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Control Strategies on Speed of DC Motor and Power Sensor Based Speed Regulator Using SCILAB

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Abstract

DC Motors have high torque with low volume and hence used in most of the industrial applications. The speed control of a DC motor can be done both through armature controlled and field control techniques. The armature speed control of DC motor is provided by two inputs. They are armature voltage and load torque. However, the resultant output is a mechanical rotation of the motor. The motor runs with angular speed Ω(s). Speed of the DC motor can be controlled by using various controllers. In many industrial applications, PI controller is generally used but for sophisticated application, PI controller is not efficient and hence PIR controller is proposed to achieve greater accuracy in controlling the speed of the motor. Here in this paper, the different controllers like PI, PID and PIR are used for controlling the DC motor armature speed. A novel PIR controller is used and the results are compared with other controllers. The results are developed with the help of SCILAB. Also, the power sensor based speed regulator for motor is developed using SCILAB.

Keywords: Controller, SCILAB, PID controller, PIR controller, Sensor

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1 Introduction

The industrial applications attract the importance of utilizing the high performance motor drives. DC Drives have various advantages such as simple in design, high reliability, high flexibility, considerable cost and excellent speed control. So, it has been used in most of the industrial applications in which the control of speed and position of motor are necessary. The motor speed should be precisely controlled to achieve the desired performance. The various controllers are used to achieve this task. In this paper, the analyses of output response of motor speed control using PI, PID and PIR controllers are discussed in detail. The effectiveness of PIR based speed controller is highlighted using SCILAB software.

"SCILAB" is the high-level programming language, developed with many functions installed to perform various operations. Console page provides various executions of the programs within the loaded initial environment. MinGW is the software that supports the power electronics models and sensors in Scilab. Macros and help are loaded for any help in the execution of the programs. Sound file handling deals with FFT on a wave file processing, random includes all the models of random variables, spreadsheet is used to read an xls file, UMFPACK involves matrix and dimensional operations, GUI, graphics are used to analyse the model in n-dimensional format, Tcl\Tk is used to perform logical colour, puzzle, scroll and scaling operations. The major demonstration is "Xcos". This function is used to perform various models. The various models are available such as control systems, electrical systems, mechanical systems models, Modelica, event and optimal positions. These help to find models at different operational states. The Scilab is used to perform programs in the sci-notes and model the overall system and find the characteristics. The speed control of a DC motor can be done both through armature controlled and field control techniques [1]. In Xcos file, at view menu option, palette browser is identified that involve huge palette components which are used to design the model of the system. Here in this article, the armature control of the DC motor with input voltage run mechanically. The DC motor's armature speed control is provided with two inputs. They are load torque and armature voltage. However, the resultant output is a mechanical rotation of motor. The motor runs with angular speed $\Omega(s)$.

The four-quadrant speed control of the motor is made with the drives designed as per the design specifications. Nowadays, hybrid electric vehicles are designed with chopper controlled drives to operate the vehicle in four-quadrant operation [2]. Nowadays, induction motors are used widely at several applications. The mathematical model can be made and the dynamic performance response can be obtained. The accurate response of the model can be obtained very clearly. The voltage source inverter helps as stiff voltage source as an input source of the model. This drives the SVPWM (space vector Pulse Width Modulation) in more suitable and efficient manner. Variable speed drive is the best among all the techniques in terms of implementation and management. The major advantage of using variable speed drive technique is the low harmonic distortion [3-4].

In the industries, most often at servo motor control, the PIR controllers can be identified as better in their operation. The exponential rate at which the system gets decayed is easily identified through the PIR controller [5]. In the generation of renewable energy, at the operation of wind power generation, the low voltage ride through need essential equipment to control and modulate the power generated through wind turbine. This equipment controller can be a PIR controller. These methods are characterized based on the external devices influence in the existing system and the controllers after modifications made in the system [6]. Therefore based on the required modifications, the PIR is allowed to function in the system. In the recent days, the smart surveillance system can be done with PIR controller through employing GSM module in the system. The system needs low power and lesser price in manufacture. A passive infrared sensor is used to monitor the activities of the environment and update from time to time. A microcontroller is used to read all the instructions and allow GSM to operate an alarm that shows the existence of man in the environment [7]. By introducing the PIR controller, the quality of power is improved. The power transferred to the load is used to satisfy various conditions like the amplitude, phase and frequency of pure sinusoidal current and voltage waveforms. The dynamic voltage restorers are used to compensate the voltage loss in the system. In addition to this, the use of resonant compensators is used and they perform the functions of integrators and filters. The major harmonic compensation is done by the PIR controller [8]. Nowadays, brushless DC motors (BLDC) have a simple construction with reliable operation. The control of speed control of BLDC motors is employed by using PIR sensor. The 4 switch, three-phase BLDC motors use the sensor-based model with PWM incorporated to exhibit better performance in the system. The zero-crossing points are detected through the hall sensors and the current-carrying capability can be known through current sensor [9]. One of the renewable energy control applications is the PIR implementation in photovoltaic illumination of light control. The standby power consumption in the household appliances generally takes 10 to 12 percentage of the total power generated by the system. To ensure no power gets lost in the system, PIR sensor is preferred. The sensor not only turns off the switch but also controls the illumination intensity based on the requirement. The home automation has turned to modernize a home to a smart home. PIR operates 24 hours and the monitoring and control of appliances is done throughout the day. Therefore the system is in safe and secure operation [10]. The security can be maintained through mobile operated by a short message service is the GSM technology. Through this technology the system can be operated even from the remote ends of the world. The integrated systems send signals to personal system detecting through the sensors, monitor through the microprocessor platform [11-12].

In section 2, the mathematical representation of DC motor is discussed. In section 3, the description of block model representation of motor speed control is discussed and results are compared using different controllers. In section 4, effects of parameters on time domain specifications of system response are explained, section 5 explains the simulation model for sensor based motor speed regulator and section 6 provides the conclusion.

2 Mathematical Representation of DC Motor

A typical speed regulator of a DC motor can be governed through the dynamics performed by the system. The following equations represent the behavior of the system. These equations are obtained by using Kirchoff's law. Figure 1 depicts the model of DC motor. To get the response of the motor, the following parameters are considered.

'J' is the rotor's moment of inertia (Kg-m^2)
'B' is the constant of motor's viscous friction (N.m.s)
'vin(t)' is the motor's input voltage (volts)
'i(t)' is the current flowing through the electrical circuit (Ampheres)
'vbe(t)' is the back emf of the motor (volts)
'Kbe' is the constant in back EMF
'K' is the torque constant
'di(t)/dt' is the differential current (Ampheres)
'w(t)' is the mechanical speed of the motor (r.p.m)
'dw(t)/dt' is the differential speed of the motor (r.p.m)
'Tm(t)' is the motor torque (N-m)
'Tl(t)' is the load torque (N-m)
'Ω(t)' be the angular speed of the motor (rad/sec)
'R' is the electrical resistance (Ohms) and 'L' is the electrical inductance (H).

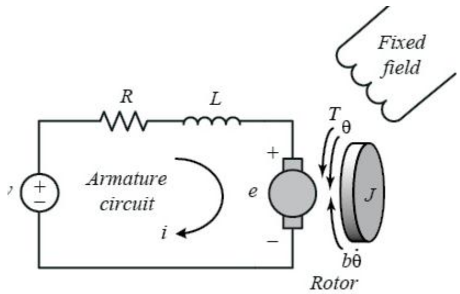

Figure 1 DC motor model

Let Gres(s) be the response of output to the input of the motor. Both the motor mechanical and electrical operation of the motor is mentioned through these equations [2].

$$vin(t) = [R * i(t)] + \left[L * \frac{di(t)}{dt}\right] + [vbe(t)] \quad (1)$$

$$vbe(t) = [Kbe * w(t)] \quad (2)$$

From Figure 1, the current and motor torque are directly proportional to each other by using torque constant and is given by,

$$Tm(t) = [K * i(t)] \quad (3)$$

$$\left[J * \frac{dw(t)}{dt}\right] + [B * w(t)] = [T_m(t)] - [T_l(t)] \quad (4)$$

By applying Laplace transform to the inputs, the equations are obtained as:

$$V(s) = L\{vin(t)\}$$

$$Tl(s) = L\{Tl(t)\}$$

By applying Laplace transform to the dependent variables, the equations are obtained as:

$$I(s) = L\{i(t)\}$$

$$T(s) = L\{T(t)\}\ and$$

$$\Omega(s) = L\{w(t)\}$$

Taking Laplace transform of Eq. 1 gives,

$$I(s) = \frac{V - K\omega}{R + sL} \quad (5)$$

Taking Laplace transform of Eq. 4 gives,

$$\omega(s) = \frac{T_m - T_L}{Js + B} \quad (6)$$

By solving all the above equations, the simplified equations are obtained as follows:

$$Gres(s) = \left[\frac{\Omega(s)}{vin(s)}\right]$$

$$= \frac{\left[\frac{1}{(L*s+R)}\right] * Kt * \left[\frac{1}{J*s+B}\right]}{\left[1 + Kbe * \frac{1}{[L*s+R]} * Kt * \frac{1}{[J*s+B]}\right]}$$

$$= \frac{Kt}{[(L*s+R)*(J*s+B) + Kbe*Kt]} \quad (7)$$

Table 1 shows the values of the parameters of DC motor used in this paper.

Table 1 DC motor parameters

Parameters	Value
Armature resistance (ohm)	1 ohm
Armature Inductance (H)	0.5 Henry
Rotor inertia (kgm^2)	0.0017 Henry
Armature voltage (Volt)	230 V
Viscous friction coefficient(Nms/rad)	0.017 (N.m.s)
Motor torque constant (Nm/A)	0.01
Back emf constant (V s/rad)	0.01
Speed	1800

3 Block Models of DC Motor

The simulation model includes the characteristic transfer function of armature controlled DC motor, Eq. 7. The proposed model involves regulation of speed through PID control, PIR control and also involving the sensor.

3.1 DC Motor's Simulation Model (With and Without PID Controller)

The block diagram representation of motor speed control without and with PID is shown in Figure 2. The block diagram is constructed using Eq. 5 and Eq. 6. The voltage of 230V is given as an input and speed 1800 RPM is obtained as an output without PID controller. The same system is constructed using PID controller. The outputs of both are connected through MUX to scope to obtain comparison graph. The motor speed is regulated and the regulated characteristics are shown in Figure 3. With PID controller, speed can be controlled and it is reduced to 1175RPM. For this, the value chosen for Kp, Ki and Kd are 0.1,0.5 and 0.05. It can be seen that without PID controller, system reaches steady state value at 1.758 secs and with PID controller, system reaches steady state value at 0.6 secs

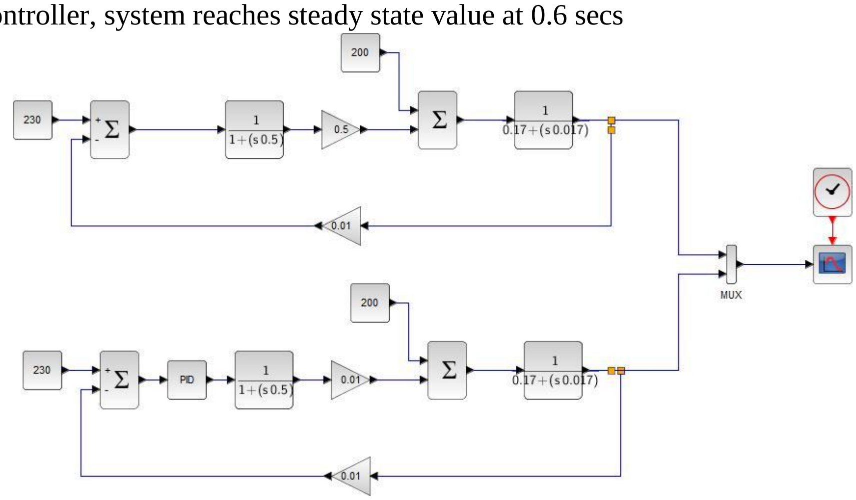

Figure 2 Block diagram of DC motor speed control (without and with PID controller)

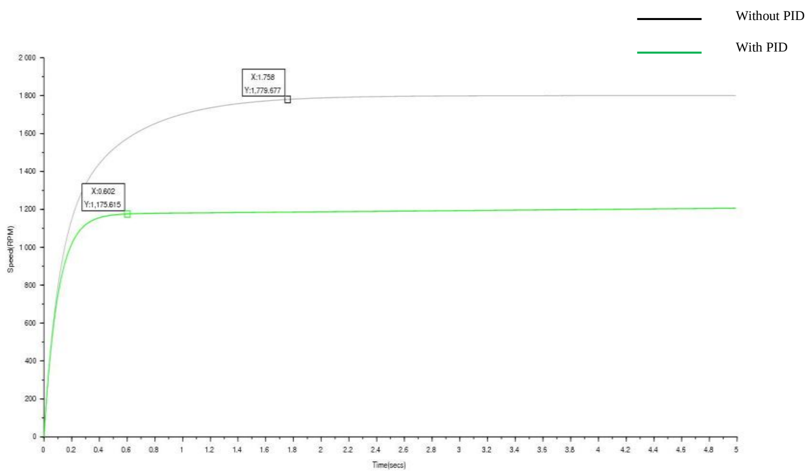

Figure 3 DC motor speed response (with and without PID controller)

3.2 State-Space Model of DC Motor

This model can be represented through the state-space analysis. The transfer function can be represented in state-space through representing in state-variables.

$$\left[J * \frac{dw(t)}{dt}\right] + [B * w(t)] = [K * i(t)] \quad (8)$$

$$vin(t) - [vbe(t)] = [R * i(t)] + \left[L * \frac{di(t)}{dt}\right] \quad (9)$$

The states space model of DC motor is given below

$$\begin{pmatrix} \frac{dw(t)}{dt} \\ \frac{di(t)}{dt} \end{pmatrix} = \begin{pmatrix} \left[-\left(\frac{B}{J}\right)\right] & \left[\frac{k}{J}\right] \\ \left[-\left(\frac{K}{L}\right)\right] & \left[-\left(\frac{R}{L}\right)\right] \end{pmatrix} \begin{pmatrix} w(t) \\ i(t) \end{pmatrix} + \begin{pmatrix} [0] \\ \left[\frac{1}{L}\right] \end{pmatrix} (v(t)) \quad (10)$$

$$(Y(t)) = (1 \quad 0) \begin{pmatrix} w(t) \\ i(t) \end{pmatrix} \quad (11)$$

The depiction of the DC motor state-space with feedback is controlled through a PID controller. The reaction of the DC motor state-space model is similar to the response of model with transfer function. Here, in the models, to represent the difference, values of Kp, Ki and Kd are taken as 0.1, 0.5 and 0.05 for state space model. The values for transfer function model are selected as 0.1, 50 and 0.05. Both the models have the same settling time with different peak magnitude. This model can further be regulated by using a current sensor and a DC voltage that controls the output response. DC motor depends upon voltage alone. By using controller, control over the speed of DC motor can be achieved. Figure 4 represents the state space model. The response characteristics are shown in Figure 5 for both state space model and transfer function model. It is found that steady state value is same for both model but settling time and steady state error differs due to difference in controller gain value.

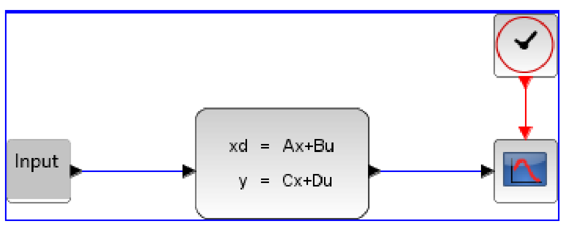

Figure 4 State space model

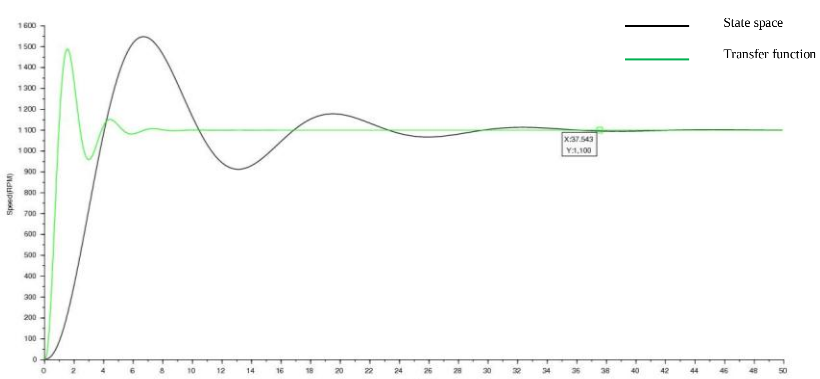

Figure 5 DC motor speed response

3.3 *Simulation Model of DC Motor (With PIR Controller)*

The simulation model of simple PIR control and the normal response of the system are designed and shown in Figure 6.

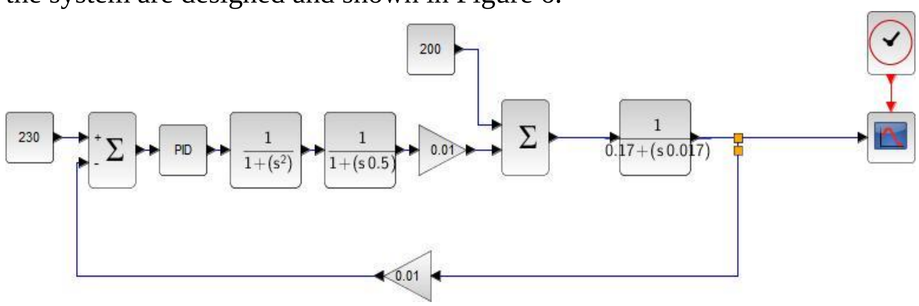

Figure 6 Block model of PIR control of DC motor.

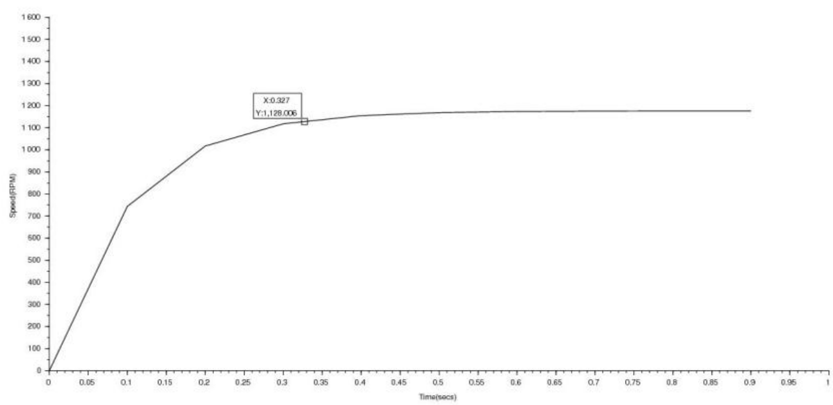

Figure 7 DC motor response (PIR controller)

The response of the system is represented in Figure 7. By using the PIR controller, the regulation can further be made improved. Here in this model, a small steady-state error occurred and shown in Figure 7. Also, the required rise-time and peak-overshoot can be obtained. Here the regulated speed can be obtained with 0.3 secs i.e less settling time compared to PID controller with 0.55 secs considering same specifications in motor parameters. The speed control results in maximum torque and improves efficiency. The PI control is commonly applied to the control methodology where maintaining V/F as constant help in easy identification of response of the system performance. Scalar or vector control is implemented for a closed-loop with or without feedback network. The feedback can be a sensor and a sensor less. This actually provides the values of the network. In the AC current applications, the controllers are applied for different applications. Based on the applications, the control algorithms are employed in the system. For the more complex control models, the PIR (proportional Integral Resonant current control) controlling technique is preferred. AC currents though controlled but however subject to the switching frequency variations. These can be controlled based on the PIR controllers. The PIR is more advantageous than the PR controller because the PR is a part of PIR controller. The PR and P-PROG 3 phase control can be done by the 1st order rather than using a 2nd order PIR controller [13]. For a second-order system, the system can be represented as follows:

$$X(Re) = Kr * (e^\wedge(-w))$$

The Laplace transform of the PIR controller for a second-order equation is [8]:

$$X(s) = \left(\frac{Kr}{s^2 + w^2}\right) \qquad (12)$$

The resonant controller is also used for the induction motors to compensate for the dead-time of the system. In this paper, the value of w=0.1. For a few permanent magnet motors, this drive is used to control the system and analyze the performance of the system model. In addition to this model, a quasi-capacitor is connected that controls the system by reducing the harmonics and ripples in the system. For this function to get the pure waveform, the PIR controllers are employed in the model of a system [14]. In a multi-phase motor system, the high torque density, low cost and robustness of the system helps in applications like development of the propulsion unit in the system. The current control of all sinusoidal and non-sinusoidal fundamental and multiples of the fundamental harmonics are controlled by the PIR controller [15].

4 Comparison Table

The PID controller helps to control the system by changing the different values of Kp, Kd and Ki controller. The faster response at less settling time is the desired operation of a system provides the least steady-state error value.

Table 2 Effect of PID controller with different values

Controller Type	Kp	Kd	Ki	Settling time (sec)
P-D	0.13	0.60	0.00	1.38
P-I	0.120	0.00	0.30	1.06
P-I-D	0.1	0.05	50	0.6
P-I-R	0.1	0.5	0.2	0.327

From the Table 2, with Kp, the maximum peak amplitude decreases. Therefore, the P controller is proportional to the peak magnitude. With an Ki value, the steady-state error decreases as the integration of the signal integrate the error signal. Therefore the I controller is proportional to the steady-state error. With the Kd, the settling time is adjusted. Therefore, the settling time is proportional to the D controller. This analysis is made based on varying the values of the PID controller. In control systems, generally either in parallel or in series, the PR controller is provided. The major drawback of the PR controller is that it doesn't eliminate the DC harmonic content. The model gives the desired regulated output. The advantage of using PIR controller is decreases in settling time, peak-overshoot and steady state error.

With change in the values of all parameters in the PID and PIR controller, the corresponding changes take place. The changes are noted in Table 3.

Table 3 Effect on time domain specifications with increasing values of parameters

Parameter Type	**Kp**	**Ki**	**Kd**	**PIR CONTROL**
Rise-time	Reduces	Reduces	Small reduce	Reduces
Peak-overshoot	Improves	Improves	Reduces	Greater improvement
Settling-time	Small change	Improves	Reduces	Greater Improvement
Steady-State error	Reduces	Reduces	No change	Reduces

Based on the variation of different values in the controller gain, the conclusions are made for the response of each controller. Among all the controllers used, PIR controller plays a crucial role in the better operation. Though the maximum peak amplitude is quite less compared to other controllers, the system peak response can be improved by changing the Kp and Kd values. Each controller has a specific task. However, the most preferred controller can be PIR due to resonance phenomenon. By following the traditional methods of PID controller may lead to poor performance of the system. The proportional integral retarded controller is proposed to solve the issue of performance factor. The PIR controller has all the properties that PI and PR have and thereby provide efficient operation. PIR tuning technique through varying different values just by trial and error values to the nearest values tune the circuit in a systematic format.

5 Simulation Block Models

The model of DC motor sensor-based speed regulation is shown in figure 8.

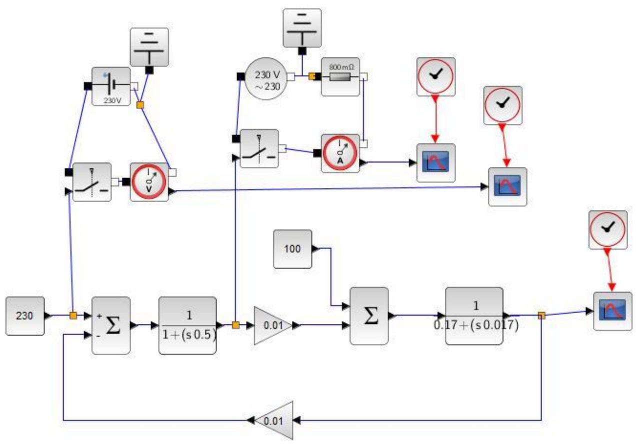

Figure 8 Model of DC motor system using sensor-based speed regulator.

By using the sensor-based speed regulation, the regulation is further made to a very small value. The voltage at the switch determines the level of the regulation. Input V_{in} is measured by using voltage sensor. This can be done by using a switch. Here the set speed is 600RPM.

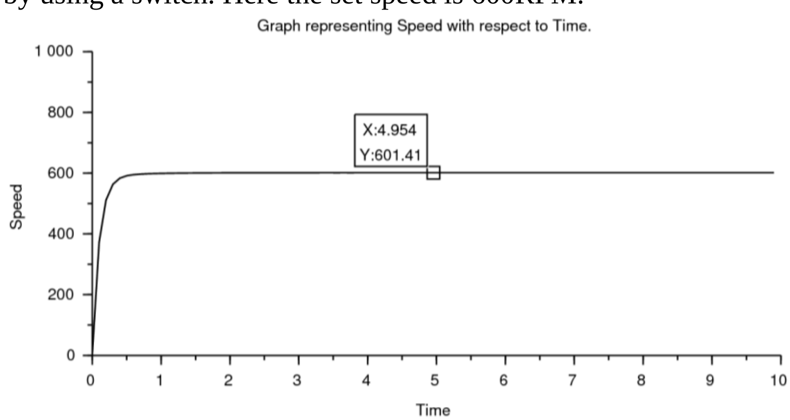

Figure 9 DC motor Speed response (Sensor based)

The value of the DC voltage can be obtained through scope. Similarly the current I(t) can be obtained by the equation given below.

$$I(t) = \left(Vin(t) - Vb(t)\right) * e^{-t*\left(\frac{R}{L}\right)} \quad (13)$$

This value is obtained by using a switch and a voltage sensor. In addition to this, the output speed can be obtained as output response of the model.

Figure 9 shows the DC motor speed control based on sensors. From the modifications, it has been noticed that the controller based on the sensor improves the regulation of the model. However, the sensor-based model is dependent on the voltage at the switch. The lowest possible regulation can be obtained through the sensor circuit. From the model graphs, it can be observed that the settling time of the graphs is less. The current sensor used in the circuit is connected in series to the electrical circuit measures current in the circuit. It is noted that the current flowing in the circuit conventionally is taken to be positive. The ohmic resistance of the current sensor is taken to be zero value. To current sensor is found at the macros in the electrical model and the Modelica of the model can also be made in the system.

6 Conclusions

In this paper, the speed control of the sensor-based dc motor is simulated in a systematic manner. The response characteristic graph of the system is obtained. Then, the obtained characteristics from the system model are controlled by various controllers. It is observed that the PIR controller provides the better output among all the controllers. The sensor-based network of the model is designed and the response is observed to be more regulated. The regulation of speed control of the model is represented in state-space model and the comparative graph is obtained. It is observed that the transfer function system response and the state-space model response resembles similar to each other. A simple PIR controller model of the system is designed and analysis is made through comparing with the system response. It is noted that the improvement in the output characteristics is better compared to PID controller. Therefore, the experimental study of the sensor-based model using controllers provides a huge scope of use of controllers in the safe environment.

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