Automotive Control Systems (MEEM/EE5812)

Drive Cycle Analysis and Vehicle Mode Control

Instructor

Dr. Bo Chen

Submitted By

Rahul Srikanth Kandi

Drive Cycle Analysis :

Process of Calculating Longitudinal Forces Acting on the Vehicle :-

Given Parameters :-

$m = 1449$ kg
$\rho = 1.22$ kg/m^3
$A = 2.22$ m^2
$g = 9.8$ m/s^2
$C_w = 0.3$.
$f_r = 0.01$.
$r = 0.283$ m
$V_w = 0$ m/s^2

From standard road load force equations :-

1. Aerodynamic Drag force :-

$$F_{aero} = \frac{1}{2} \times \rho \times C_w \times A \times V^2$$

$$= \frac{1}{2} \times 1.22 \times 2.22 \times 0.3 \times V^2$$

$$= 0.40626 \times V^2$$

2. Rolling Resistance force :-

$$F_{roll} = m \times g \times f_r$$

$$= 1449 \times 9.8 \times 0.01.$$

$$= 142.002 \text{ N}.$$

3. Grade Resistance force :-

$$F_{grade} = m \times g \times \sin\theta.$$

Since a flat road is given, we neglect this term.

4. Inertial force :-

$$F_{inertia} = m \times a. \qquad \left[\because a = \frac{\partial v}{\partial t}\right]$$

$\rightarrow$ v is derived from simulation.

We are given a gain of $8/1500$ to be multiplied with a.

$$\therefore \quad F_{inertia} = 1449 \times \left[\frac{8}{1500} \times \frac{\partial v}{\partial t}\right]$$

5. Road Load forces :-

$$F_{total} = F_{aero} + F_{roll} + F_{grade} + F_{inertia}.$$

$$= (0.40626 \times V^2) + 142.002 + (0) + \left(1449 \times \frac{8}{1500} \times \frac{\partial v}{\partial t}\right)$$

6. Traction Power :-

$$P_{traction} = F_{total} \times v$$

When the total force is positive we have traction power.

$$P_{braking} = | F_{total} \times V |$$

when the total force is negative we get braking power.

When in the mode of braking power, usually this is used to store as regenerative braking.

7. Torque :-

$$T = F_{total} \times r_w .$$

where, r_w = wheel radius.

Tractive Torque $= F_{total} \times r_w$ (when total force is positive)

Braking Torque $= | F_{total} \times r_w |$ (when total force is negative)

In our model after multiplying the total force with V, we directly respective torques. Therefore we can get force by dividing the power term with V.

8. Total Power :-

$$P_{total} = F_{total} \times U .$$

We get this term directly, so we solve for Force.

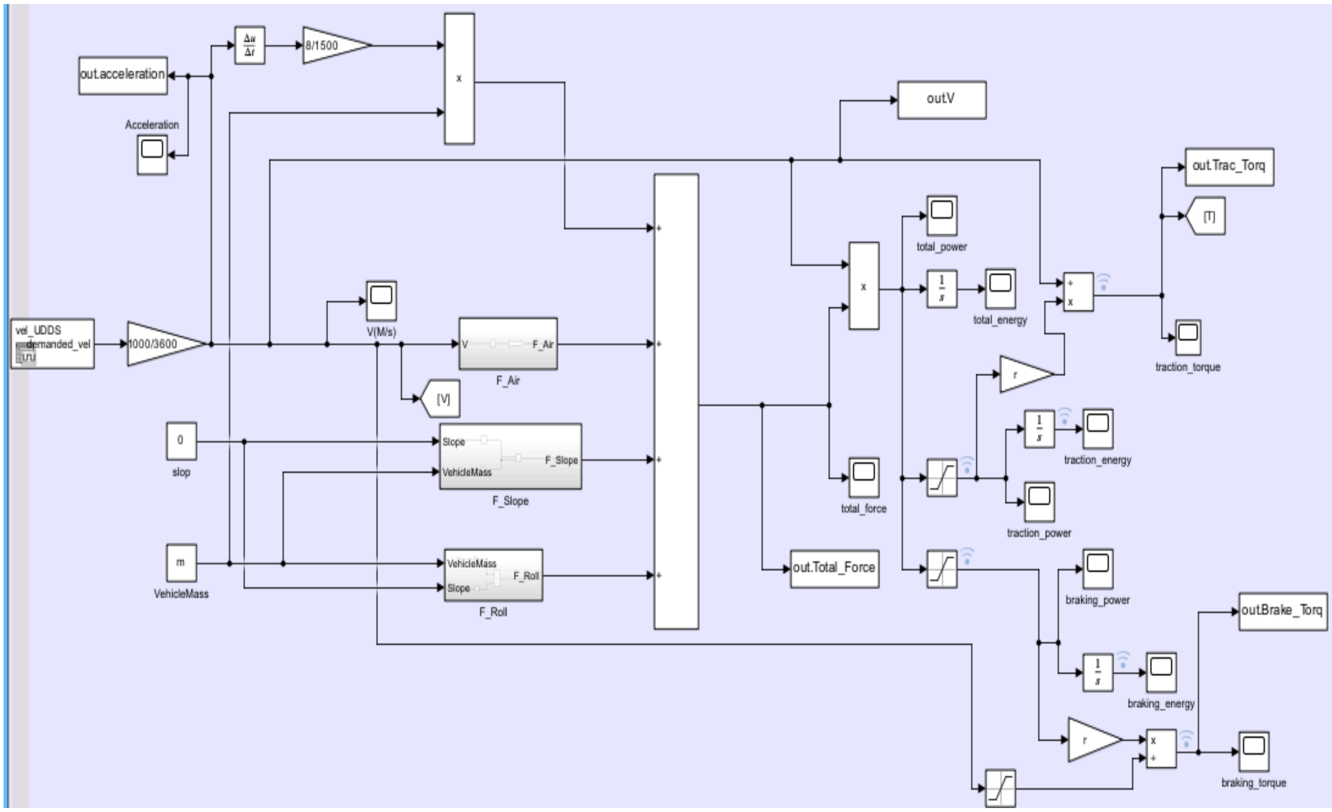
9. Total Energy :-

For total energy consumption over the cycle -:

$$E = \int P_{total} \, \partial t .$$

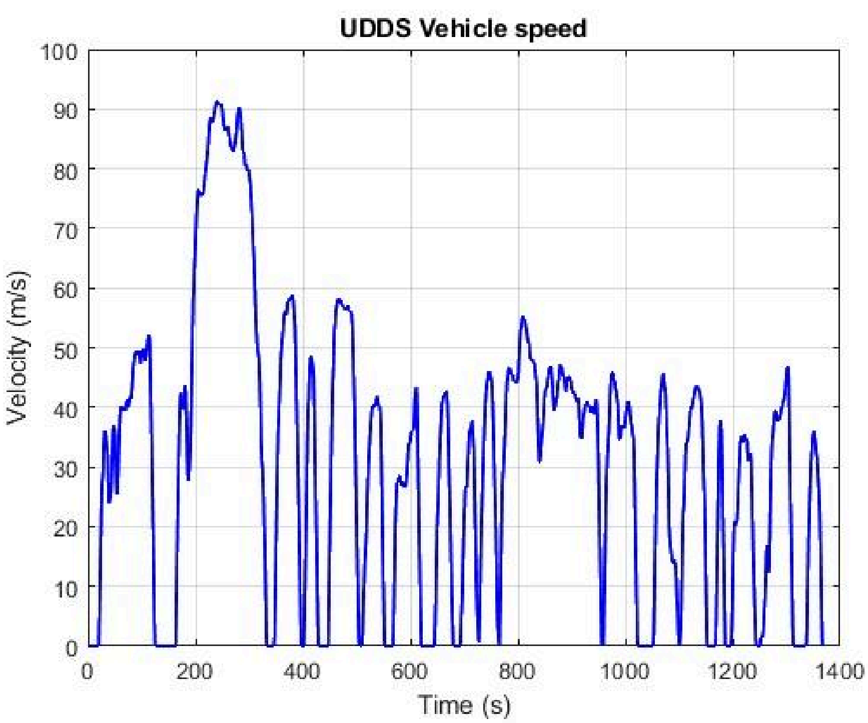
In our model, the total power term is sent through an Integrator block to obtain total Energy Consumption over the cycle.

Above are the pictures for the process of calculating vehicle total force/ total power / total energy, traction/braking power and torque respectively along with the road load force equations. The velocity in the equations is calculated by the simulink model for the given velocity data.

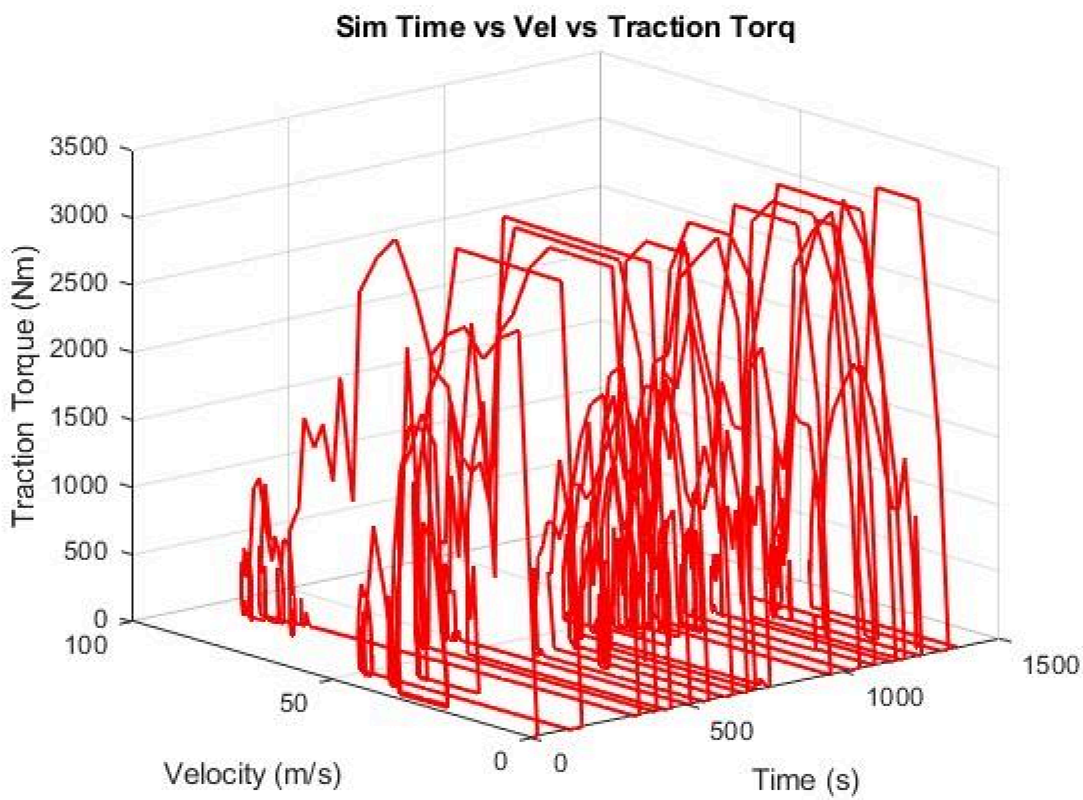


Above is the simulink model for the drive cycle analysis.

Results :

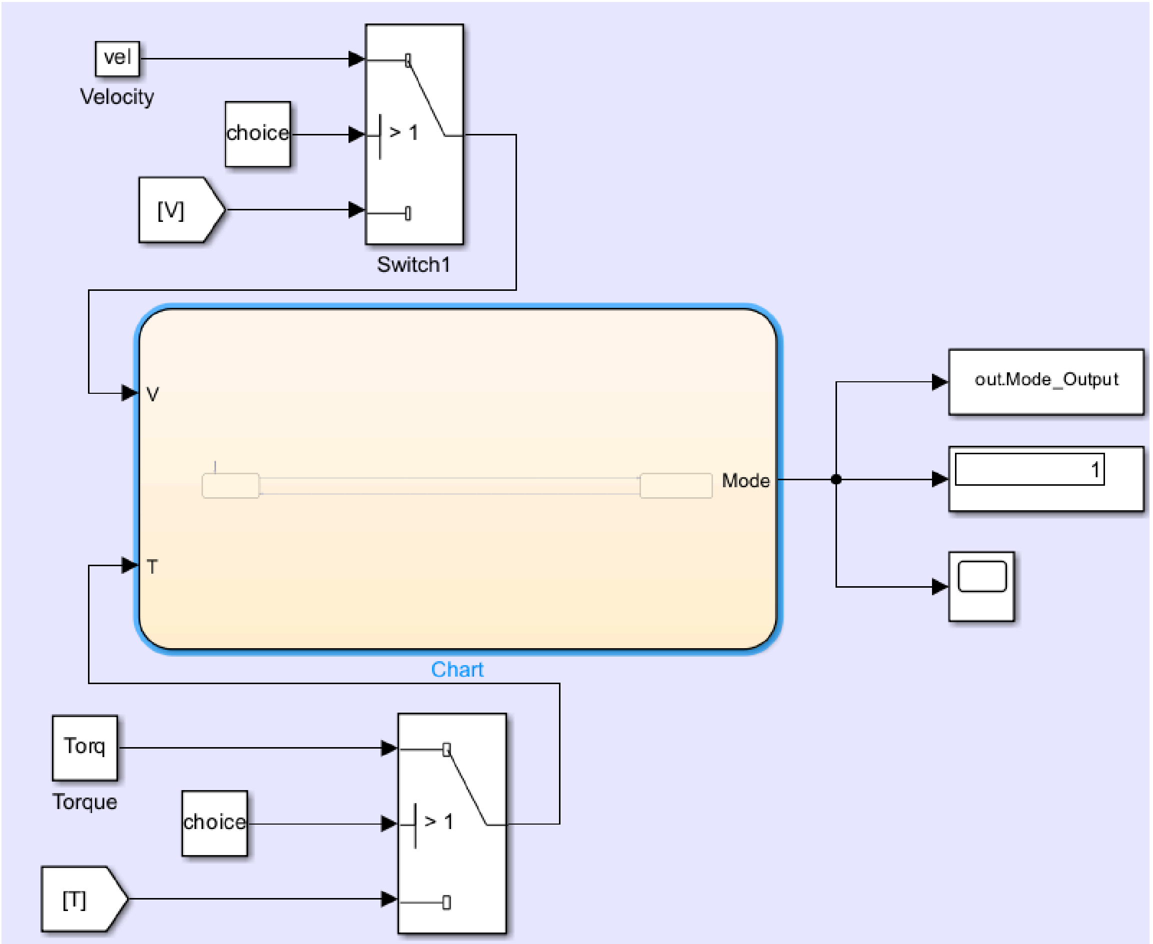


The above plot is a representation of a UDDS drive cycle totally showing that it is of urban driving conditions because it represents the n-number of stops in between typically the stop signs or the traffic signals in a city.
The gaps where there is zero velocity shows us the condition of idling of the engine therefore there is no sign of speed of the vehicle. These stop signs or idling times of the engine usually gives us regenerative braking and stores the power for later use.

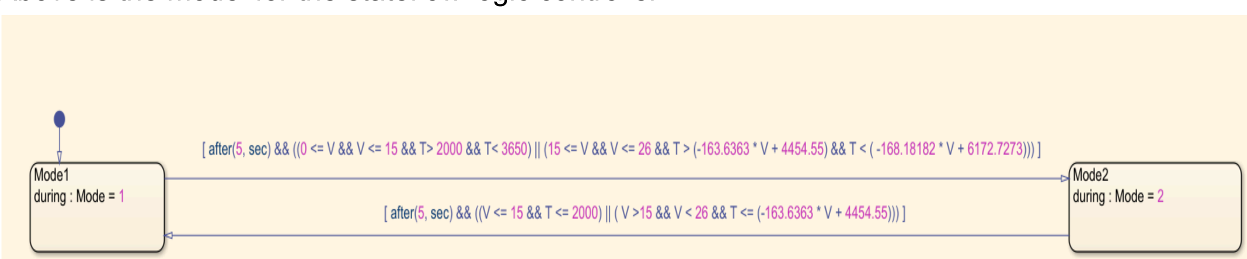


- This plot is a clear demonstration of traction torque as a function of vehicle speed and the simulation time.
- We observe that we get higher torque demand when we accelerate and while we climb a hill (typically) also we get to see that there is a lot of higher torque needed when the speed of the vehicle is high.
- While on the other hand when we get a significant amount of time to cruise at steady speed the traction torque demand goes down.
- Based on this we can understand that when we identify the pattern of the torque demand we can optimize the efficiency of the vehicle and specifically in our model we can give a better mode selection logic for the stateflow controller according to the regions of the modes given in the graph.

Simulink Model : ***STATEFLOW LOGIC CONTROLLER***



Above is the model for the stateflow logic controller.



This is the inside of the chart for the controller with two states and state 1 as Mode 1 which is also the default state. I have attached the screenshots of deriving these conditions from the graph.

The Graph of Tractive Torque vs. Vehicle Speed has two operating modes, mode 1 & mode 2, where mode 1 is the default mode.

To switch modes according to the regions specified, we are given corner points of regions.

A (0,0) E (26,200)
B (26,0) F (0,3650)
C (0,2000) G (15,3650)
D (15,2000) H (26,1800).

Mode 1 region is within ACDEBA region, &
Mode 2 region is within CFGHEDC region.

Mode 1 to 2 :-

According to graph,
when velocity is less than 15, and greater than 0, then this comes under the horizontal boundary conditions & we take values of Torque from 2000 to 3650.

i.e when $0 \leq V \leq 15$ then $2000 < T < 3650$.

But when it comes to sloped boundaries, we use line equation $y = mx + c$ to calculate lower limit for the mode 2.

Line DE is the lower limit, i.e
D (15,2000) E (26,200).

using formula :-

$$\text{(Slope) } m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{200 - 2000}{26 - 15}$$

$$= \frac{-1800}{11} = -163.6363$$

point - slope formula :

$$y - y_1 = m(x - x_1) \qquad \begin{bmatrix} y = T \\ x = V \end{bmatrix}$$

$$T - 2000 = (-163.6363)(V - 15)$$

$$\therefore \quad T = -163.6363 + 4454.55$$

for calculating C value :

$$y = mx + C$$

$$2000 = (-163.6363)\,15 + C$$

$$\therefore \quad C = 4454.55$$

Therefore, we take the condition :-

for the upper limit we have taken GH line & did the same process.

G (15, 3650) H (26,1800)

point - slope formula :-

$$T = -168.18182 + 6172.7273$$

C is calculated by $y = mx + C$

$C = 3650 + (168.18182 \times 15)$
$C = 6172.7273$.

Combining all the three conditions, we got, i.e, the horizontal line, the lower limit & the upper limit of mode 2 we take the final condition.

Mode 2 to 1 :-

To come back to mode 1, the vehicle speed & torque must not be in the region of mode 2. Therefore, we take Velocity & torque below the CD – Horizontal line, and DE — sloped line to obtain region of (V,T) for mode 1.

When velocity is less than 15, torque less than or equal to 2000, the vehicle will be in region of mode 1. This is for horizontal line.

For sloped line :-

We derived point slope formula for line DE i.e the lower limit of mode 2. But in this case it is the upper limit, therefore $T \leq -163.6363 \times V + 4454.55$ is the typical region for velocity greater than 15 but less than 26. Hence we take this as final condition.

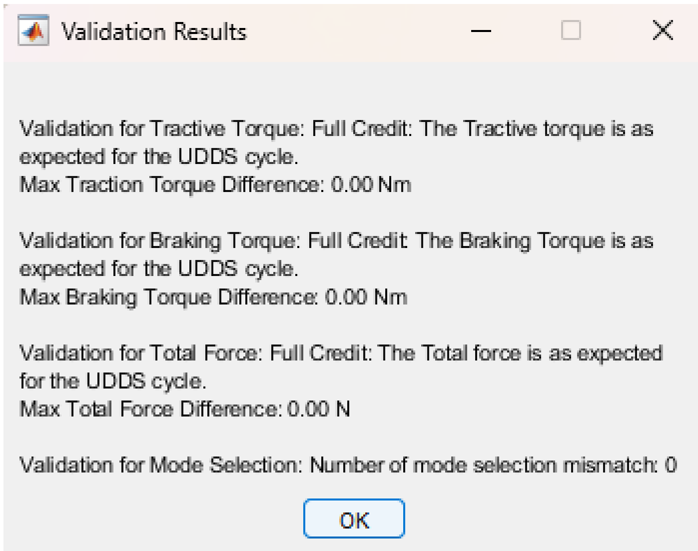
Combining both horizontal line equation with sloped line point-slope formula we take full & final condition for the stateflow logic controller to switch back to mode 1 from mode 2.

Therefore with the graph given the final conditions for transition of modes is done.

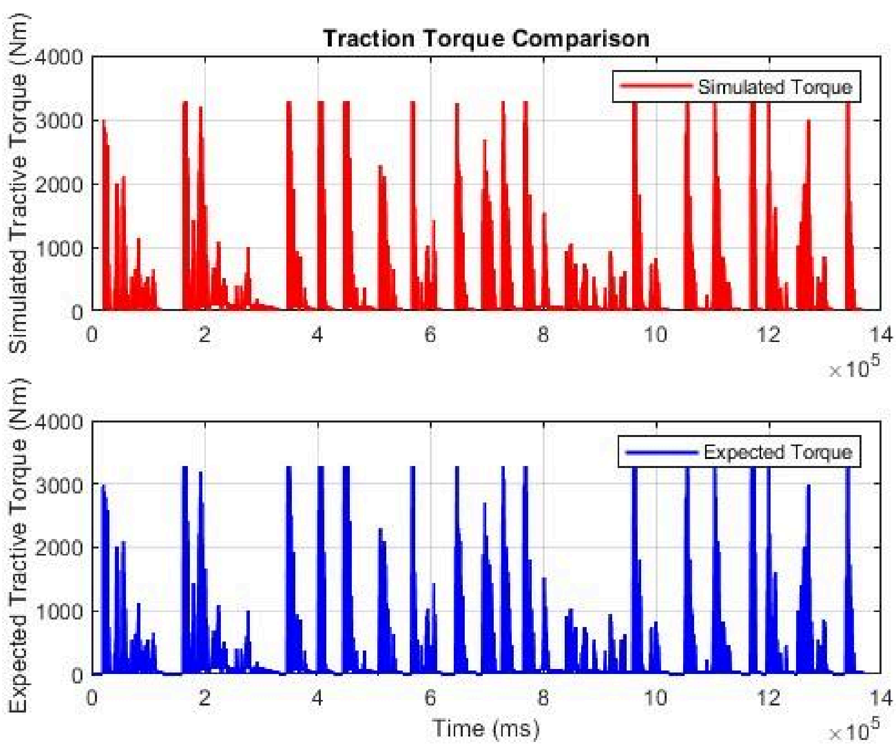
```
[ after(5, sec) && ((0 <= V && V <= 15 && T> 2000 && T< 3650) || (15 <= V && V <= 26 && T > (-163.6363 * V + 4454.55) && T < ( -168.18182 * V + 6172.7273))) ]

[ after(5, sec) && ((V <= 15 && T <= 2000) || ( V >15 && V < 26 && T <= (-163.6363 * V + 4454.55))) ]
```

In the above picture the first condition is for transition between Mode 1 to Mode 2, and the second line is the transition between Mode 2 to Mode 1. The after (5,sec) condition is given to the controller for delay so as to avoid frequent switching.

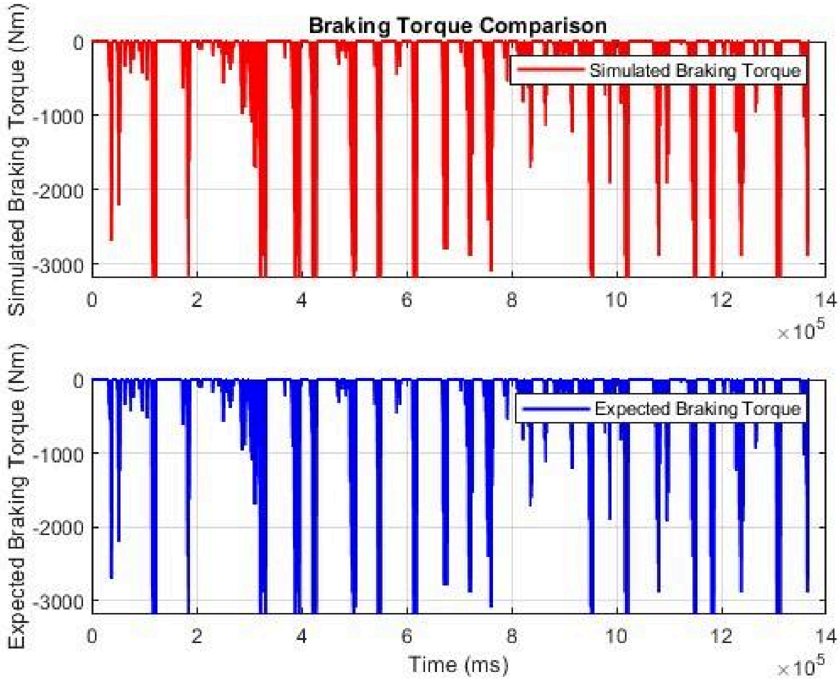
Results :



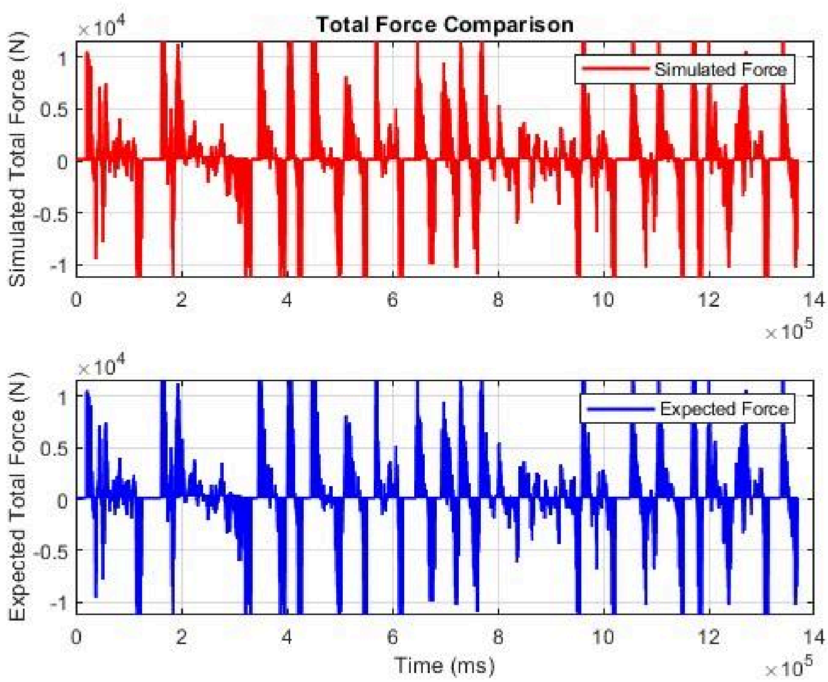
This is the auto evaluated validation result after we completed running the stateflow controller model. We obtained full credits for all the parameters such as Tractive torque, Braking torque, Total force and Mode selection as it gets validated against the expected values of the respective parameters.



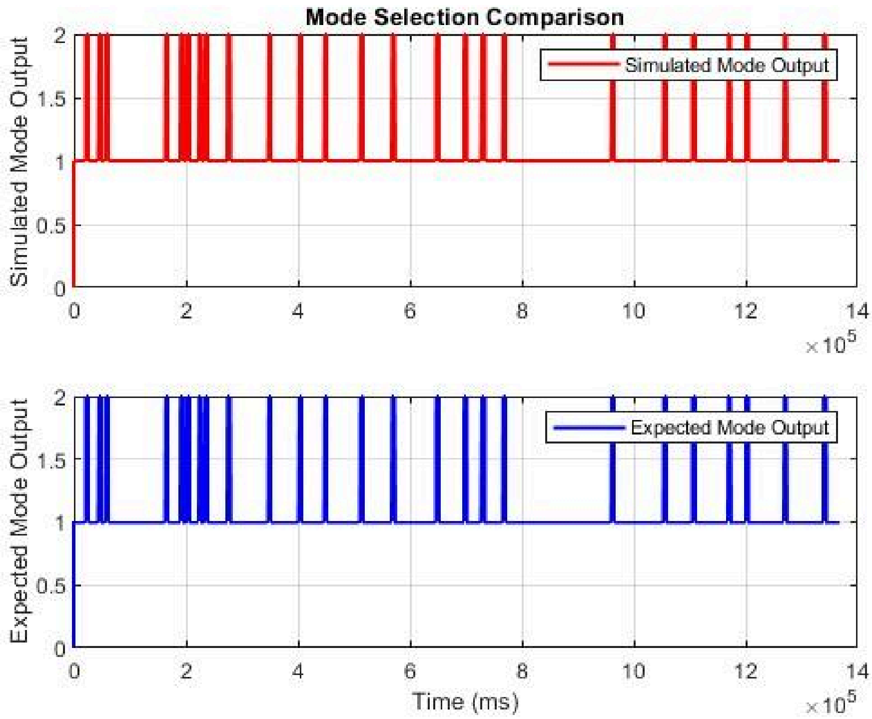
The simulated traction torque is perfectly the same when compared to expected output given with 0 Nm difference. Therefore the power modelling in the model is perfectly accurate.



The braking torque validated result says it is as expected for the UDDS drive cycle resulting in 0 Nm difference in between simulated and expected output.



There is no comparison between the simulated and expected output of the total force for the UDDS drive cycle as it perfectly aligns with the expected force for the cycle. The difference is 0 stating the summation of the forces we have taken is correct.

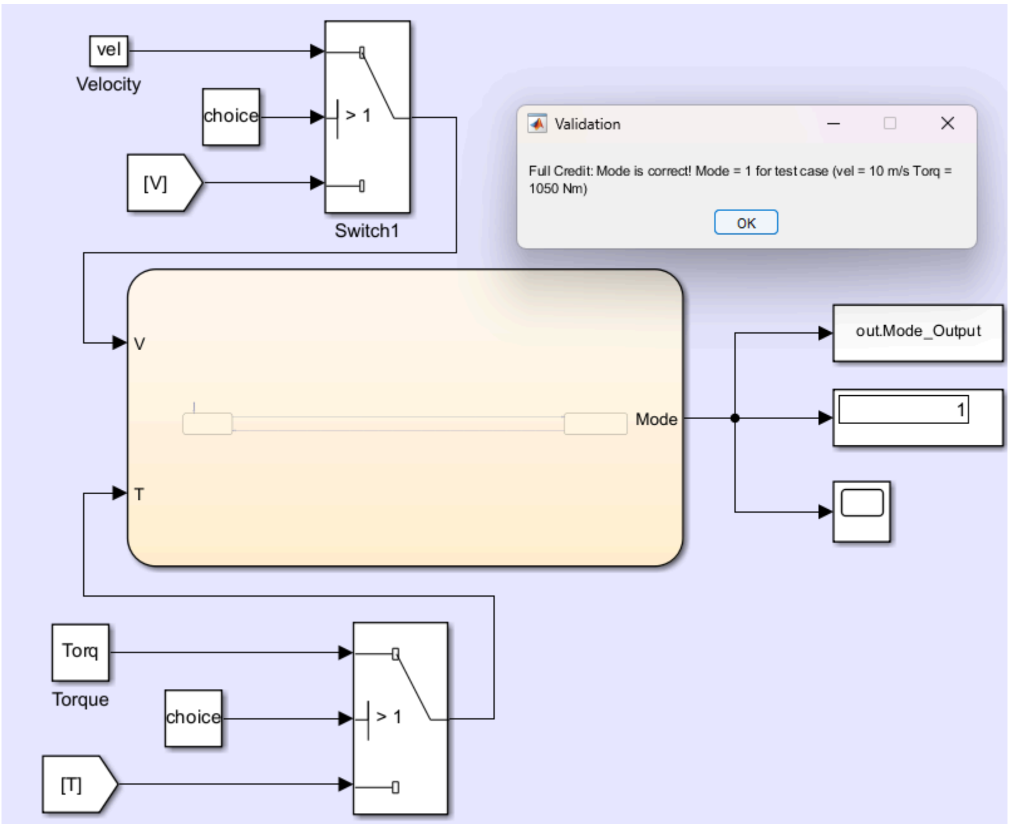


The switching of modes according to the regions stated in the graph given is perfectly done therefore there is no mismatch in the validated result of Mode selection. Therefore it states that the logic of the stateflow controller according to the required question is correctly done.

We have successfully validated our simulation results with absolutely no difference when compared to the expected output values given.

Point Load Cases :

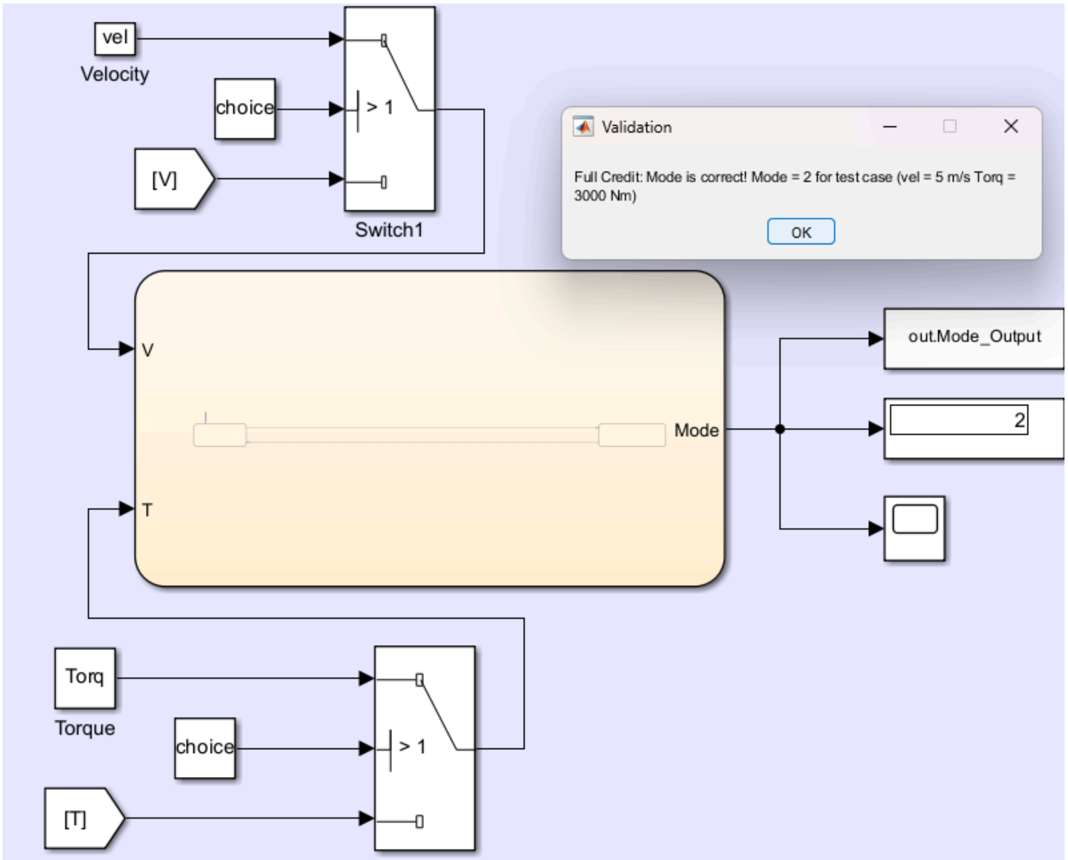
Case 1 :



Velocity = 10 m/s, Torque = 1050 Nm , Mode 1

This is the given information from the auto evaluation code.
We have obtained this with speed and torque lying in the Mode 1 region.
Therefore we can say that for low speed and torque conditions this logic of the controller is working.

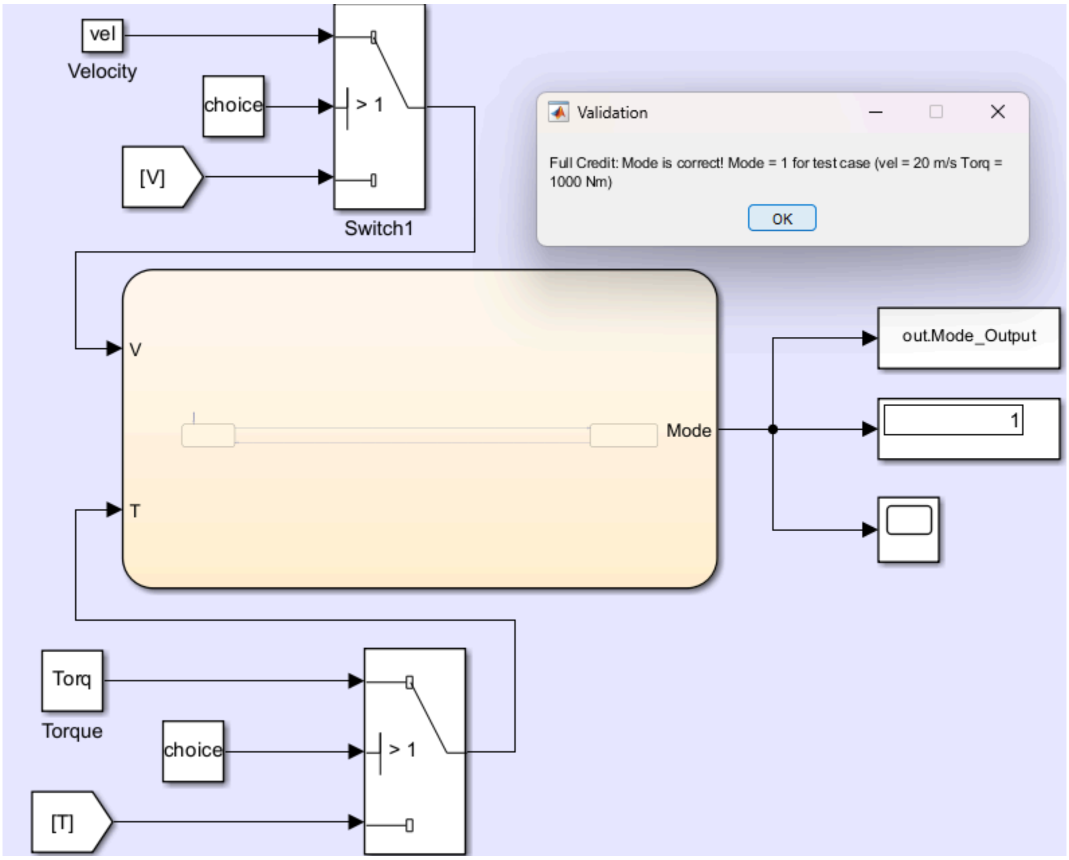
Case 2 :



Velocity = 5 m/s, Torque = 3000 Nm , Mode 2

This is the given information from the auto evaluation code.
We have obtained this with speed and torque lying in the Mode 2 region.
The controller transitions from mode 1 to mode 2 by ensuring the region boundaries given by the conditions in the stateflow controller.

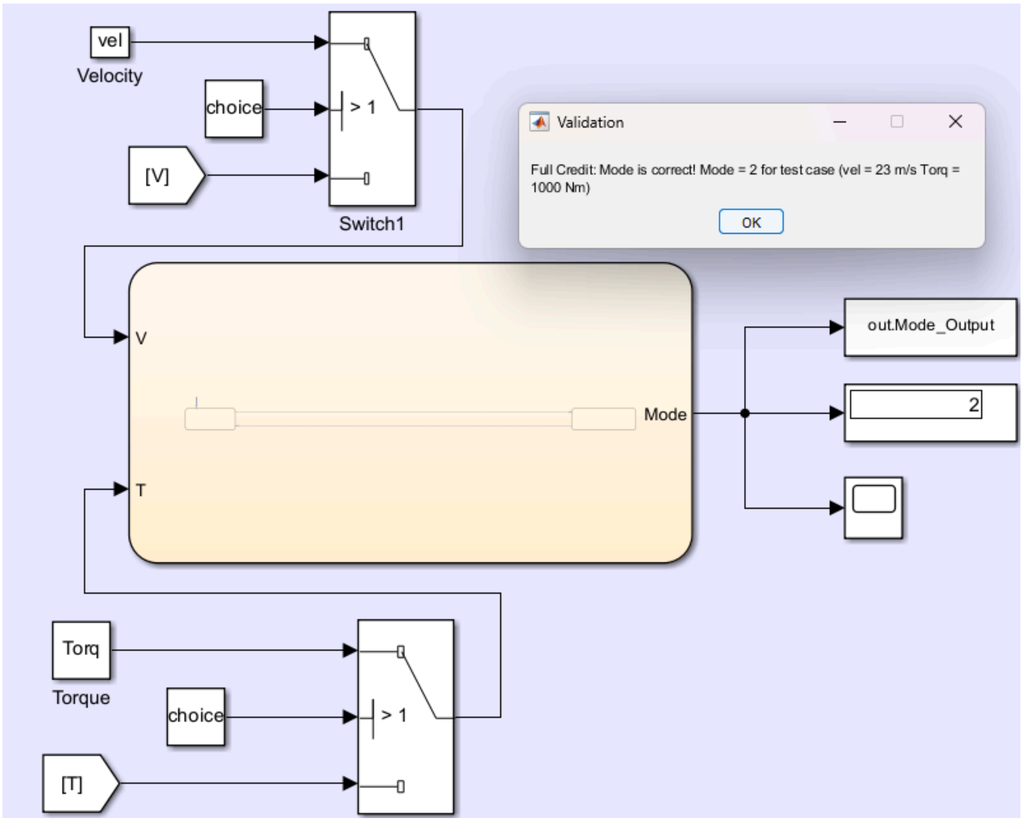
Case 3 :



Velocity = 20 m/s, Torque = 1000 Nm , Mode 1

This is the given information from the auto evaluation code.
We have obtained this with speed and torque lying in the Mode 1 region.
Compared to the first case the speed is higher but because of the torque condition this point is in Mode1 region and the controller does obtain this by the logic given.

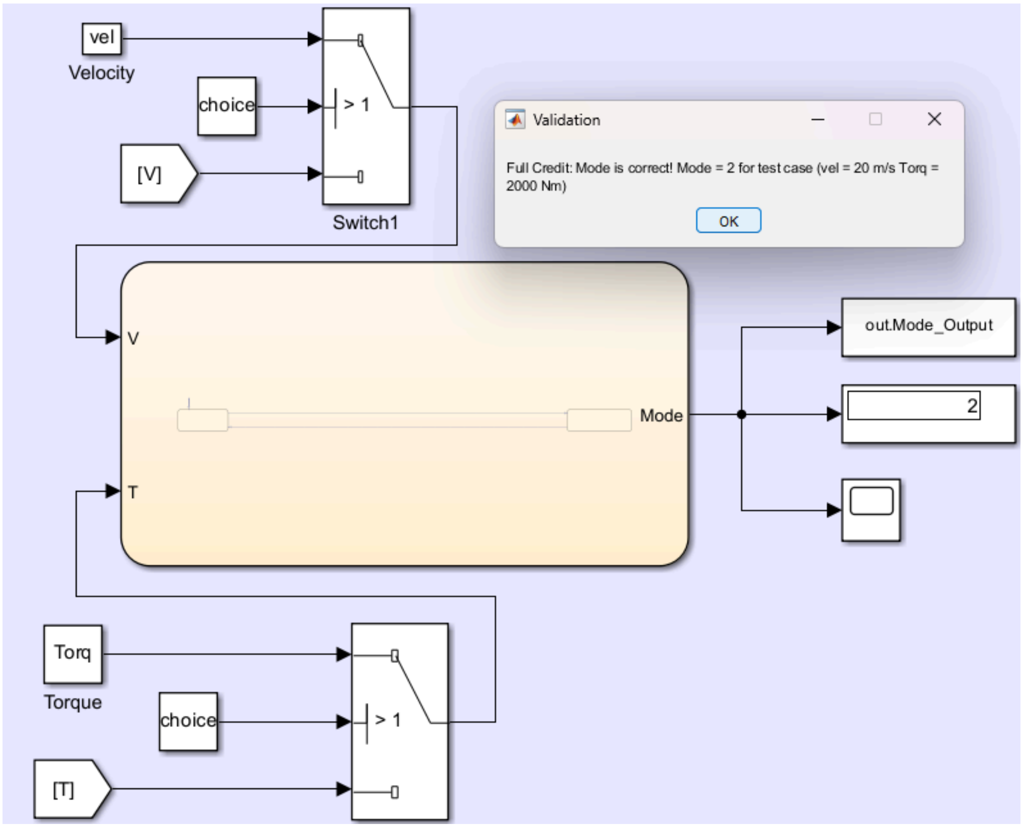
Case 4 :



Velocity = 23 m/s, Torque = 1000 Nm , Mode 2

This is the given information from the auto evaluation code.
We have obtained this with speed and torque lying in the Mode 2 region.
At higher speeds and medium torque levels the point lies in the region of mode 2 therefore with the logic of the stateflow controller we have obtained this point to be lying in the mode 2 region.

Case 5 :



Velocity = 20 m/s, Torque = 2000 Nm , Mode 2

This is the given information from the auto evaluation code.
We have obtained this with speed and torque lying in the Mode 2 region.
This is the point lying between the two sloped line boundaries but with higher speed therefore it is lying in the Mode 2 region and we obtained that with the logic we have written in the stateflow controller.

<u>Conclusion :</u>

Therefore we obtained all the 5 point load cases with perfect identification of them being in Mode 1 or Mode 2 with the help of correct logic given in the stateflow controller using transition conditions.

```
% Project 5
m = 1449;        % kg, vehicle mass
rho = 1.22;      % kg/m^3, air density
area = 2.22;     % m^2, frontal area
g = 9.8;         % m/s^2, gravitational acceleration
cw = 0.3;        % drag coefficient
fr = 0.01;       % rolling resistance coefficient
r=0.283;         % m, radius of tire
Vw = 0;          % m/s^2, Wind Velocity
load('vel_UDDS.mat');
load('mode_UDDS.mat');
load('total_force_UDDS.mat');
load('braking_torque_UDDS.mat');
load('tractive_torque_UDDS.mat');
data_vel = load('vel_UDDS.mat');
ts_vel = data_vel.vel_UDDS{1};
time_vector = ts_vel.Time;
vehicle_velocity = ts_vel.Data;
% Plot
figure;
plot(time_vector, vehicle_velocity, 'b', 'LineWidth', 1.5);
title('UDDS Vehicle speed');
xlabel('Time (s)');
ylabel('Velocity (m/s)');
grid on;
data_vel = load('vel_UDDS.mat');
ts_vel = data_vel.vel_UDDS{1};
vehicle_velocity = ts_vel.Data;
time_vector = ts_vel.Time;
data_torque = load('tractive_torque_UDDS.mat');
traction_torque = data_torque.tractive_torque_UDDS;
% 3D Plot
figure;
plot3(time_vector, vehicle_velocity, traction_torque_down, 'r', 'LineWidth',
1.5);
title('Sim Time vs Vel vs Traction Torq');
xlabel('Time (s)');
ylabel('Velocity (m/s)');
zlabel('Traction Torque (Nm)');
grid on;
```