Design and Simulation of PID Controllers for Motor Speed Control

Predefined Hardware Project

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EXECUTIVE SUMMARY

Motor Speed Control System Design :

- Proper selection and integration of DC motor and control mechanism .
- Selection and justification of sensors and actuators .
- Clarity and completeness of the system design .

PID Controller Design :

- Clear explanation of PID controllers and their role.
- Detailed explanation of the structure and functioning of each PID component .
- Step-by-step guide for tuning PID parameters (Kp, Ki, Kd) .
- Application of tuning methods for optimal system performance.

System Modelling and Simulation :

- Accurate modelling of the motor speed control system and PID controller in MATLAB/Simulink .
- Thorough analysis of transient response, steady-state error, and stability.

Response to Disturbances :

- Introduction of disturbances into the system simulation
- Evaluation of PID controller response to disturbances.
- Assessment of system robustness and ability to maintain desired speed .

Applications :

- PID Controller applications.

DC MOTOR SPEED CONTROL

The DC motors have been popular in the industry control area for a long time, because they have many good characteristics, for example: high start torque characteristic, high response performance, easier to be linear control…etc.

The speed of a DC motor is given be the relationship

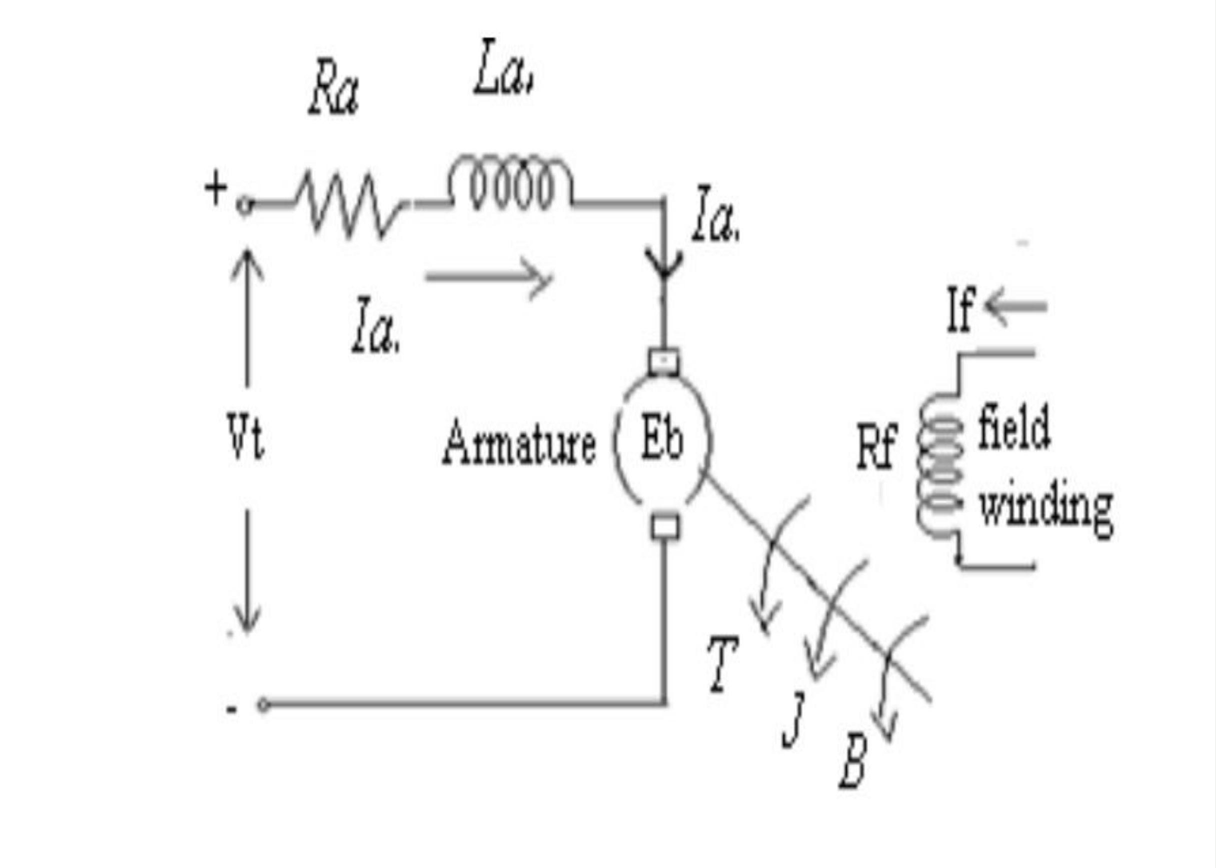
$$N = \frac{V - IaRa}{k\phi}$$

This Equation show that the speed is dependent on the **supply voltage V, the armature circuit resistance Ra, and field flux Φ**, which is produced by the field current. We can control the speed of DC motor using PID controller .For Observing this in MATLAB ,we need to find mathematical modelling of DC motor.

MATHEMATICAL MODEL OF DC MOTOR

The electric circuit of the armature and the free body diagram of the rotor are shown in the following fig:

Ra=Armature Resistance, **La**=Armature self inductance caused by armature flux, **Ia**= Armature current, **If**= field current, **Eb**=Back EMF in armature, **V** =Applied voltage, **T**=Torque developed by the motor, **θ** = Angular displacement of the motor shaft, **J** =Equivalent moment of inertia of motor shaft & load referred to the motor, **B**= Equivalent Coefficient of friction of motor shaft & load referred to the motor.



- The DC motors are generally used in the linear range of the magnetization curve. Therefore, air gap flux Φ is proportional of the field current i.e.

  $\Phi = K_f . I_f$........................(1)

  The torque T developed by motor is proportional to the armature current and air gap flux

  $T = K I_a$..............................(2)

  The motor back emf being proportional to speed is given as

  $E_b = K_b w$...........................(3)

  Applying KVL in the armature circuit

  $V_a = I_a R_a + L . dI_a/dt + E_b$..................(4)

  And the dynamic equation with moment of inertia & coefficient of friction will be

  $T = J . dw/dt + Bw + T_L$ ....(5)

  Where T_L = load torque

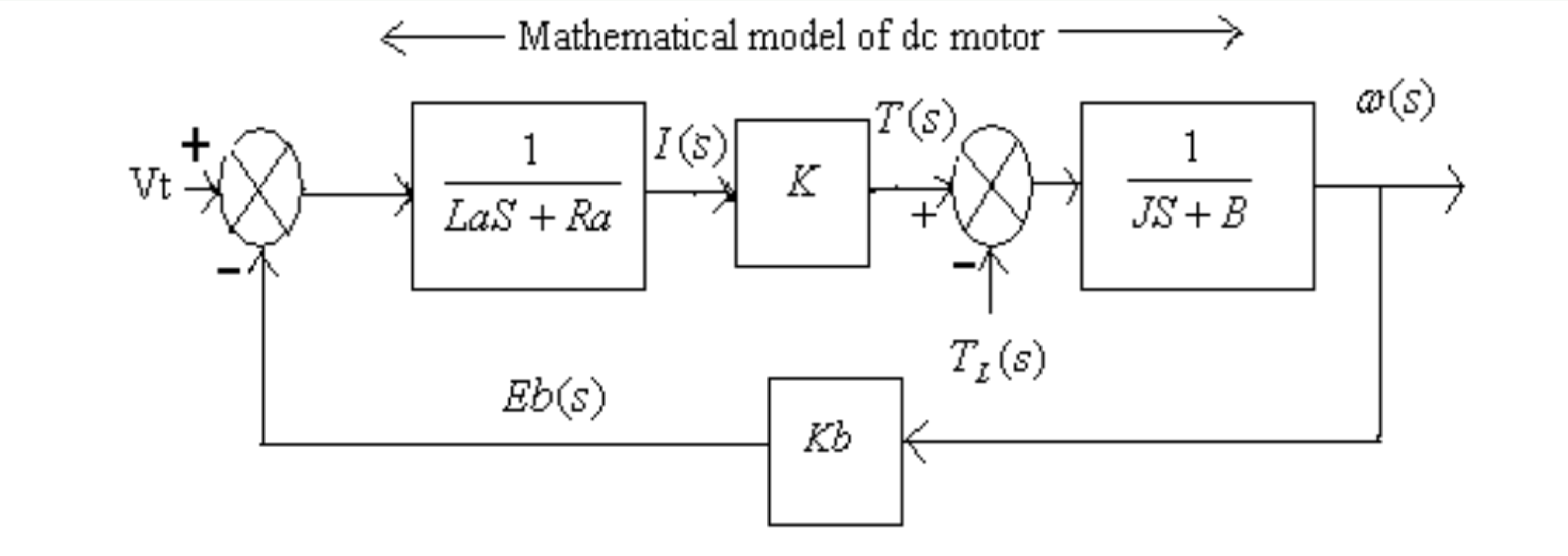
Taking the laplace transform of equation 2,3,4,5

T(s) = KIa(s)………….(6)

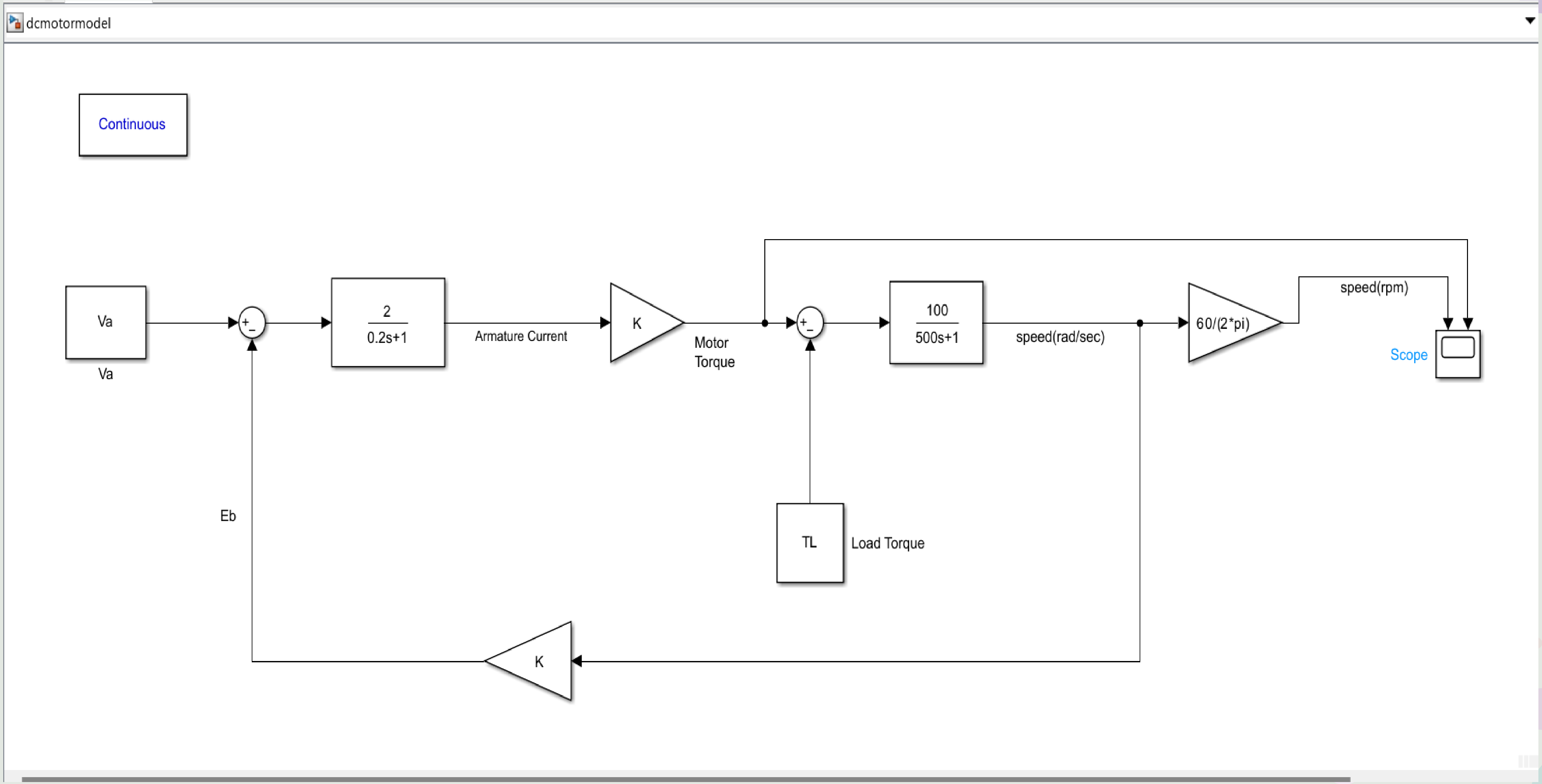
Eb(s) = Kb.W(s)…….…….(7)

Va(s)-Eb(s) = Ia(s) (Ra + sLa)…….……..(8)

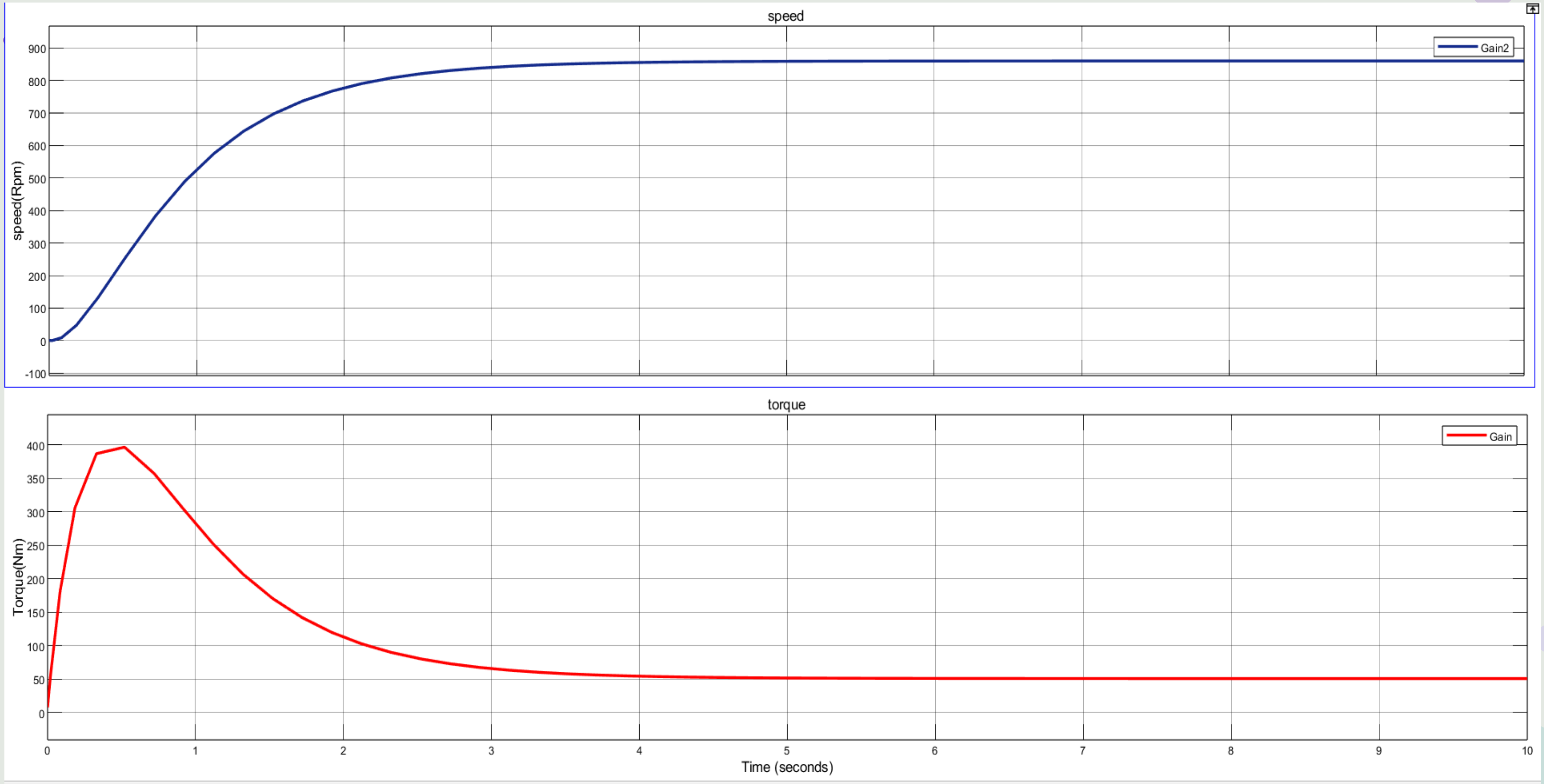
T(s)-Tl=(Js+B) W(s)…………………..(9)



MATLAB MODELLING OF DC MOTOR



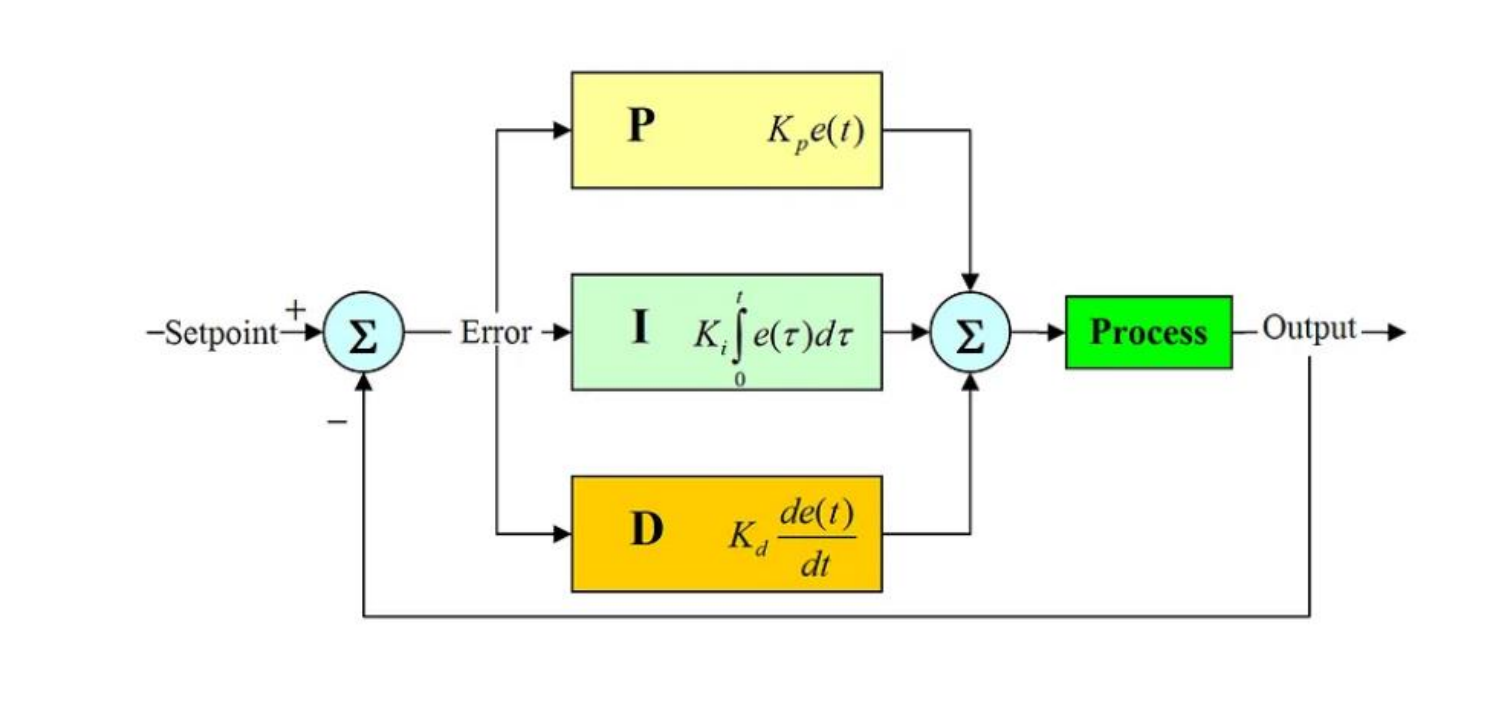
Dc motor characteristics

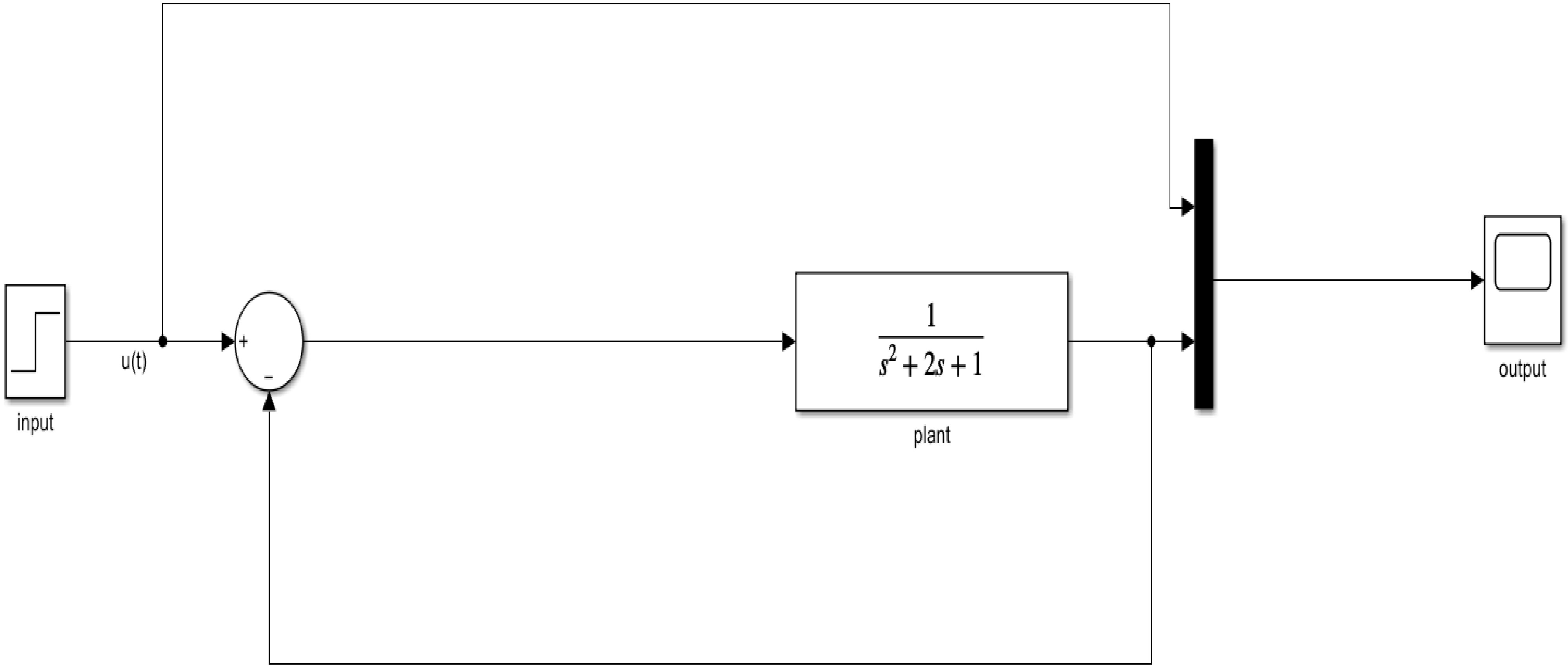


PID CONTROLLER

- A proportional-integral-derivative (PID) controller is a control mechanism that is widely used in various industrial applications. The controller's purpose is to regulate a system's output by adjusting its input, taking in to account the system's error, rate of change, and accumulated error. The PID controller has become the standard for process control applications in various industries, including manufacturing, chemical, automotive, and aerospace.
- A PID controller is a feedback control system that continuously measures the system's output and compares it to the desired output. The difference between the two is known as the error signal. The controller uses the error signal to adjust the system's input to bring the output closer to the desired output.
- The controller's input is adjusted by adding or subtracting a correction factor, which is determined by three terms:
- 1. **Proportional term (P)**: This term is proportional to the error signal and represents the immediate response of the controller. The proportional term is multiplied by a gain factor, which determines the controller's sensitivity to the error signal.

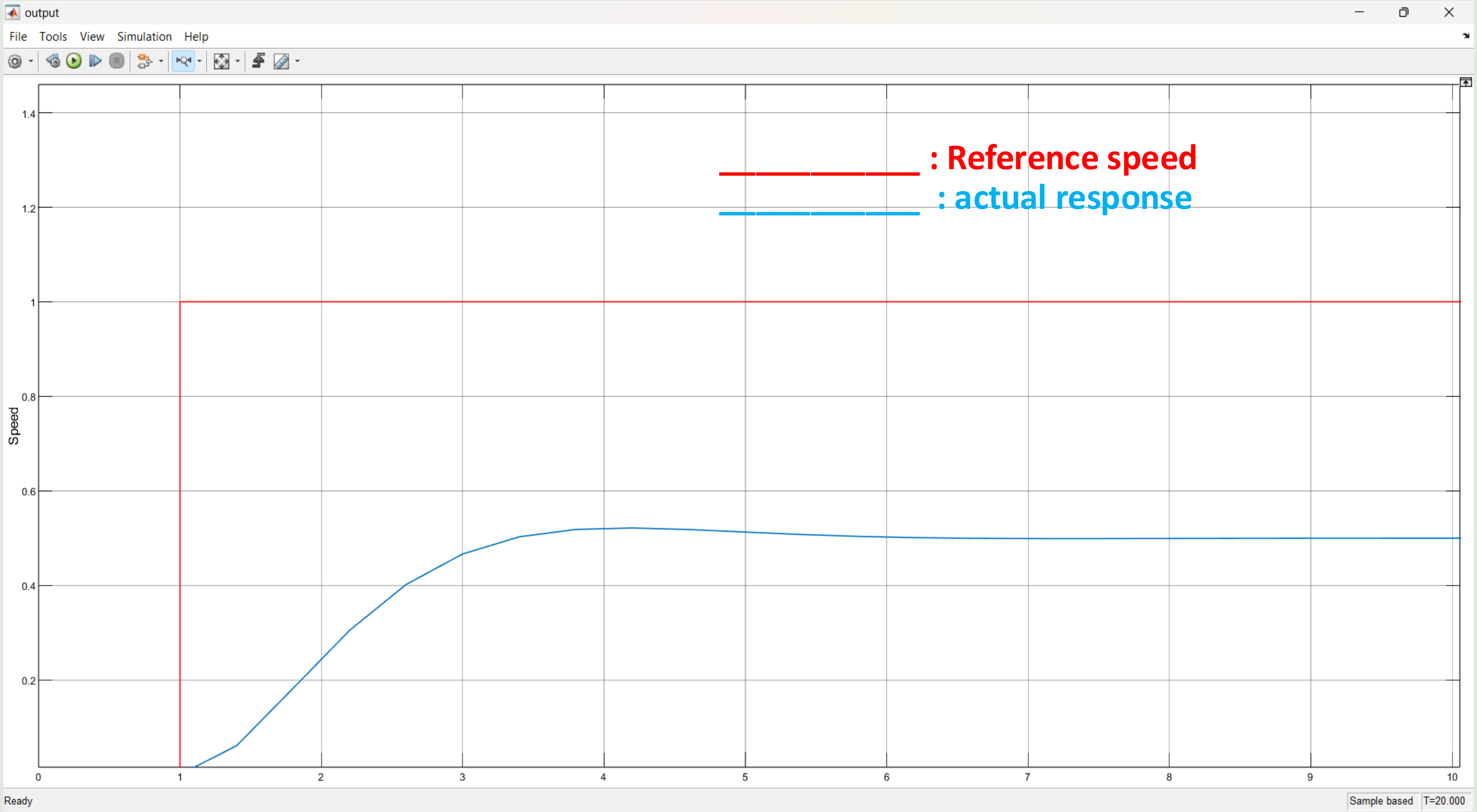
- 2. **Integral term (I)**: This term is proportional to the accumulated error over time and represents the steady-state response of the controller. The integral term is multiplied by a gain factor, which determines the controller's responsiveness to the accumulated error.
- 3 . **Derivative term (D)**: This term is proportional to the rate of change of the error signal and represents the controller's transient response. The derivative term is multiplied by a gain factor, which determines the controller's sensitivity to the rate of change of the error signal.



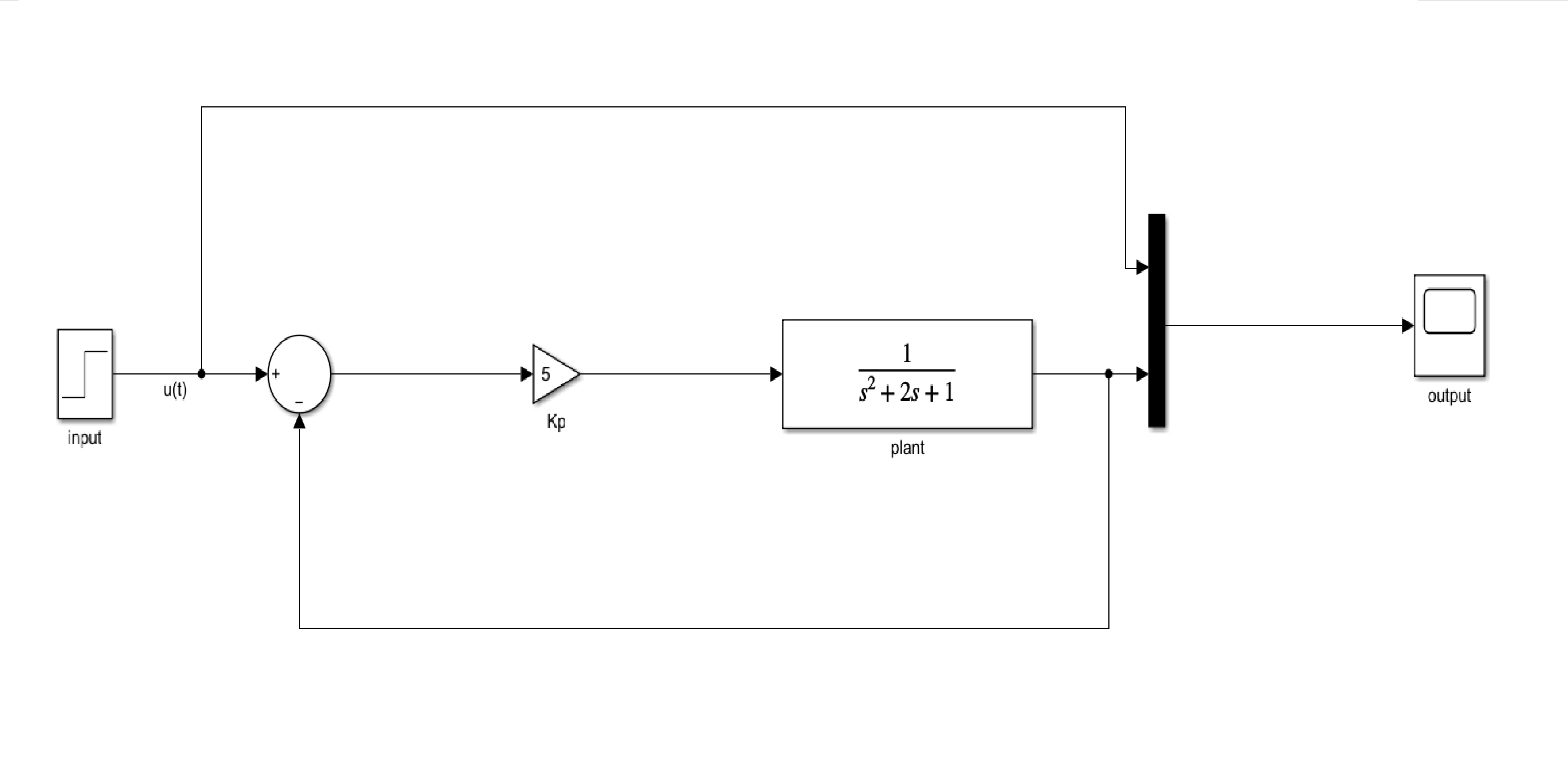


Plant without any controller

- Y-axes represents speed in rpm (for all the following graphs)
- X –axes represents time in sec (for all the following graphs)

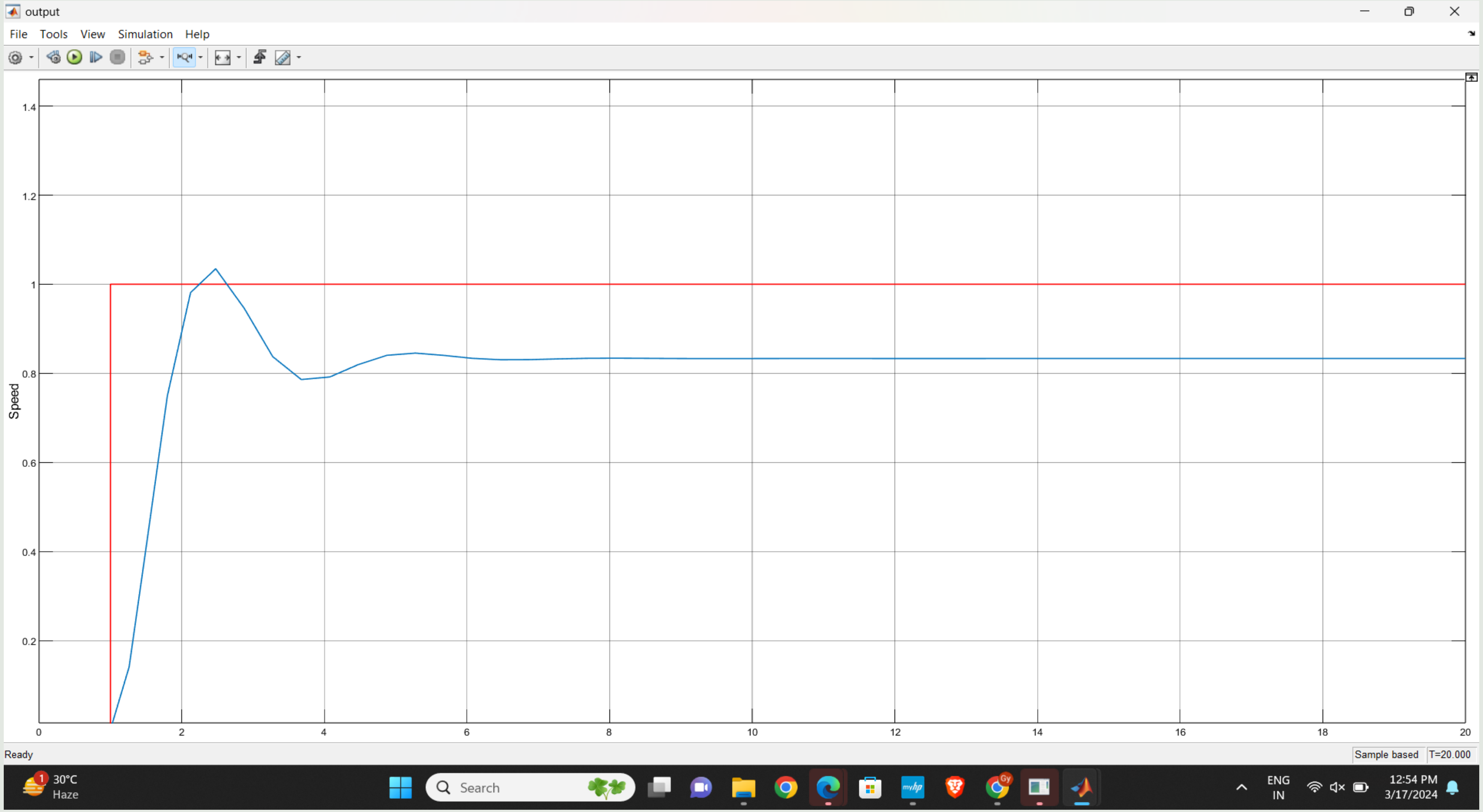


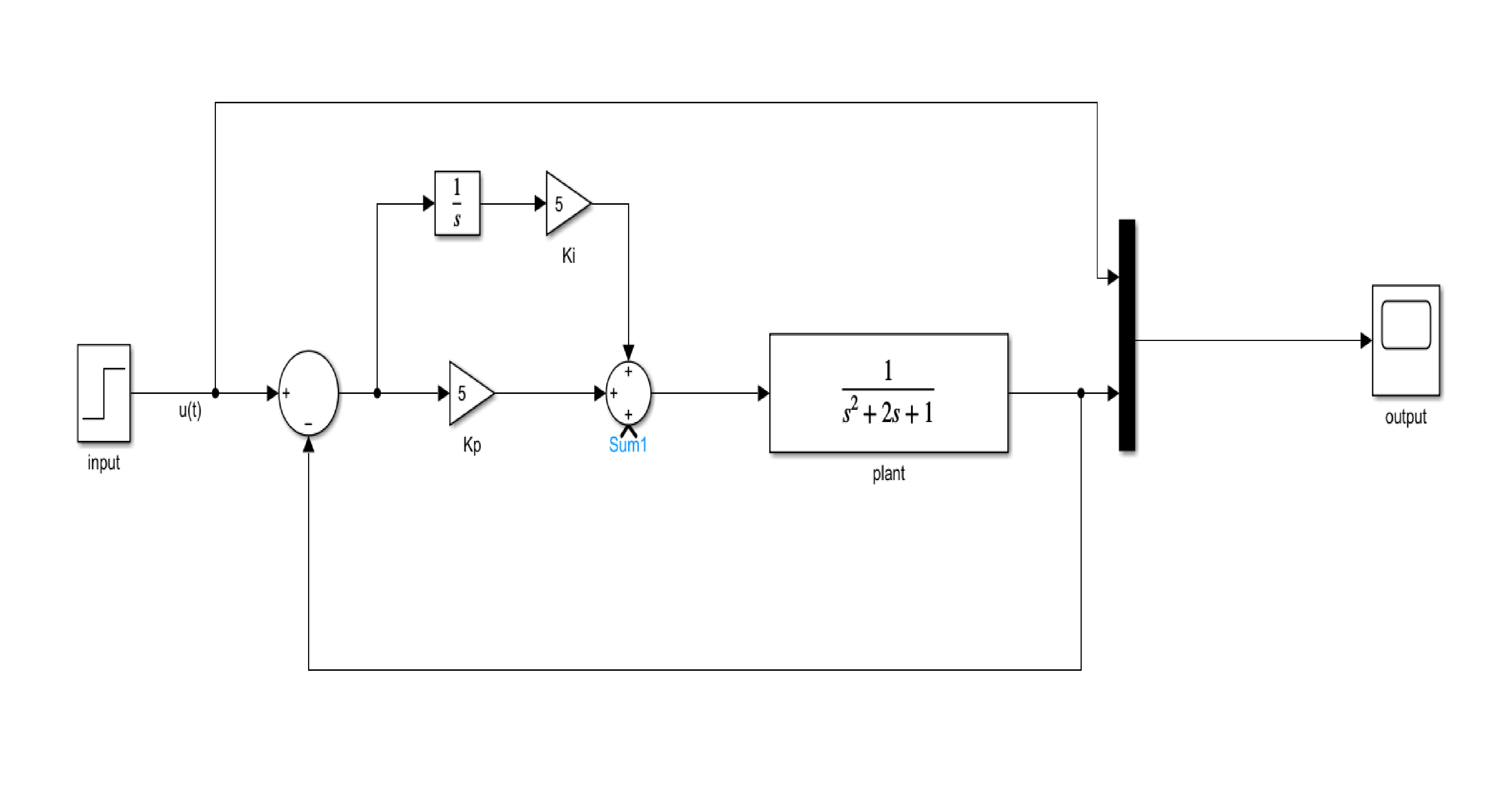
We can clearly see there is large error between reference and actual response. To reduce this response, PID controller is used. First, Proportional controller is provided to the plant to reduce the error.



Plant with proportional controller

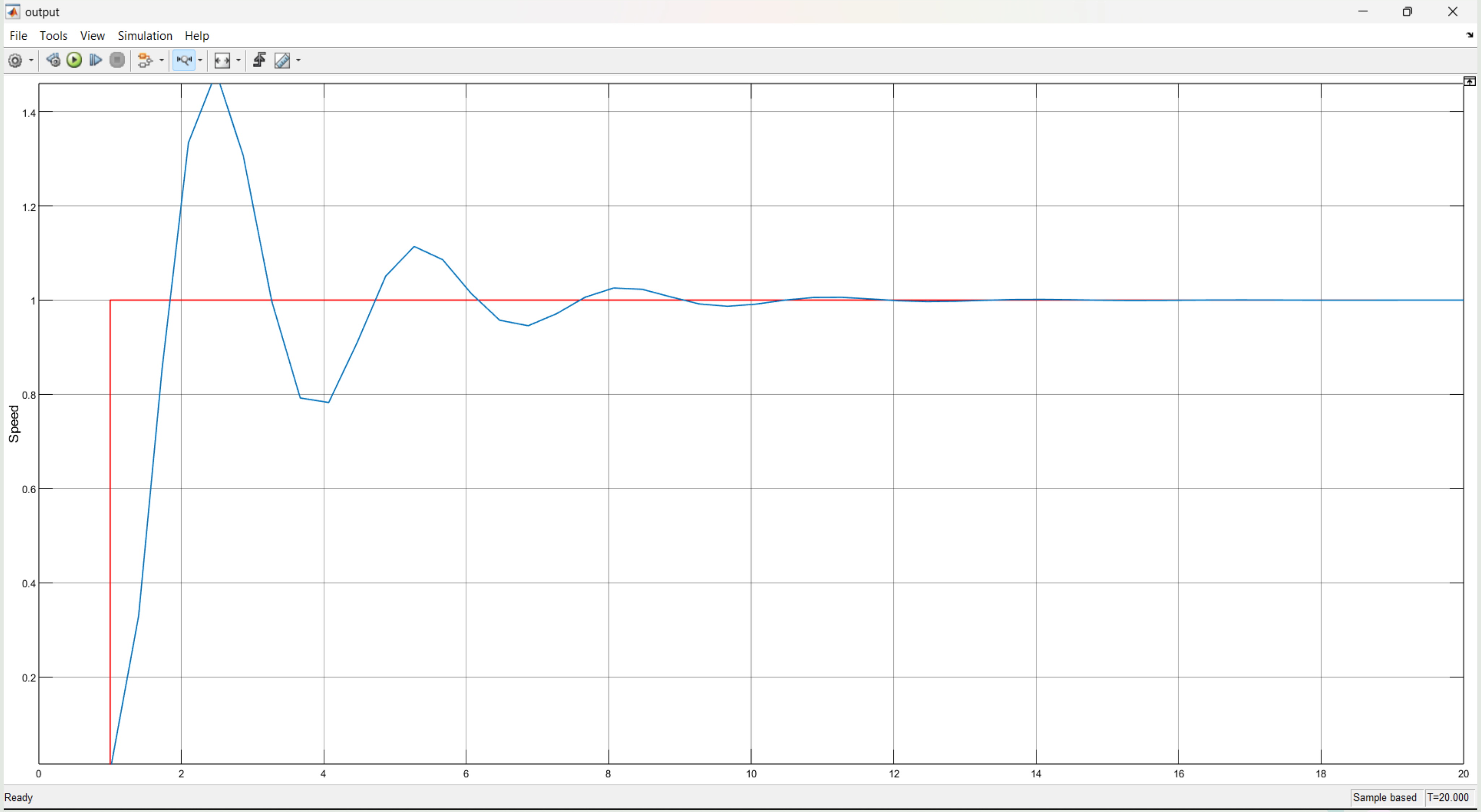
Proportional Controlled response of plant



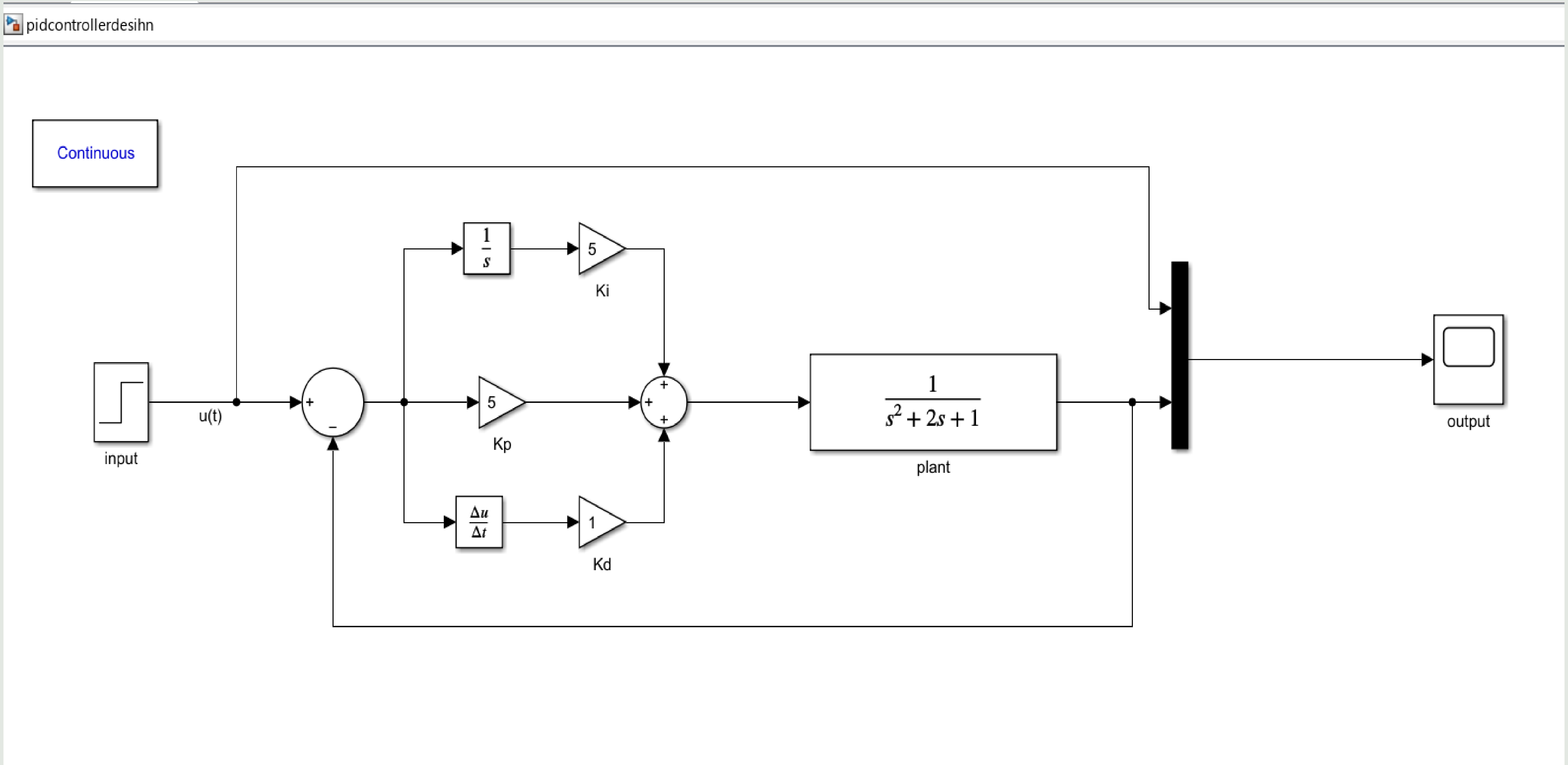


Plant with proportional and integral controller

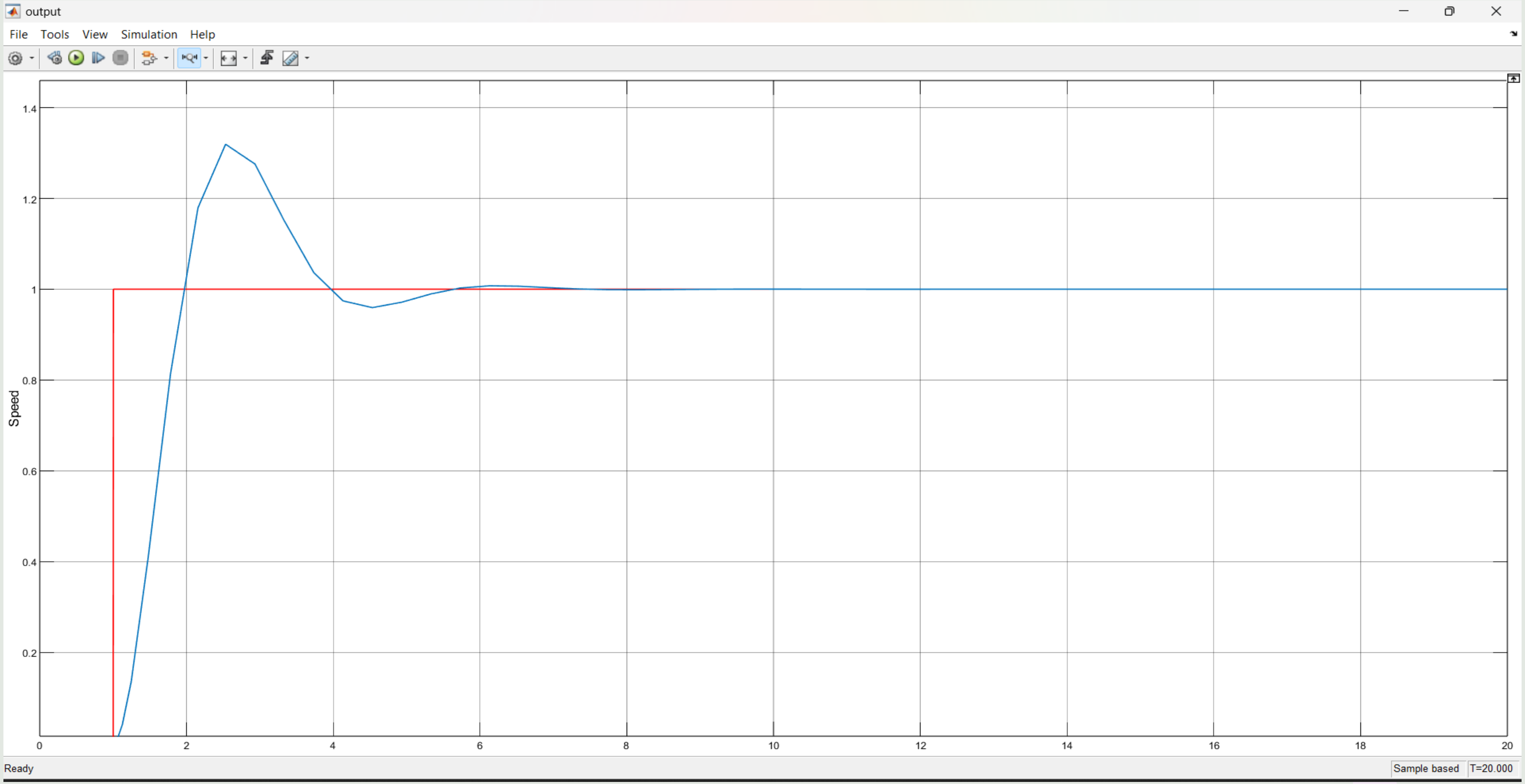
PI controlled response of plant



Plant with Proportional, Integral and Derivative controller



PID controlled response of Plant



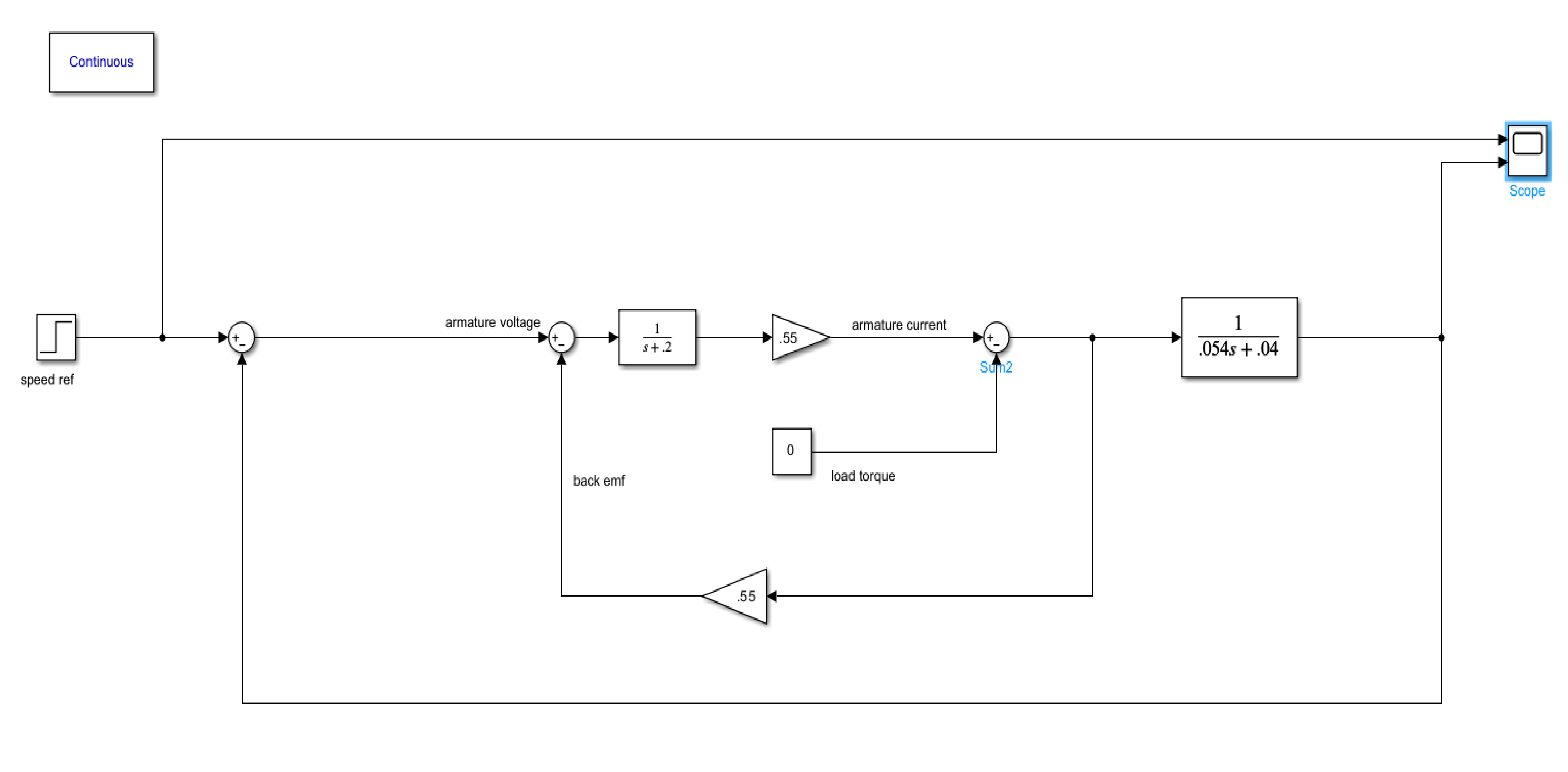
Summary of PID Controller

Effects of PID controllers parameters kp, ki and kd on a closed loop system are summarized in the table below.

Closed loop Response	Rise Time(sec)	Maximum Overshoot(%)	Settling Time(sec)	Steady State Error
As increase of K_P	Decrease	Increase	Small change	Decrease
As increase of K_I	Decrease	Increase	Increase	Eliminate
As increase of K_D	Small change	Decrease	Decrease	Small change

- A proportional controller Kp will have the effect of reducing the rise time and reduce but never eliminate the steady state error.
- An integral controller Ki will have the effect of eliminate the steady state error but it may make the transient response worse by increasing overshoot ,which further increases settling time.
- A derivative controller Kd will have the effect of increasing the stability of the system and reducing the overshoot and improve the transient response.

DC MOTOR SPEED CONTROL BY PID CONTROLLER

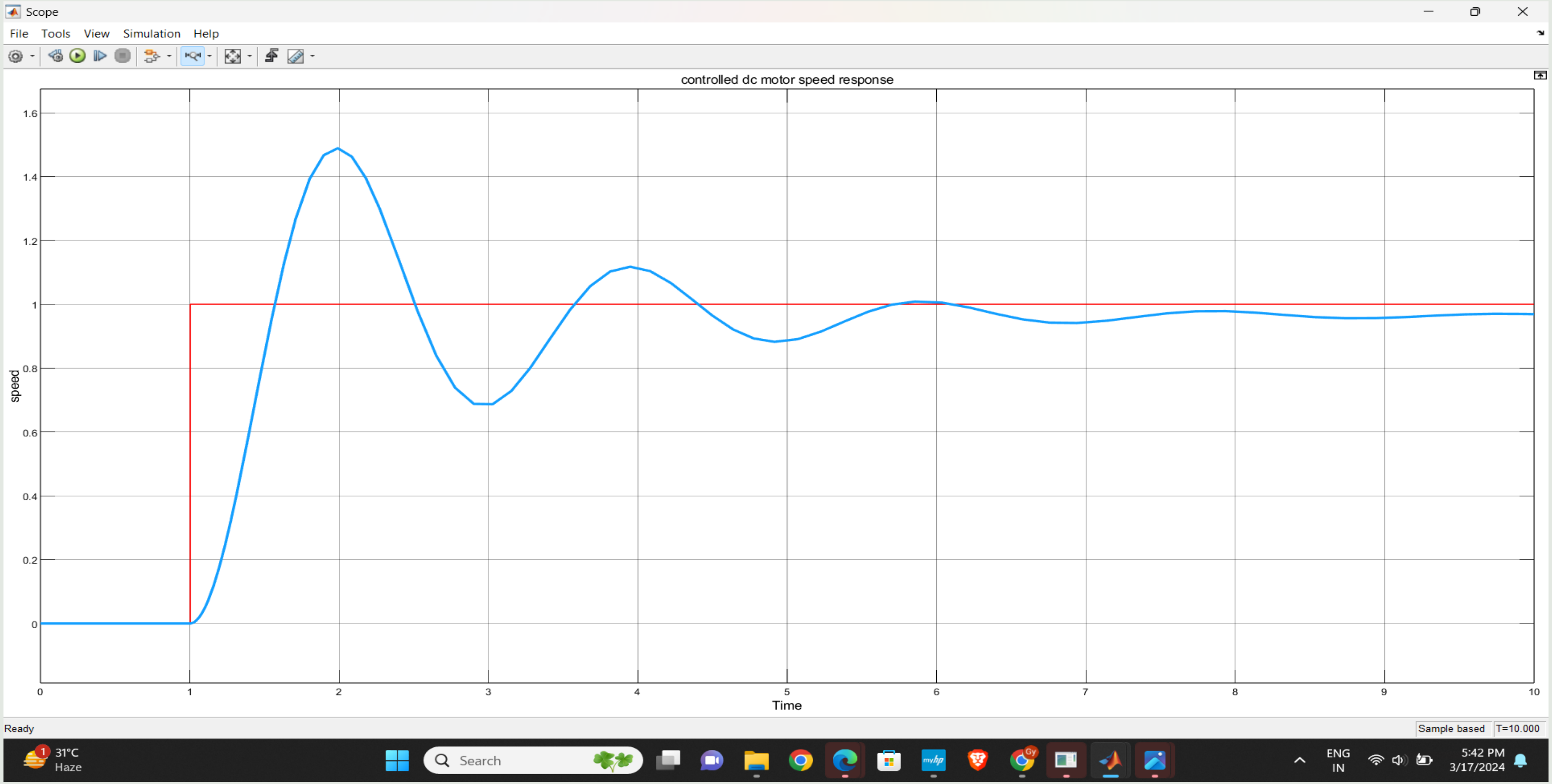


Simulink model of armature control dc motor

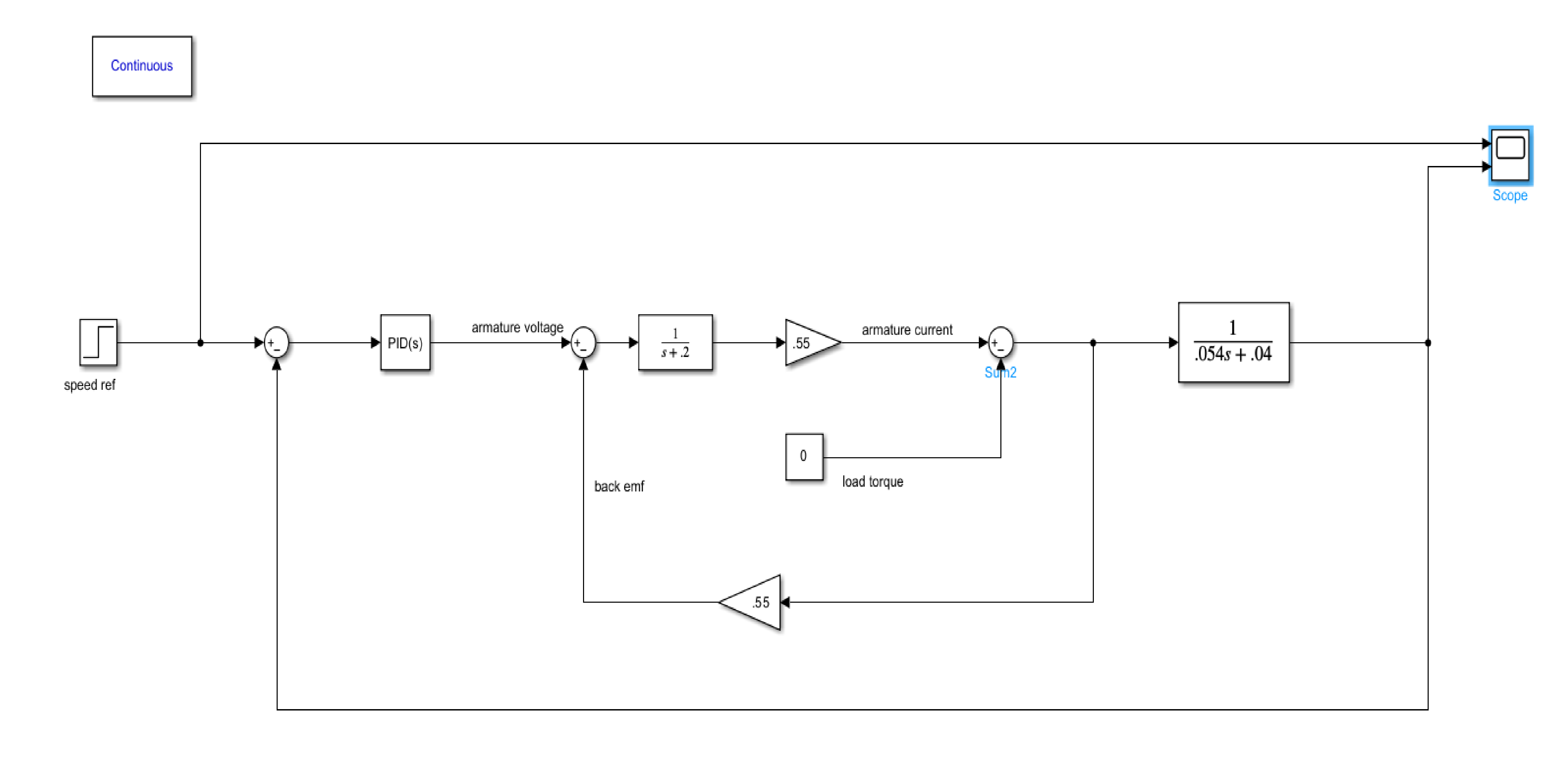
Uncontrolled DC motor speed response

______________ : Reference speed

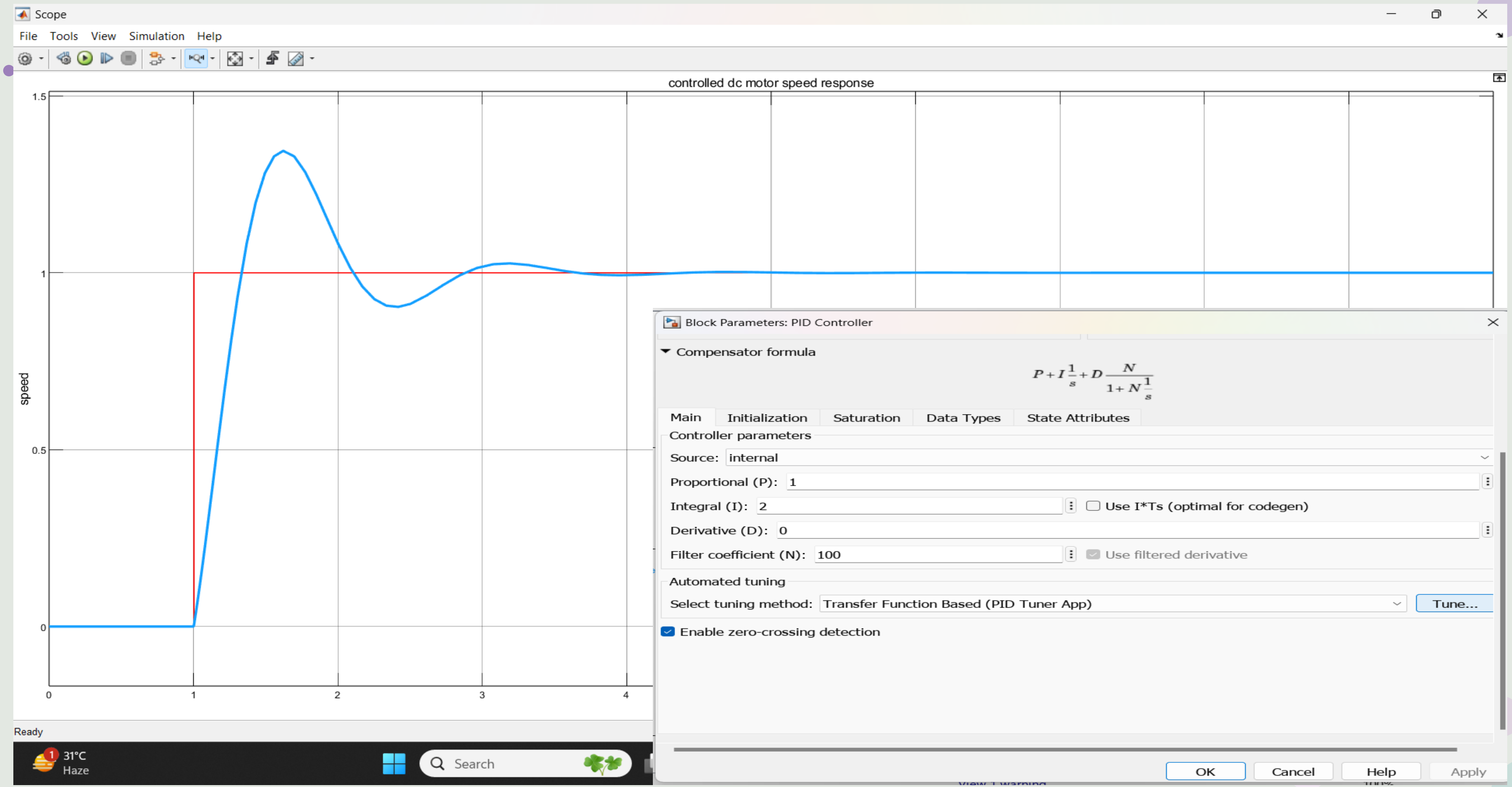
______________ : Actual speed



Block diagram of armature controlled DC motor with PID controller



Controlled DC motor speed control.



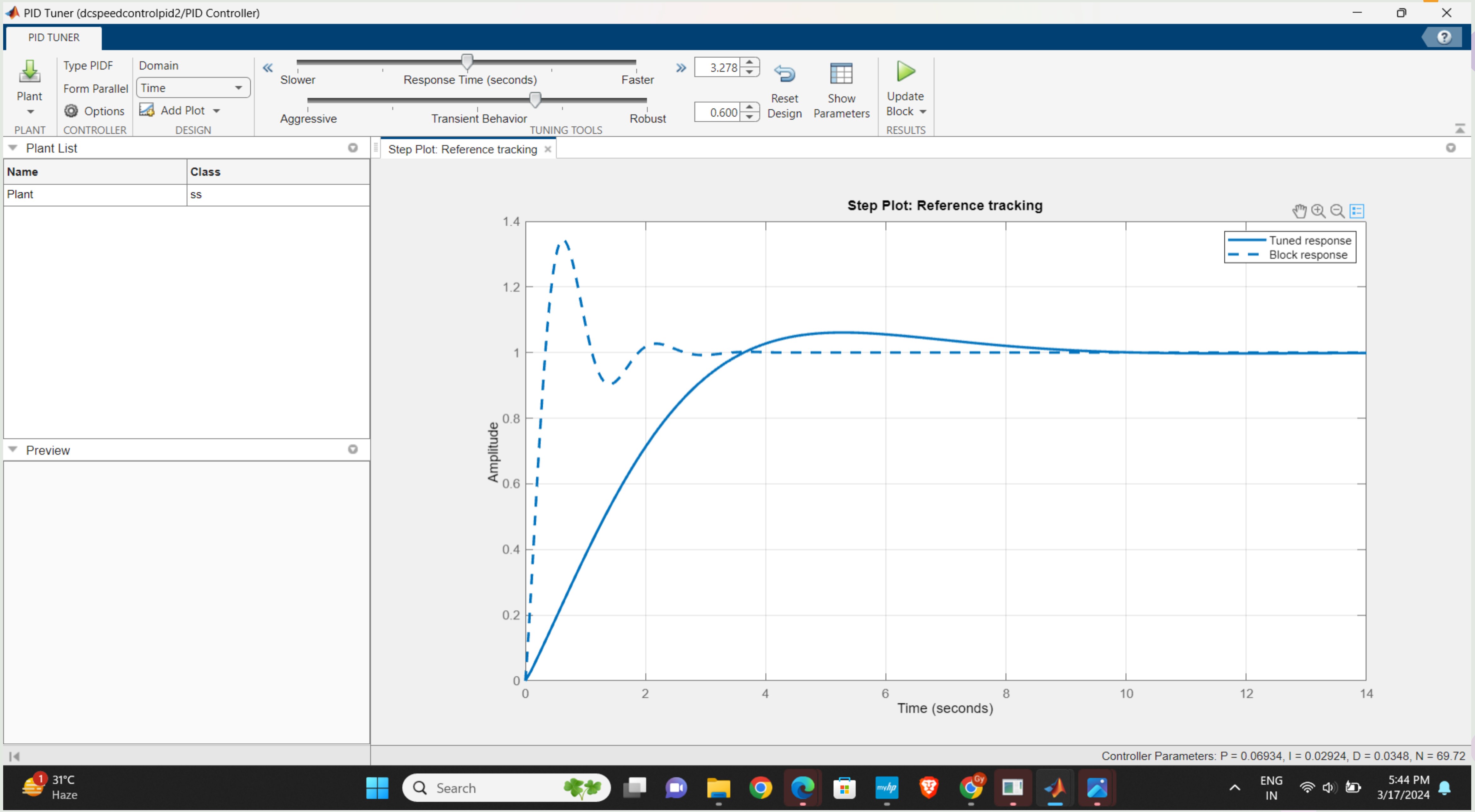
PID TUNING

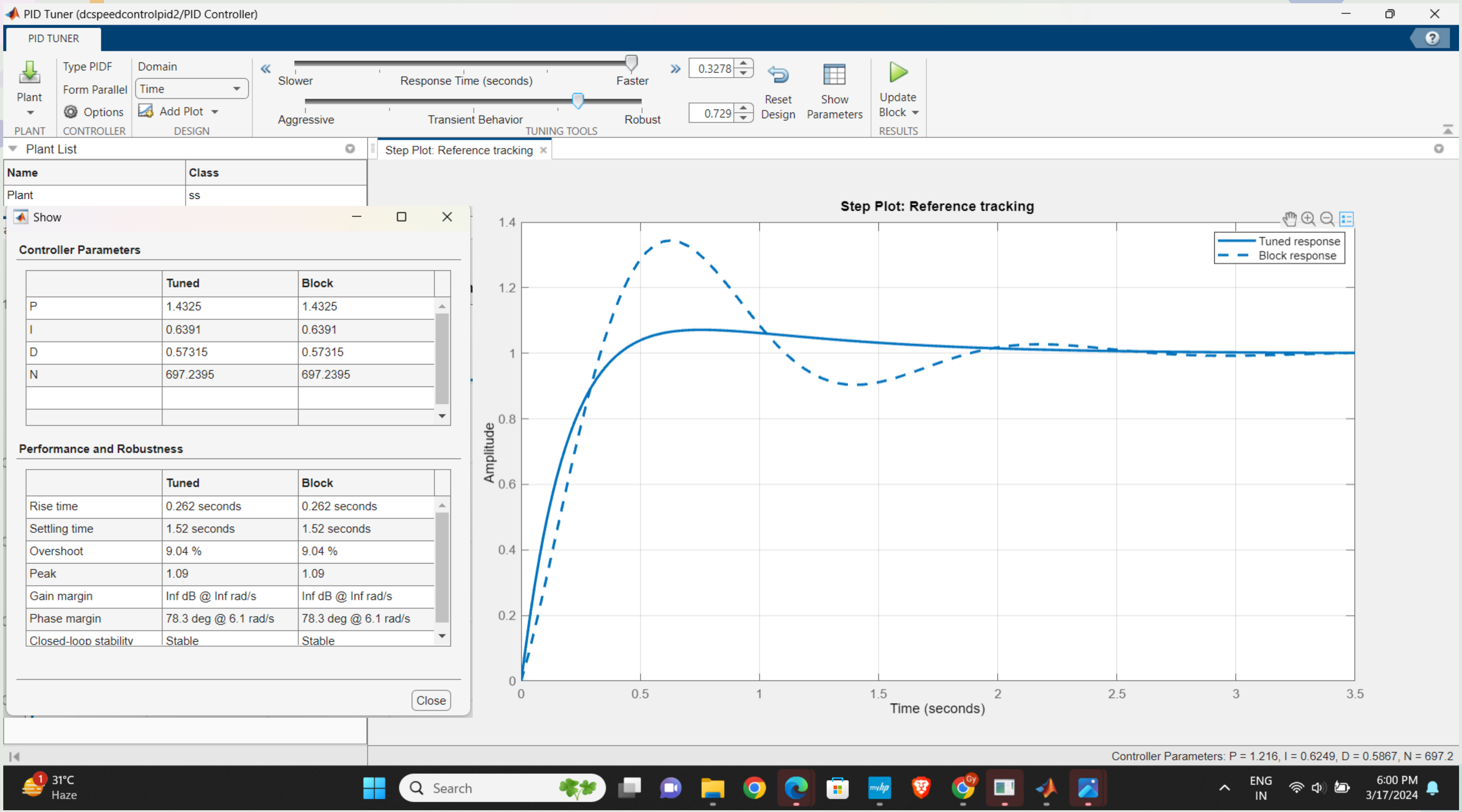
The task of tuning is find the value of Ki, kp, and kd . If they are not properly tuned, then the system can become unstable.

In power system, we commonly use the PID controller to bring the frequency, voltage , and the other pararmeters to their original value.

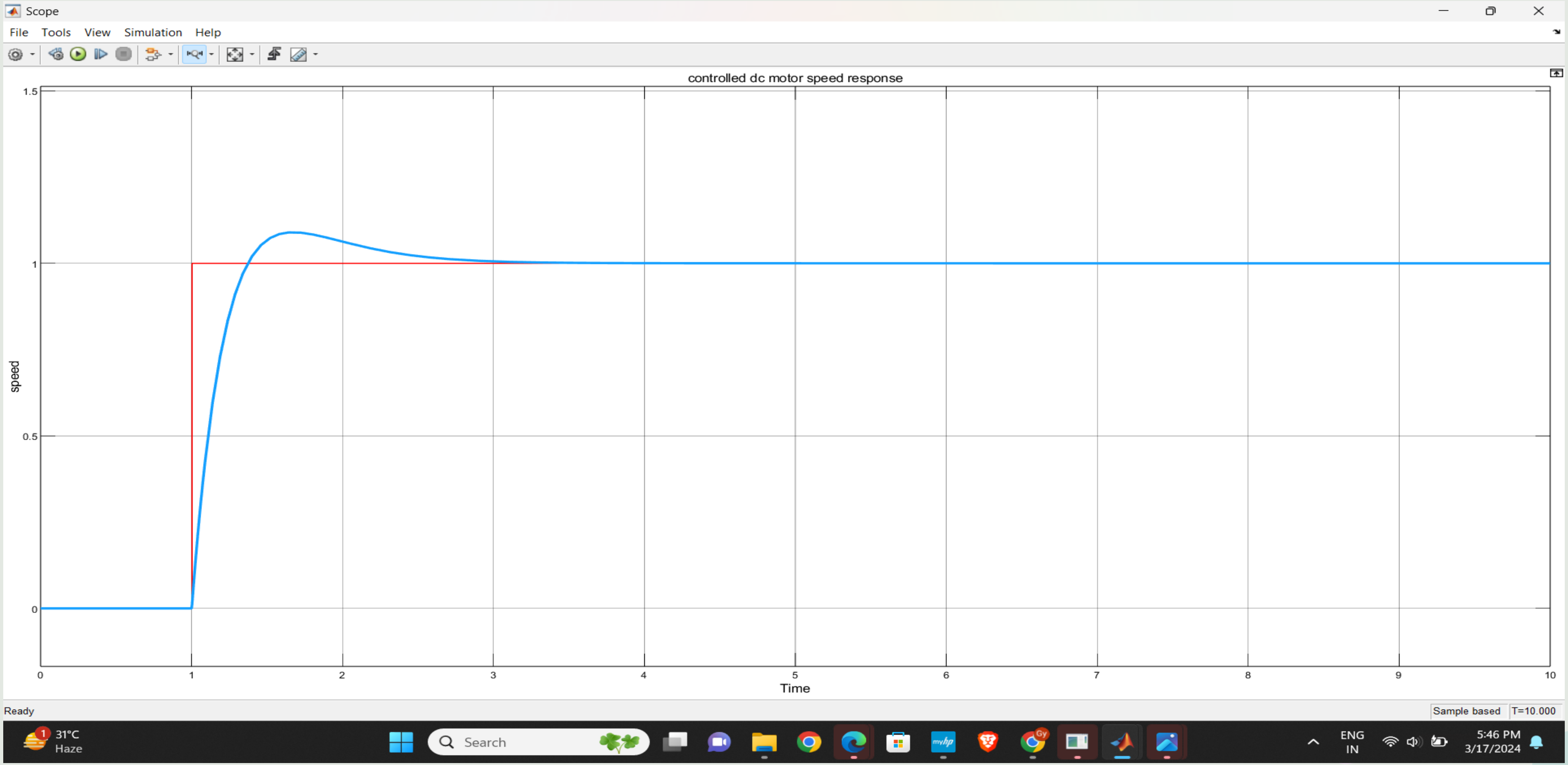
However, tuning of PID controller is very difficult most of the times, hit and trial method is used which is extremely time consuming.

MATLAB software in it's latest versions has provided the PID tuner . In this PID tuner, you just have to put the response of any model from simulink and it will automatically provide the tuned response within fraction of seconds.


PID Tuner (dcspeedcontrolpid2/PID Controller)
PID TUNER
Plant
Type PIDF
Form Parallel
Options
Domain
Time
Add Plot
PLANT
CONTROLLER
DESIGN
Slower
Response Time (seconds)
Faster
3.278
Aggressive
Transient Behavior
Robust
0.600
TUNING TOOLS
Reset Design
Show Parameters
Update Block
RESULTS
Plant List
Name
Class
Plant
ss
Preview
Step Plot: Reference tracking
Step Plot: Reference tracking
Tuned response
Block response
Amplitude
Time (seconds)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
2
4
6
8
10
12
14
Controller Parameters: P = 0.06934, I = 0.02924, D = 0.0348, N = 69.72
31°C
Haze
Search
ENG
IN
5:44 PM
3/17/2024

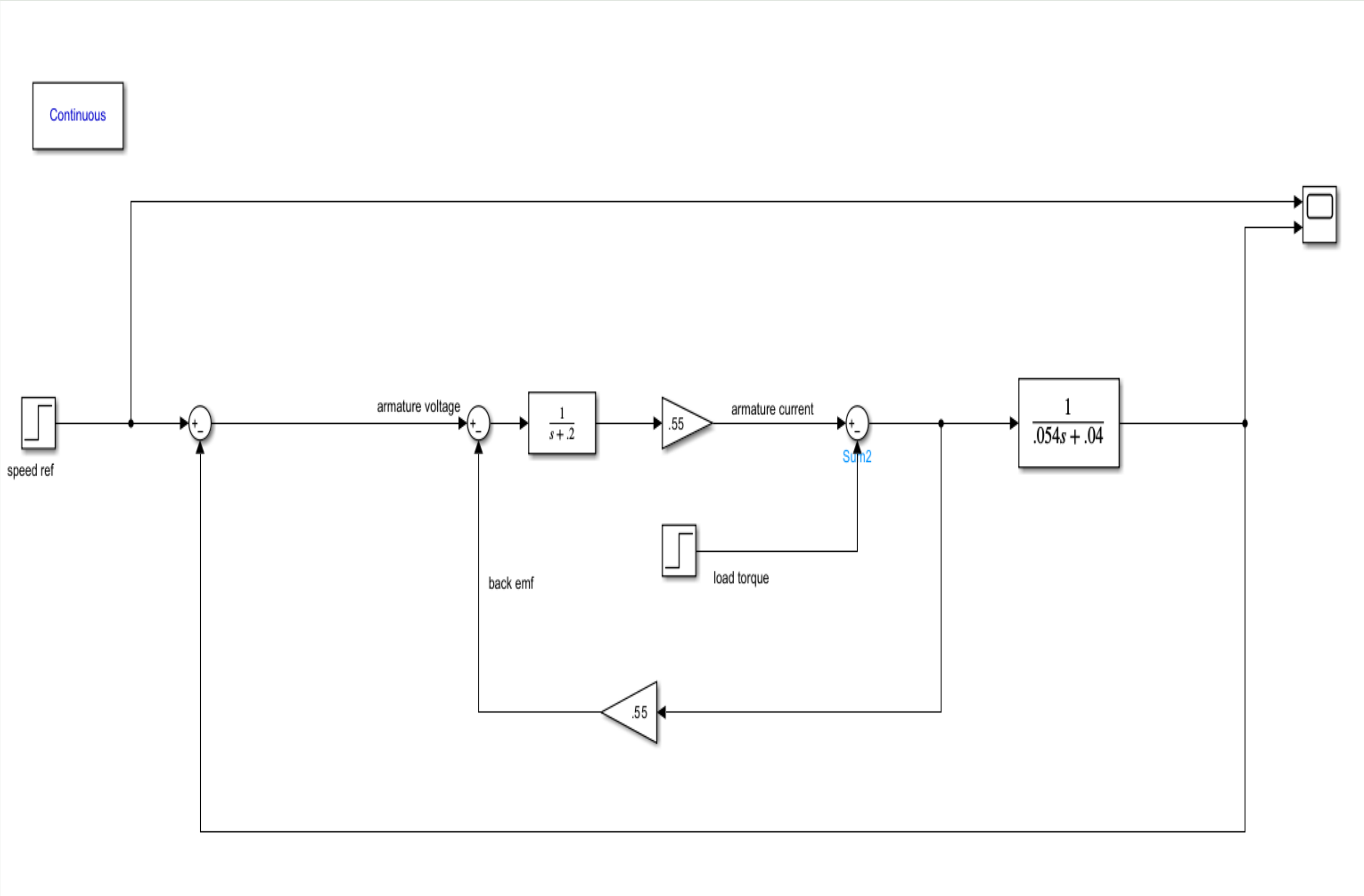

PID Tuner (dcspeedcontrolpid2/PID Controller)
PID TUNER
Plant
Type PIDF
Form Parallel
Options
Domain
Time
Add Plot
Slower
Response Time (seconds)
Faster
0.3278
Aggressive
Transient Behavior
Robust
0.729
Reset Design
Show Parameters
Update Block
PLANT
CONTROLLER
DESIGN
TUNING TOOLS
RESULTS
Plant List
Name
Class
Plant
ss
Show
Controller Parameters
Tuned
Block
P
1.4325
1.4325
I
0.6391
0.6391
D
0.57315
0.57315
N
697.2395
697.2395
Performance and Robustness
Tuned
Block
Rise time
0.262 seconds
0.262 seconds
Settling time
1.52 seconds
1.52 seconds
Overshoot
9.04 %
9.04 %
Peak
1.09
1.09
Gain margin
Inf dB @ Inf rad/s
Inf dB @ Inf rad/s
Phase margin
78.3 deg @ 6.1 rad/s
78.3 deg @ 6.1 rad/s
Closed-loop stability
Stable
Stable
Close
Step Plot: Reference tracking
Step Plot: Reference tracking
Tuned response
Block response
Amplitude
Time (seconds)
Controller Parameters: P = 1.216, I = 0.6249, D = 0.5867, N = 697.2
31°C
Haze
Search
ENG
IN
6:00 PM
3/17/2024

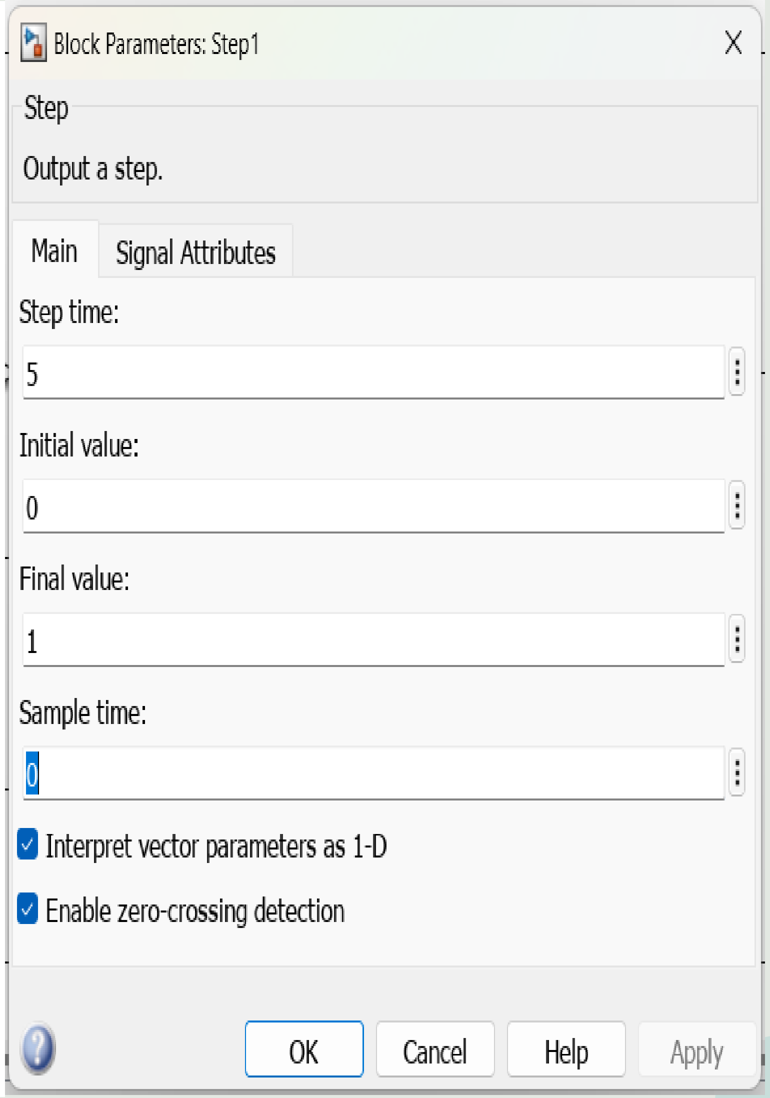
Response after PID tuning



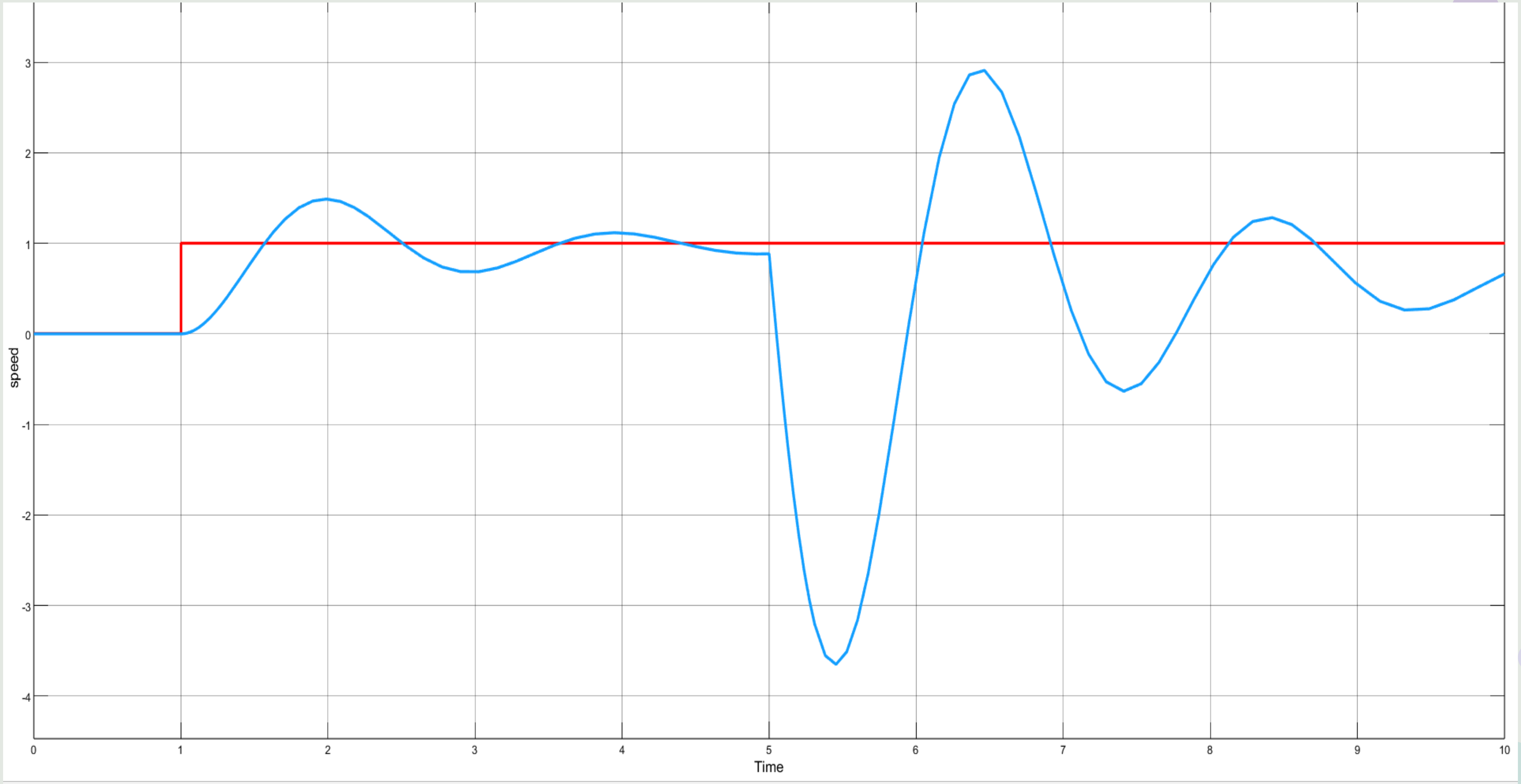
Response to Disturbances

- First, we will see the response when load disturbance is provided to an uncontrolled system.

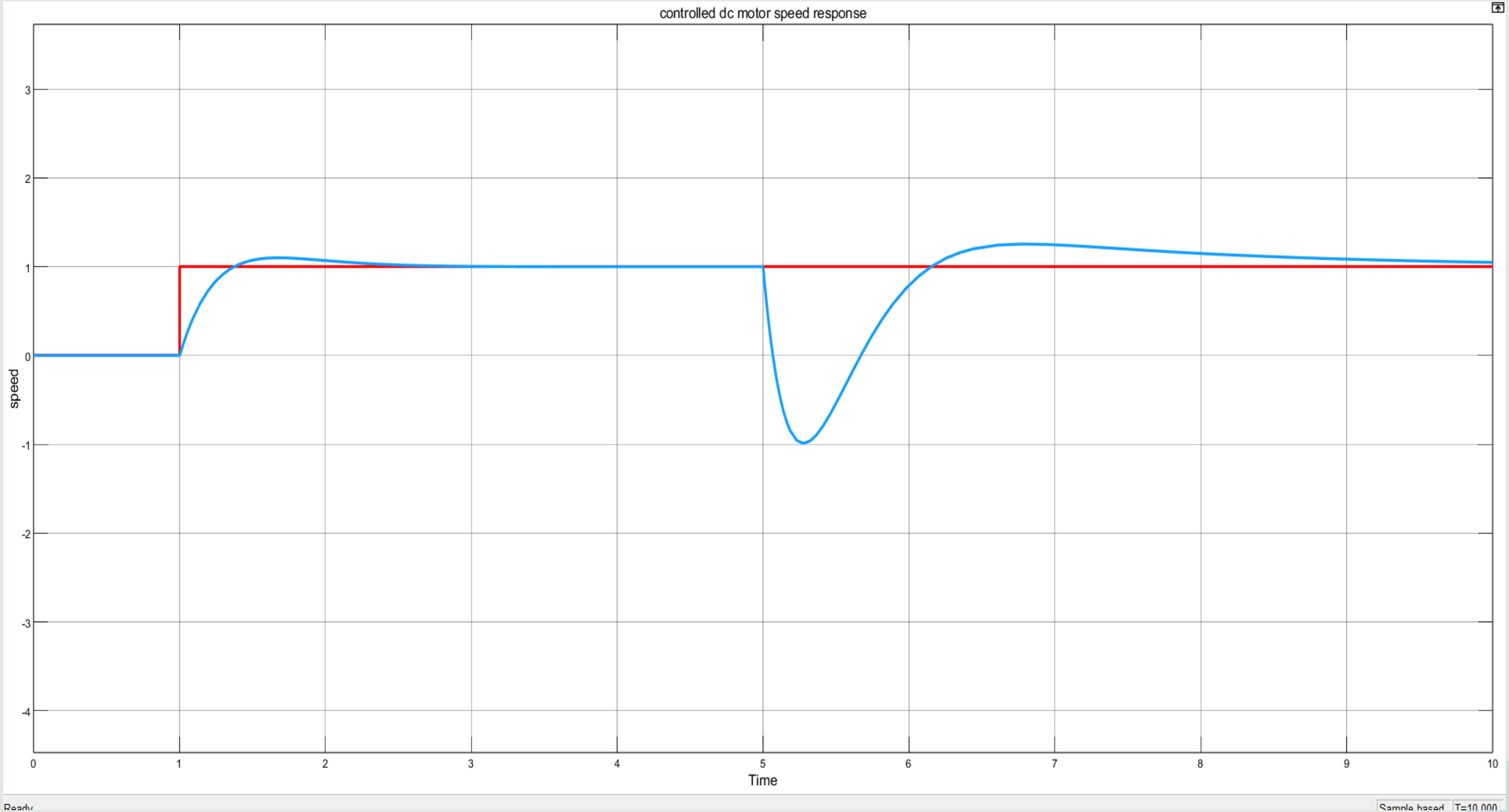




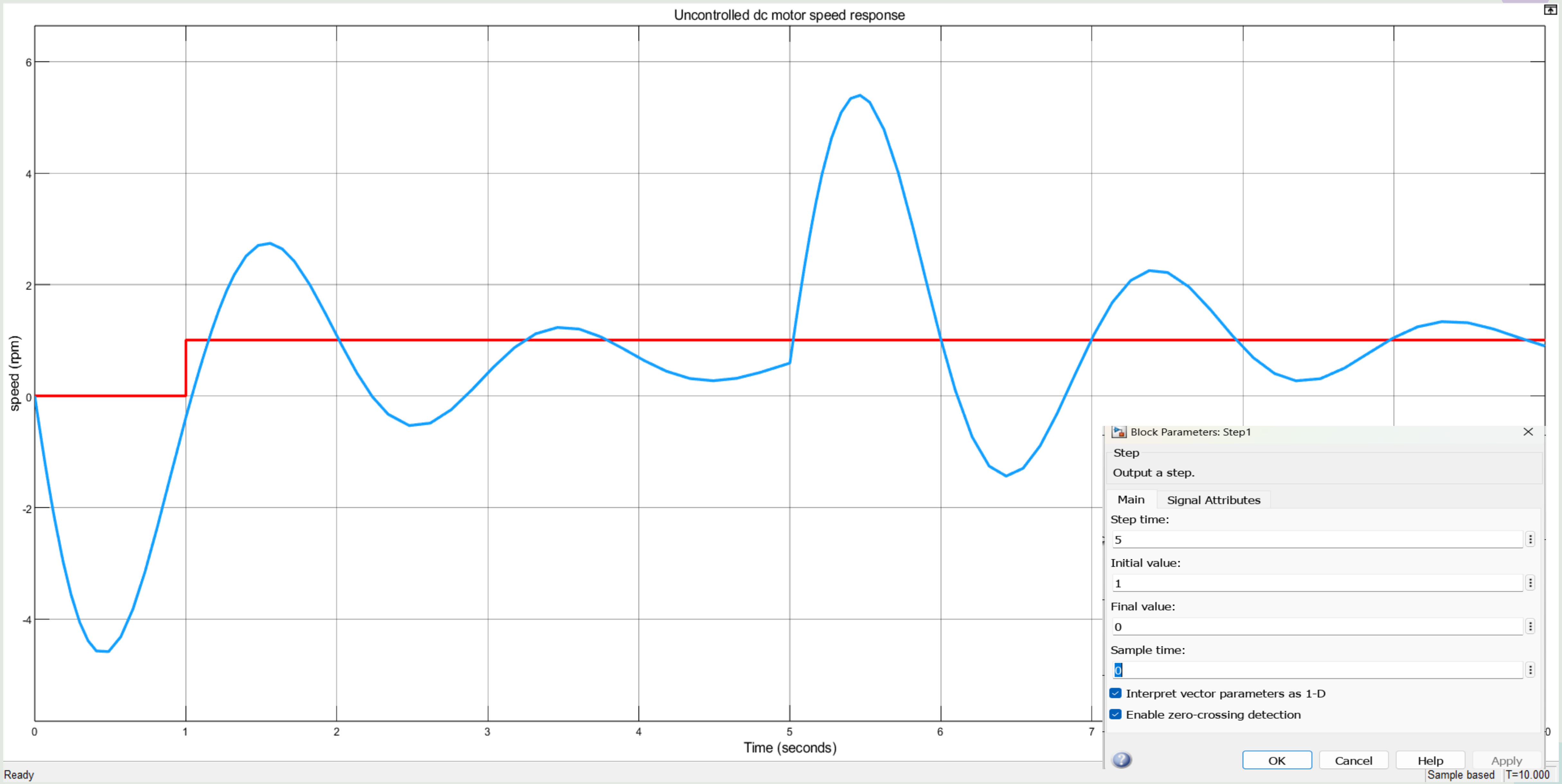
Uncontrolled speed response of DC motor under load disturbance.



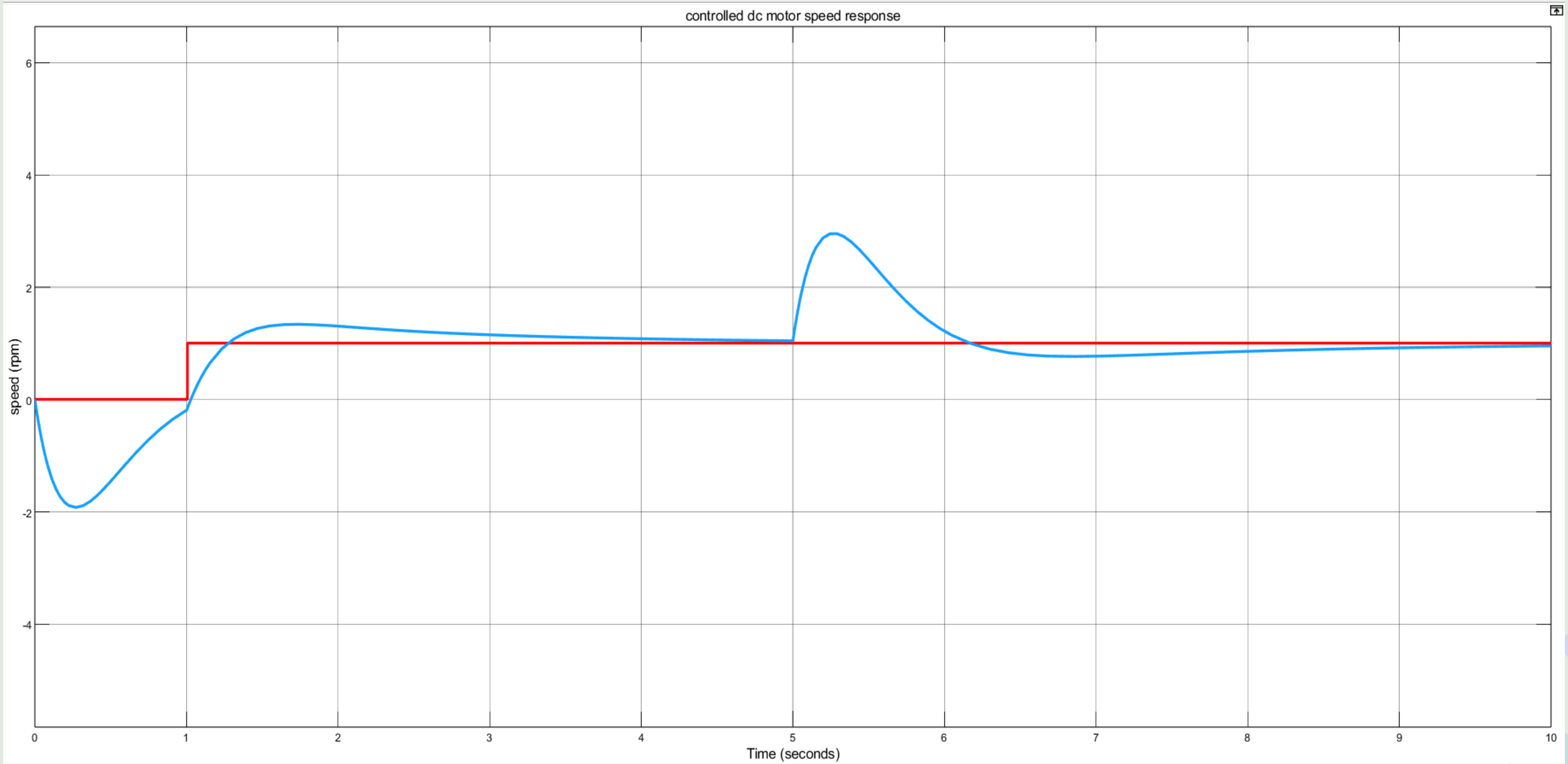
Tuned PID controlled speed response of DC motor under load disturbance



Uncontrolled DC motor speed response with Unloading condition



Tuned PID controlled DC motor speed response with Unloading condition.



Applications of PID Controller :

Temperature Control: PID controllers are widely used for temperature control in various industrial applications, such as chemical processing, food processing, and HVAC systems. The controller measures the system's temperature and adjusts the input to maintain the desired temperature.

Motion Control: PID controllers are used for motion control applications, such as robotic systems, CNC machines, and motor control. The controller measures the system's position, velocity, or acceleration and adjusts the input to maintain the desired motion profile.

Process Control: PID controllers are widely used for process control applications, such as chemical processing, power generation, and manufacturing. The controller measures the process variables, such as flow rate, pressure, or level, and adjusts the input to maintain the desired process cond

Power Control: PID controllers are used for power control applications, such as voltage regulation, power factor correction, and motor control. The controller measures the system's power output and adjusts the input to maintain the desired power level.


THANK
YOU 😊