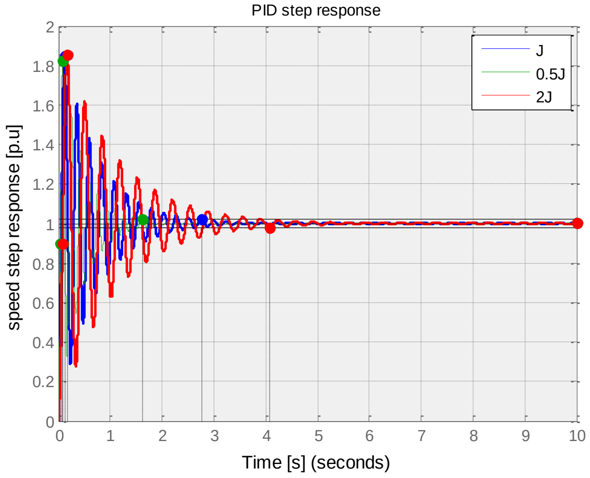

Figure 5: Graph of PID step response for variation of moment of inertia

Figure 5 to shows the summary results of PID obtained from the plots of figure 4 for the variation of moment of inertia for J, 0.5J and 2J (J = 0.01Kgm^2 , 0.5 X J and 2XJ) respectively.

The conventional PID controller still shows superiority when the moment of inertia was varied or tuned at different values of J, 0.5J and 2J (J = 0.01Kgm^2, 0.5 X J and 2XJ) respectively.

From the output (figure 5) it could also be seen that the DC motor performed optimally in terms of time responses (rise time, settling time, overshoot, peak amplitude and steady state value) when the moment of inertia was increased by some values.

Table 3: Speed variation and Characteristics of PID for J

Time Response *Specifications for* J	**Rise Time(Seconds)**	**Settling Time(Seconds)**	**Steady State**	**Overshoot (%)**	**Peak Amplitude**
PID	0.040	2.76	1.000	84.800	1.850

Tables 3 to shows the summary results of PID obtained from the plots of figure 4 for the variation of moment of inertia for J, 0.5J and 2J (J = 0.01Kgm^2 , 0.5 X J and 2XJ) respectively.

V. CONCLUSION

It could be seen that the conventional PID controller have been considered in this paper for the dynamic modelling and control of the speed of a DC motor. The performance of the controller is validated through simulations. A number of simulation results are presented for comparison. Based on the comparative simulation results, one can conclude that the proportional integral derivative controller realizes a good dynamic behavior of the DC motor with a rapid settling time, little overshoot of 1.85%, and zero steady state error under nominal condition. But the comparison between the speed controls of the DC motor by conventional PID controller shows clearly that the PID gives better performances. The PID controller also realizes good dynamics in terms of parameter variations. Furthermore, the simulation results obtained shows that the conventional PID controller gives better value of percentage overshoot and settling time.

VI. ACKNOWLEDGEMENT

The first author (Bendor, Sampson Akem) wishes to thank the Petroleum Technology Development Fund (PTDF) for the financial support granted to him to carry out this research work.

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