Objectives:

- To create and implement a mathematical model for the control system of Tesla Model S P85 using Simulink.
- To design a SIMULINK model which simulates the complete dynamics of our Model S.
- To control the speed of our Tesla using a PID Speed Controller.

Mathematical Model Design:

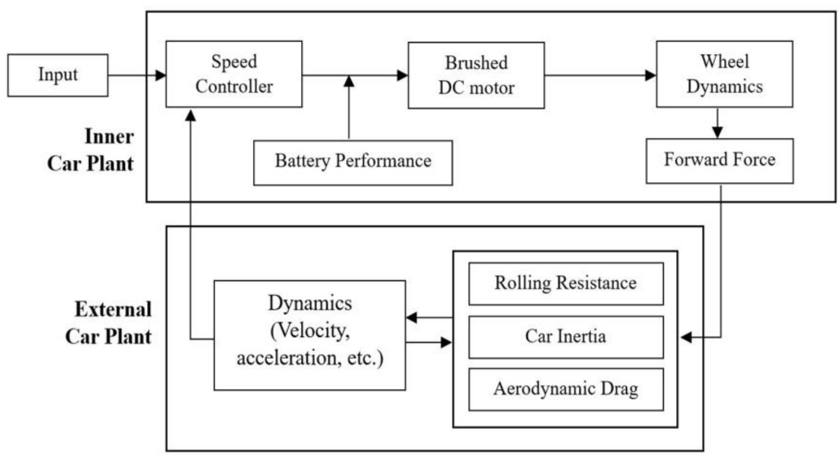
General Characteristics:

1. Weight(m): 2,108kg
2. Power(HP): 460HP/343 KW @8600 rpm
3. Drag Co -efficient(μ): 0.24
4. Torque(τ) : 600 Nm @ 0 rpm
5. Fontal Area: 2.34m²
6. Rolling Resistance Co-efficient on Asphalt : 0.02

Components:

1. Input(0 to 100%)
2. Wheels
3. 85KWh Battery
4. Brushed DC Motor

Mathematical Model Diagram:



Designing Process:

1. Derive the mathematical expressions for each part of our model.
2. Translate these expressions to a MATLAB/SIMULINK model.
3. Use this model to program our speed controller.
4. Enjoy the results and compare to real world examples

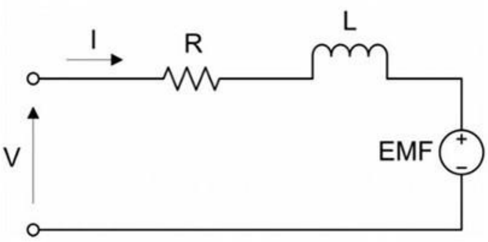
The Battery and Actuator (Input):

The Model S Battery is assembled with 7,104 18650 Lithium ion cells arranged 16 Modules wired in Series each containing 6 groups of 74 cells wired in parallel , total capacity is 85,000Wh and Weights 540 kg . Each cell has an average capacity of 3300mah, a nominal voltage of 3.6V so about 11.9Wh , with a max voltage of 4.2V and a discharge limit of 2.5V.

So, we can calculated max operating voltage , V = 3.6*16*6 = 346V & max current will be set through torque cap.

The Electro-Motor:

The Tesla model S uses a three phase AC four pole induction motor , here a DC brush motor will be used for model.



Using KVL operation ,

V =$I(t) * R + L\frac{dI(t)}{dt} + E(t)$

Putting E(t) = $K_E * \omega(t)$ and transforming laplace equation

$V(s) = RI(s) + sLI(s) + K_E\omega(s)$

So,

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

The Torque in an electrical DC motor, $T(t) = K_T * I(t)$ and in Laplace domain

$T(s) = K_T * I(s)$

$$T(s) = K_T * \frac{V(s) - K_T\omega(s)}{sL + R}$$

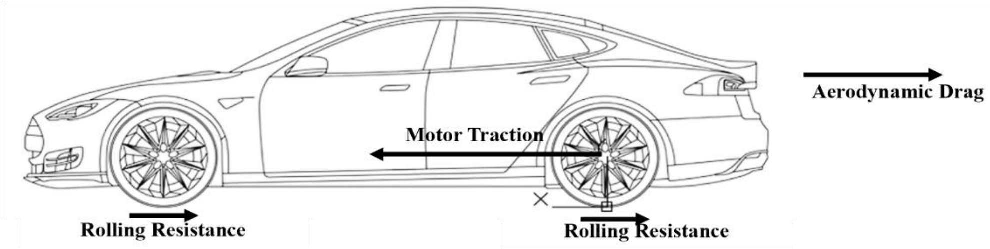
So, equation for motor will show ,

$$T(s) = 0.25 * \frac{V(s) - 0.12 * \omega(s)}{493 * 10\text{^-}9s + 5.3 * 10\text{^-}3}$$

Here,

R = 5.3 $*$ 10^-3 Ohm , L = 493 $*$ 10^-9 $Henrys$, KE = 0.12 Vs/rad , KT = 0.25 Nm/Amp

Forces at play :



Motor traction force, $F_f = \frac{T}{L} * G_r$ where gear ratio, G_r = 9.73 and distance from center of rotation, L = 24 cm.
So, $F_f = 40.5T$

Aerodynamic drag, $D = \frac{1}{2}\rho V^2 S C_D$ where, air density ρ = 1.225 kgm^{-3} the frontal area, S = 2.3 m^2 and coefficient of Drag is C_D = 0.24.

So D = $0.3381V^2$

Rolling resistance, $F_r = C_r * m_r * g$, where, for car tires on a dry/asphalt road rolling resistance coefficient, C_r = 0.02, total mass of Model S, m_r = 2108 kg and the gravitational constant is 9.81 m/s^2.

So the Rolling resistance of the car, Fr = 413 N

Model's Plant Dynamics :

According to Newton 2nd law ,

$$\sum F = ma$$

Or in our case:

$$0.7 * 40.5T - 413 - 0.3381v^2 = ma = 2108 * a$$

Here,
Motor Traction: F_f= 40.5T
Overall efficiency = 70%
Rolling Resistance: F_r = 413 N
Aerodynamic Drag: D = 0.3381v^2
Total mass of Model S: m = 2108 kg

Which is equivalent to:

$$\frac{0.7 * 40.5T - 413 - 0.3381v^2}{2108} = \frac{dv}{dt}$$

Mathematical Model Implementation :

Using MATLAB Simulink the following inner car plant was created which is an open loop system

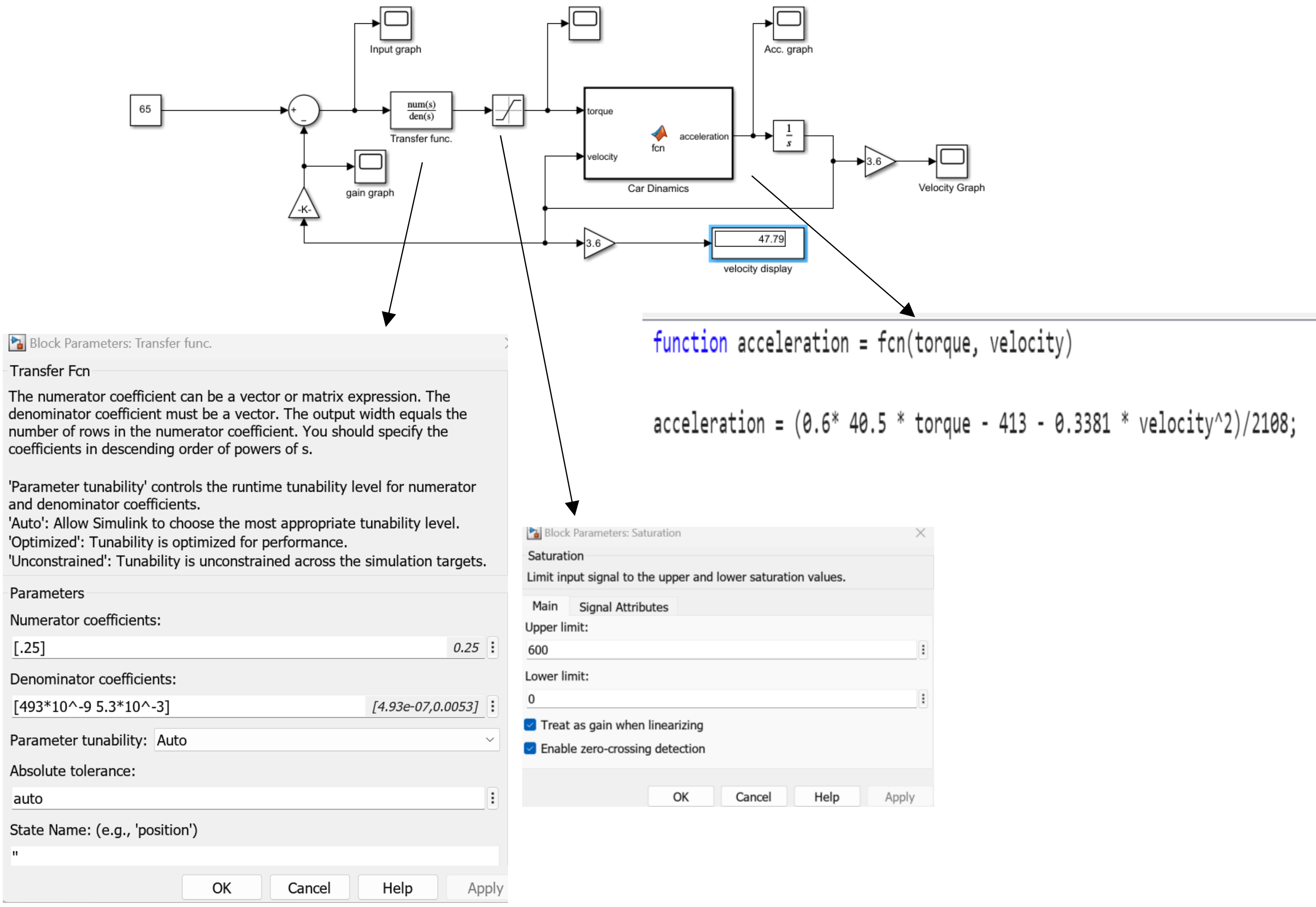
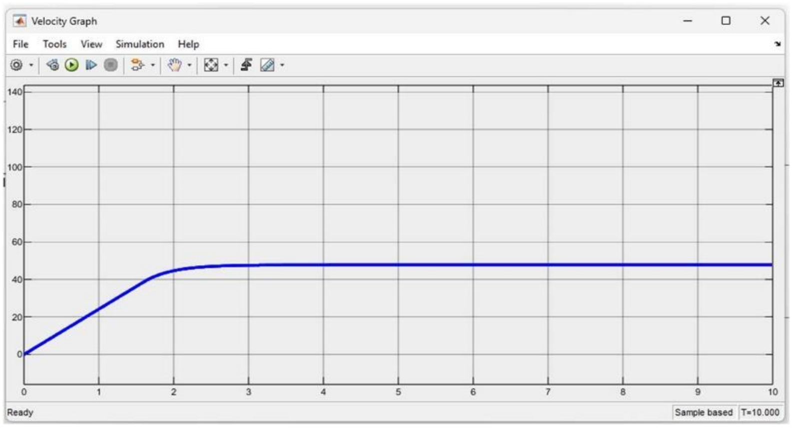


Figure : Inner car plant without controller and feedback plant

Output velocity graph:



Lets add a PID controller and take velocity gain as feedback of the controller

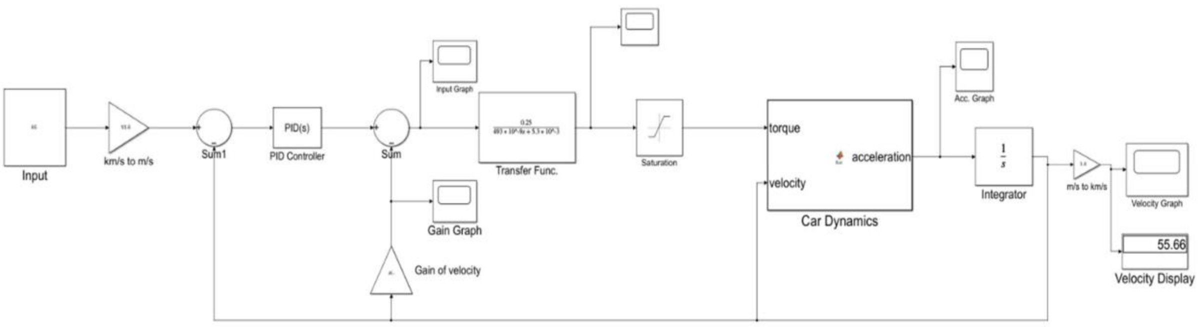
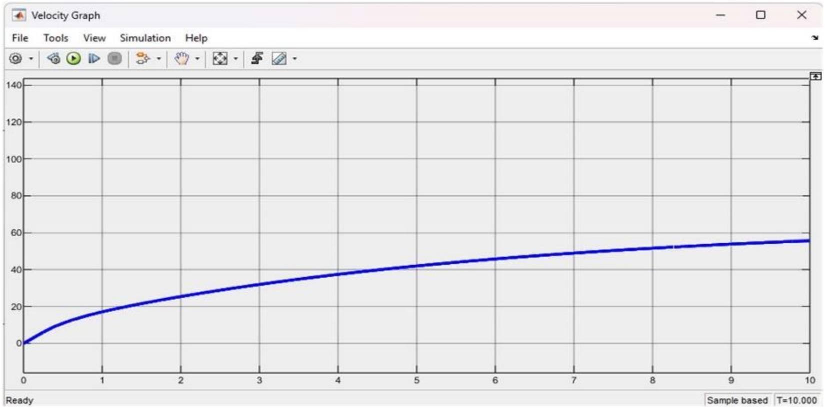


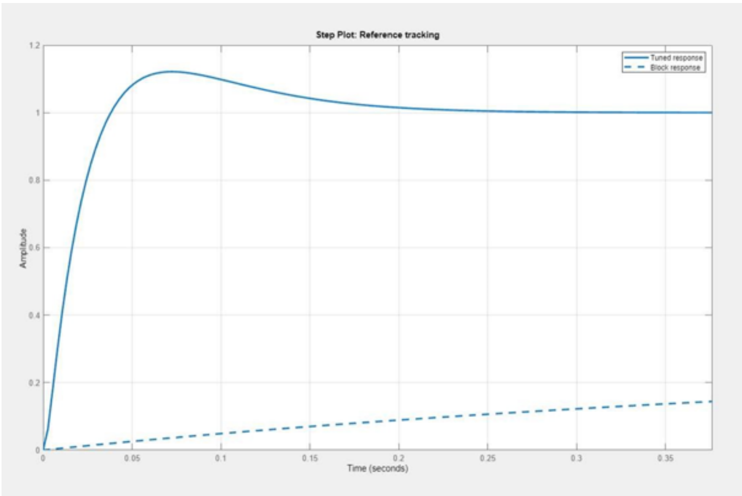
Figure : Inner car plant without external car plan- controller and feedback plant

Output velocity graph :

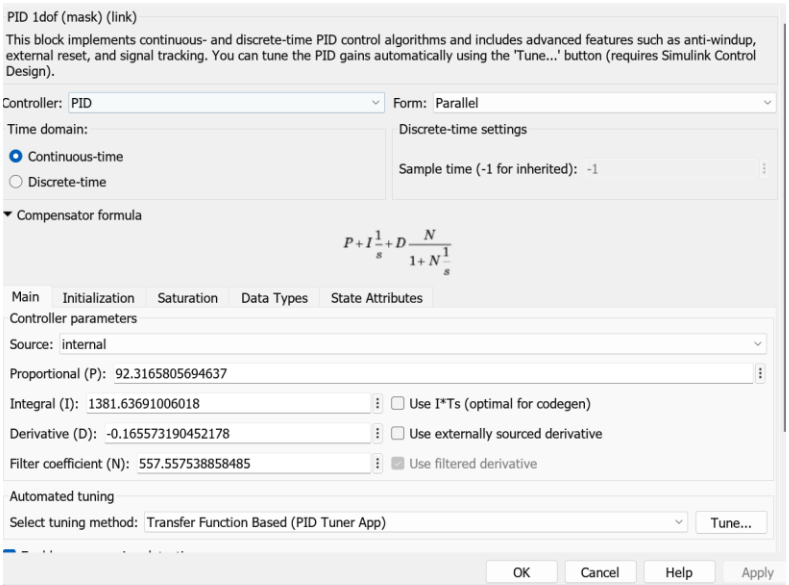


It tooks 10 sec to reach 56km/h

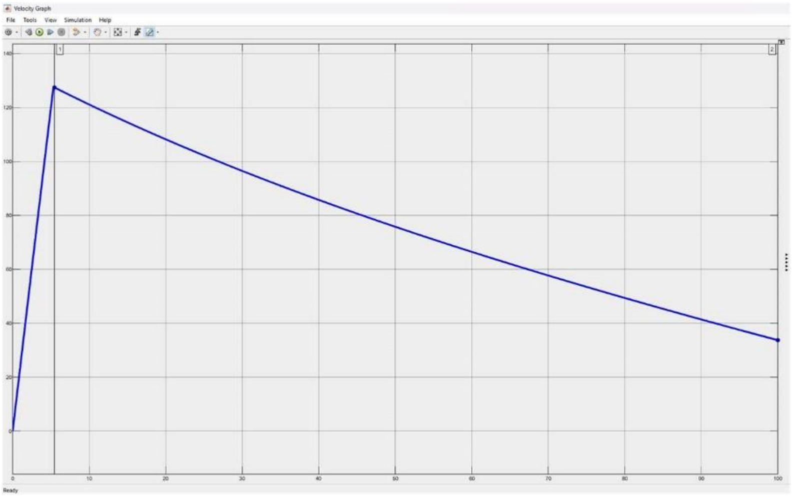
Here , auto tune PID controller PID tune app



Response time is faster and Transient behaviour to aggressive , following values Kp , Kd , Ki is found

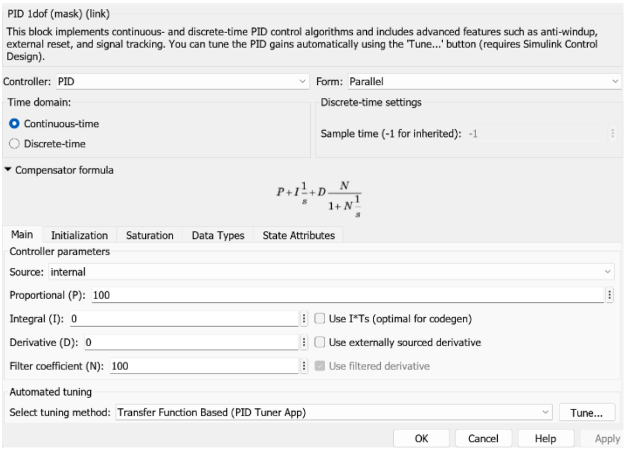


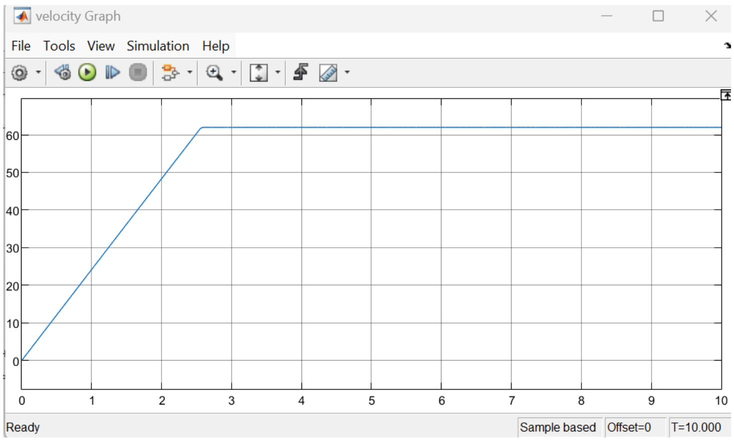
Output velocity graph :



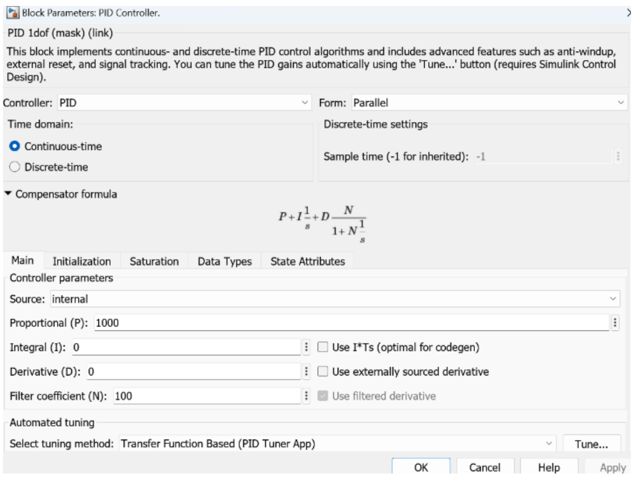
Lets set PiD manually:

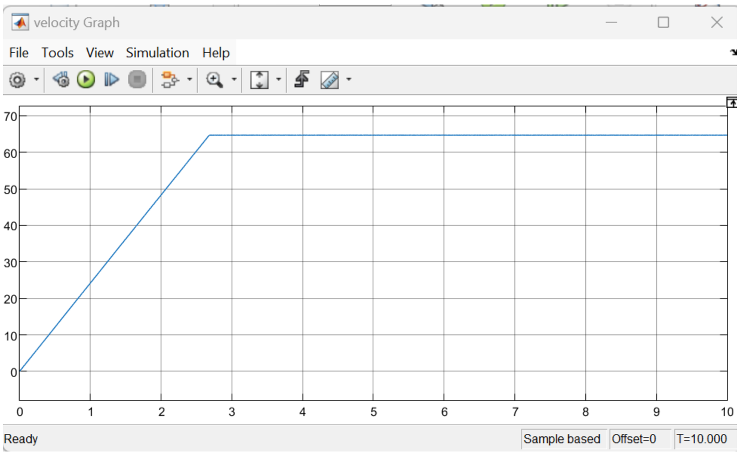
After setting (kp, ki , kd) = (100,0,0) the following results are found , which outputs 62 km/s.



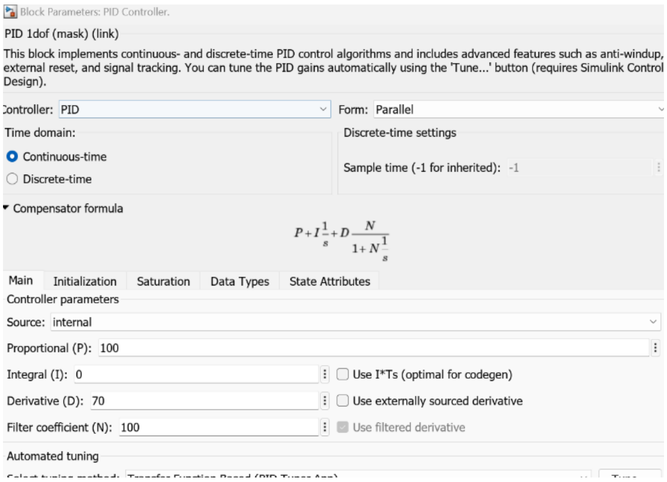


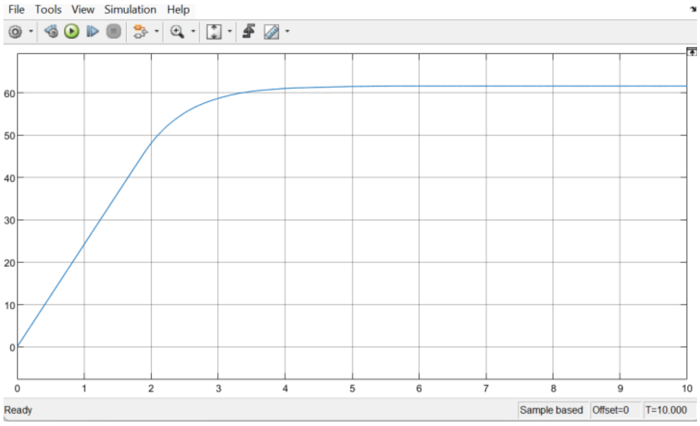
Now setting (kp, ki , kd) = (1000,0,0) the following results are found , which outputs 64.3 km/s



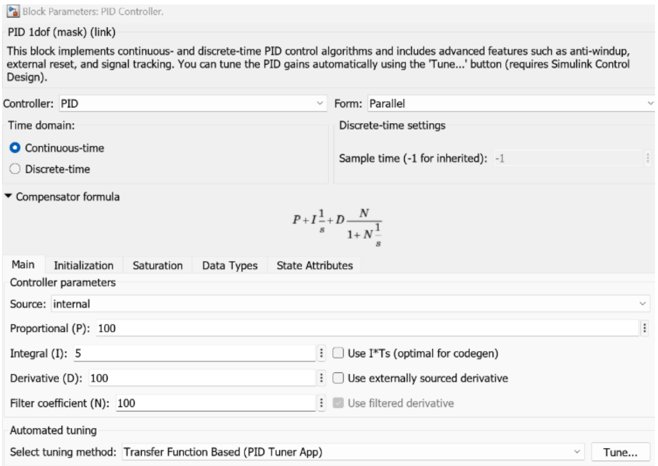


Now setting (kp, ki , kd) = (100,0,70) the following results are found , which outputs 61.3 km/s

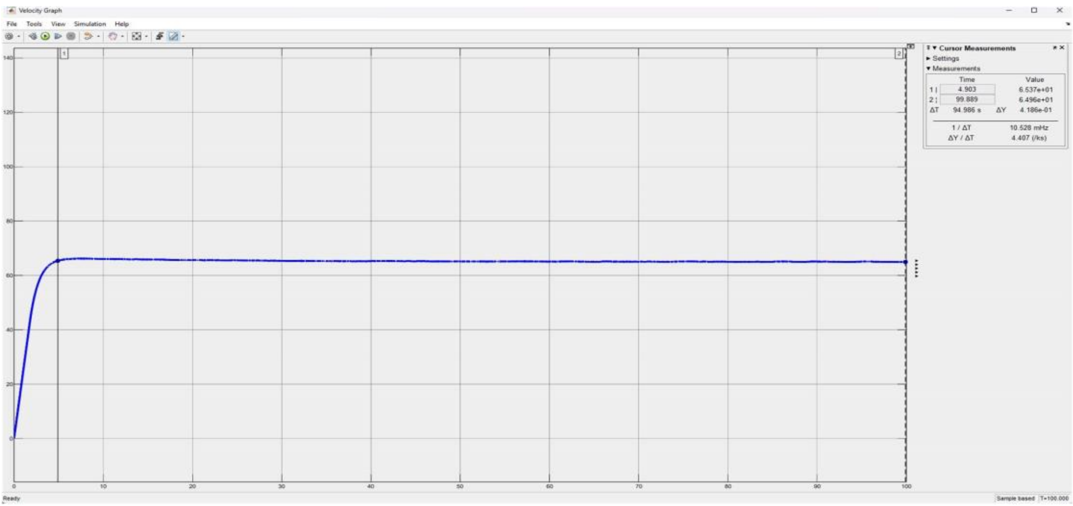




Now setting (kp, ki , kd) = (100,5,100) the following results are found , which outputs 65.5 km/s



This is final PID Controller of the system



Discussion :

1. 1. The Tesla Model S P85 was modeled in Simulink using a basic version, where a brushed DC motor was implemented to simulate vehicle dynamics.
2. 2. A PID controller was set up, which highlighted how small adjustments could significantly impact the vehicle's speed control. Observing these changes provided valuable insights into controller responsiveness.
3. 3. Each model parameter's effect on performance was examined, and the variations in behavior were analyzed, deepening the understanding of how parameter tuning influences system output.
4. 4. Although the model functioned effectively, it was noted that future iterations could benefit from implementing a more complex motor model and conducting finer tuning of the controller for improved accuracy. This modeling experience has strengthened the understanding of vehicle dynamics and control design.