EE3600 Assignment 1

Modelling the Powertrain of an Electric Vehicle

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INTRODUCTION

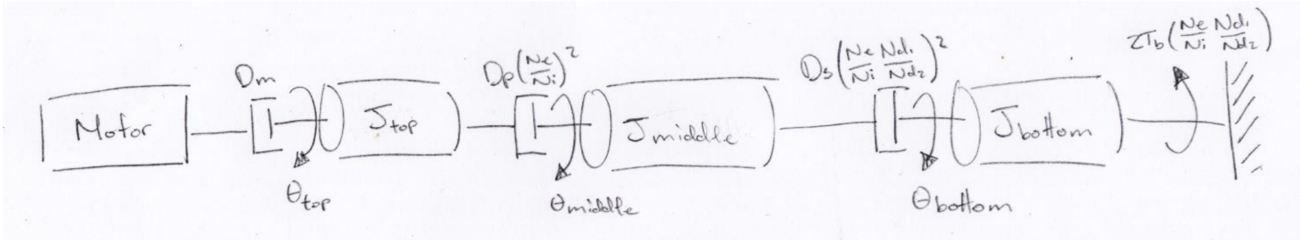
In this assignment, the powertrain/driveline of an electric vehicle was simulated using Simulink. The model includes various subsystems and components, such as driver inputs, an electric pedal, a brake, a DC motor engine, a 4-speed gearbox, and other related elements.

This assignment followed the following process to come to a solution:

First, the total inertial and viscous damper elements were derived using the equivalent rotational mechanical system diagram (Figure 1). A transfer function was then found for ω_{wheel} / θ_{pedal} using the equations for the armature circuit of the motor (equation 1) and the total torque developed by the motor (equation 2). All these equations were then implemented to create a simulation in Simulink.

As a result, a working simulation was achieved by incorporating the mathematics that describe the driveline of an electric vehicle.

SYSTEM MODEL



where: $J_{top} = J_e + J_m$

$$J_{middle} = \left(J_1 + J_2 + J_3 + J_4 + J_p + J_{d1}\right)\left(\frac{N_e}{N_i}\right)^2$$

$$J_{bottom} = \left(2J_w + J_s + J_{d2}\right)\left(\frac{N_e}{N_i}\frac{N_{d1}}{N_{d2}}\right)^2$$

Figure 1 – Diagram of equivalent rotational mechanical system

The equivalent J_{total} and D_{total} terms of the different gear ratios were then derived as follows:

$$J_{total} = J_e + J_m + \left(J_1 + J_2 + J_3 + J_4 + J_p + J_{d1}\right)\left(\frac{N_e}{N_i}\right)^2 + \left(2J_w + J_s + J_{d2}\right)\left(\frac{N_e}{N_i}\frac{N_{d1}}{N_{d2}}\right)^2$$

$$D_{total} = D_m + D_p\left(\frac{N_e}{N_i}\right)^2 + D_s\left(\frac{N_e}{N_i}\frac{N_{d1}}{N_{d2}}\right)^2$$

$$T_{b\,total} = 2T_b\left(\frac{N_e}{N_i}\frac{N_{d1}}{N_{d2}}\right)$$

$$\boxed{w_{top} = s\theta_{top}}$$

Therefore:

$$T_{total} = \left(J_{total}s^2 + D_{total}s\right)\theta_{top} + T_{b\,total}$$

$$\therefore \quad k_t i = J_{total}\, s w_{top} + D_{total}\, w_{top} + T_{b\,total}$$

The following calculations show the derivation of the system transfer function for wheel rotation speed (rad/s) to electric pedal angle.

let $T_{btotal} = 0$

$$V = L\frac{di(t)}{dt} + Ri(t) + k_b w(t) \quad (1)$$

$$k_t i(t) = J\dot{w}(t) + Dw(t) \quad (2)$$

$\Downarrow$ Laplace Transform

$$V(s) = Lsi(s) + Ri(s) + k_b w(s) \quad (1)$$

$$k_t i(s) = Jsw(s) + Dw(s) \quad (2)$$

Rearrange (1) for i

$$i = \frac{V - k_b w}{Ls + R} \quad (1a)$$

Sub (1a) into (2)

$$k_t\left(\frac{V - k_b w}{Ls+R}\right) = Jsw + Dw$$

$$k_t(V - k_b w) = (Jsw + Dw)(Ls + R)$$

$$k_t V - k_t k_b w = JLs^2 w + DLsw + JRsw + DRw$$

$$k_t V = w\left(JLs^2 + DLs + JRs + DR + k_t k_b\right)$$

$$\therefore \quad \frac{\omega_{motor}}{V} = \frac{k_t}{JLs^2 + (DL+JR)s + DR + k_t k_b} \qquad (3)$$

Sub. in the following equations into (3):

$$V = k_e \theta_{pedal} \qquad (4)$$

$$\omega_{wheel} = \omega_{motor}\left(\frac{N_e}{N_i}\frac{N_{d_1}}{N_{d_2}}\right)$$

$$\therefore \quad \omega_{motor} = \omega_{wheel}\left(\frac{N_i}{N_e}\frac{N_{d_2}}{N_{d_1}}\right) \qquad (5)$$

Therefore:

$$\frac{\omega_{wheel}\left(\frac{N_i}{N_e}\frac{N_{d_2}}{N_{d_1}}\right)}{k_e \theta_{pedal}} = \frac{k_t}{JLs^2 + (DL+JR)s + DR + k_t k_b}$$

$$\frac{\omega_{wheel}}{\theta_{pedal}} = \frac{k_e k_t \left(\frac{N_e}{N_i}\frac{N_{d_1}}{N_{d_2}}\right)}{JLs^2 + (DL+JR)s + DR + k_t k_b}$$

Assume L is small enough to be ignored:

$\therefore \quad L = 0$

$$\therefore \quad \frac{\omega_{wheel}}{\theta_{pedal}} = \frac{k_e k_t \left(\frac{N_e}{N_i}\frac{N_{d_1}}{N_{d_2}}\right)}{\cancelto{0}{JLs^2} + (\cancelto{0}{DL} + JR)s + DR + k_t k_b}$$

$$\frac{\omega_{wheel}}{\theta_{pedal}} = \frac{k_e k_t \left(\frac{N_e}{N_i}\frac{N_{d_1}}{N_{d_2}}\right)}{JRs + DR + k_t k_b}$$

$$\frac{\omega_{wheel}}{\theta_{pedal}} = \frac{\frac{k_e k_t}{JR}\left(\frac{N_e}{N_i}\frac{N_{d_1}}{N_{d_2}}\right)}{s + \frac{1}{J}\left(D + \frac{k_t k_b}{R}\right)}$$

SIMULATION

The following figure shows the overall structure of the simulation which consists of 5 main subsystems. The simulation functions as follows: the system takes in the value of the electric pedal and that of the brakes as well as the chosen gear to output a simulated wheel speed.

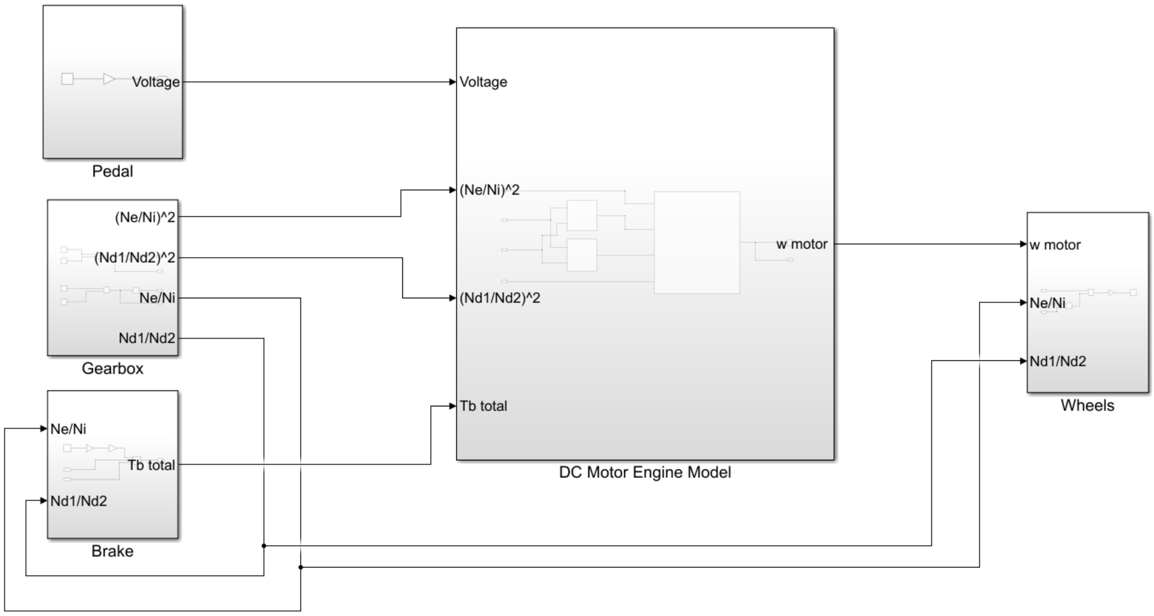


Figure 2 – Overall structure of simulation

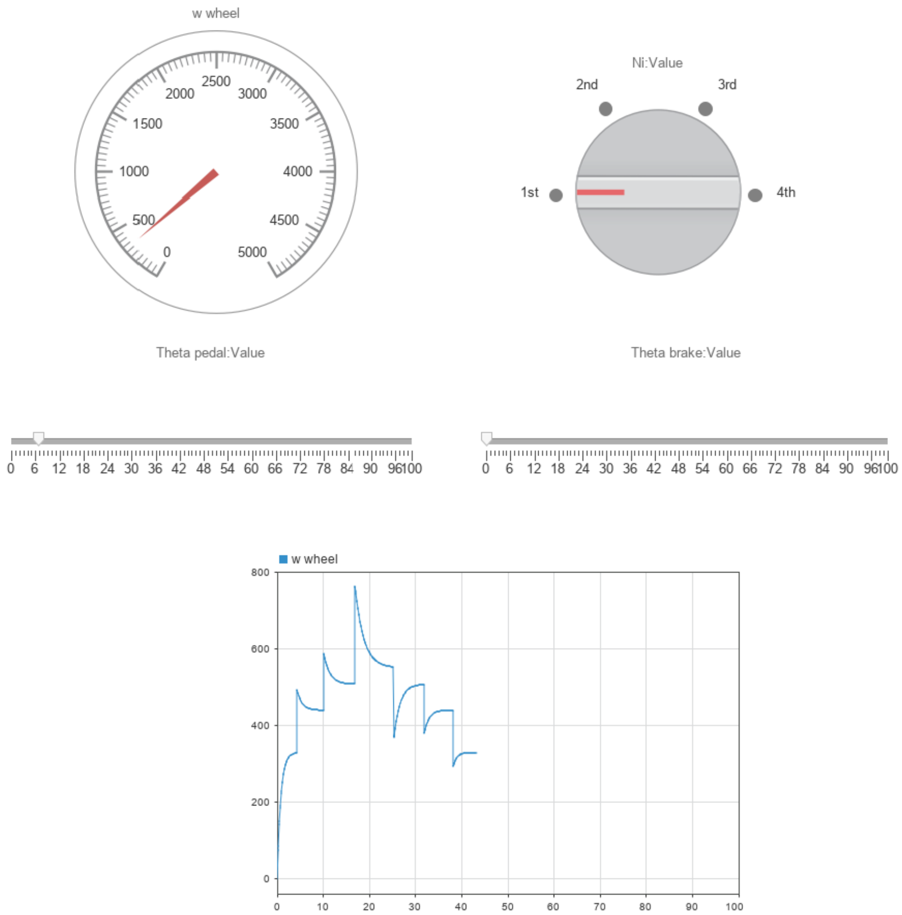


Figure 3 – Controls and dashboard of simulation

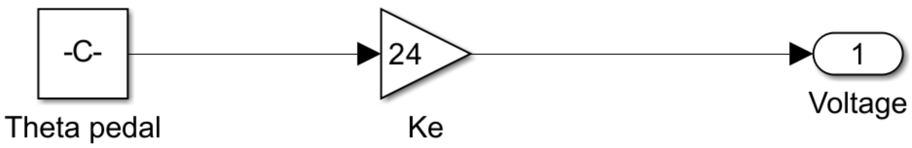


Figure 4 – Pedal subsystem

The pedal subsystem (Figure 4) consists of recreating the following equation where θ_{pedal} is linked to a slider in the controls:

$$V = k_e \theta_{pedal} \ (0 < V < 24\,V)$$

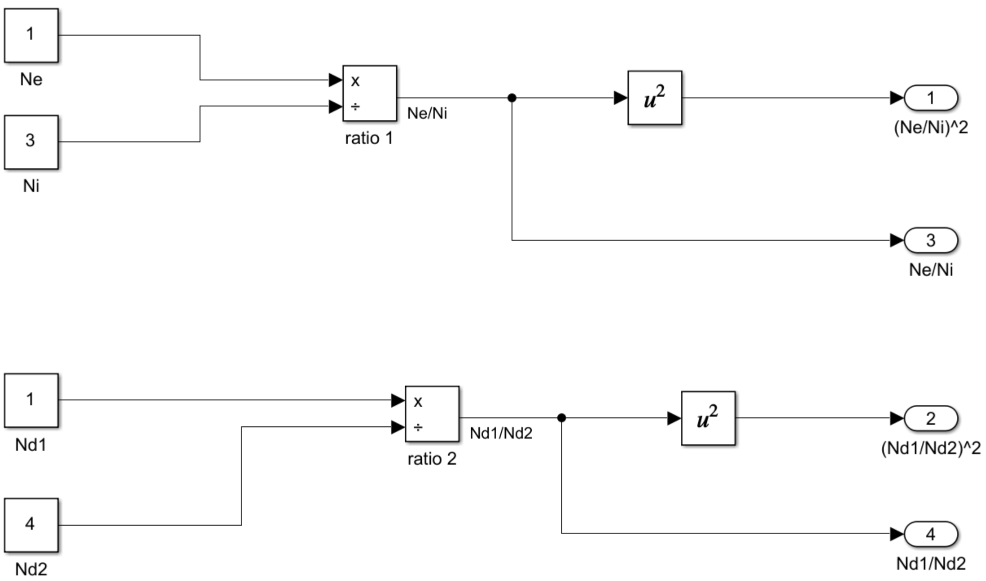


Figure 5 – Gearbox subsystem

The gearbox subsystem (Figure 5) comprises of all the gear ratios to be later distributed to other subsystems. It most importantly holds the value Ni which is linked to the rotational switch in the controls.

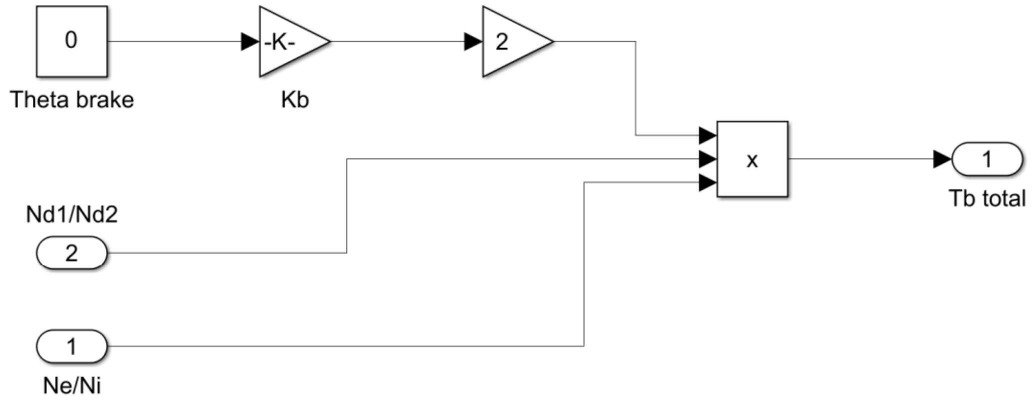


Figure 6 – Brake subsystem

The brake subsystem (Figure 6) consists of the recreating the following equation for the top shaft where θ_{brake} is linked to a slider in the controls:

$$T_b = k_b \theta_{brake}$$

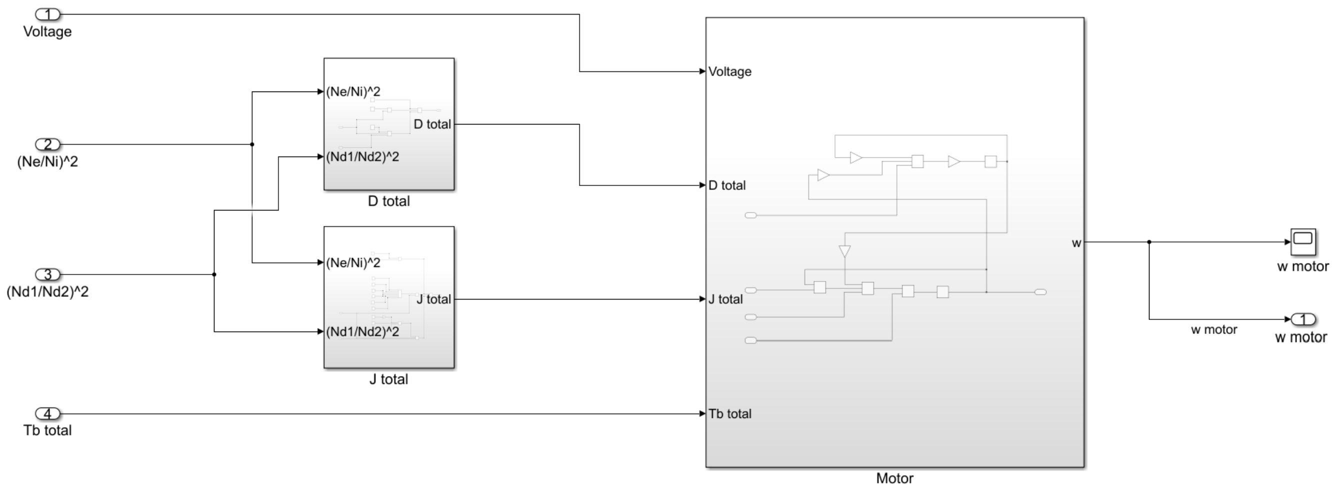


Figure 7 – DC motor engine model subsystem

The DC motor engine model subsystem (Figure 7) consists of 3 additional subsystems. The D total subsystem holds all the viscous damper elements (Figure 8) whereas the J total subsystem holds all the inertial elements (Figure 9). On the other hand, the motor subsystem (Figure 10) withholds equations 1 and 2.

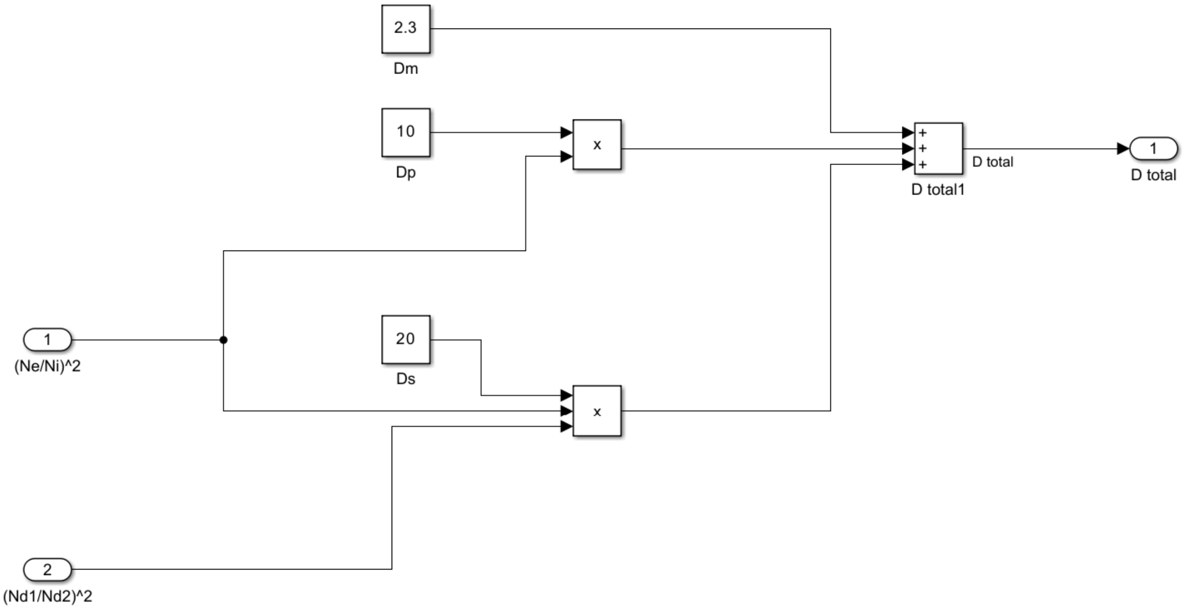


Figure 8 – D total subsystem

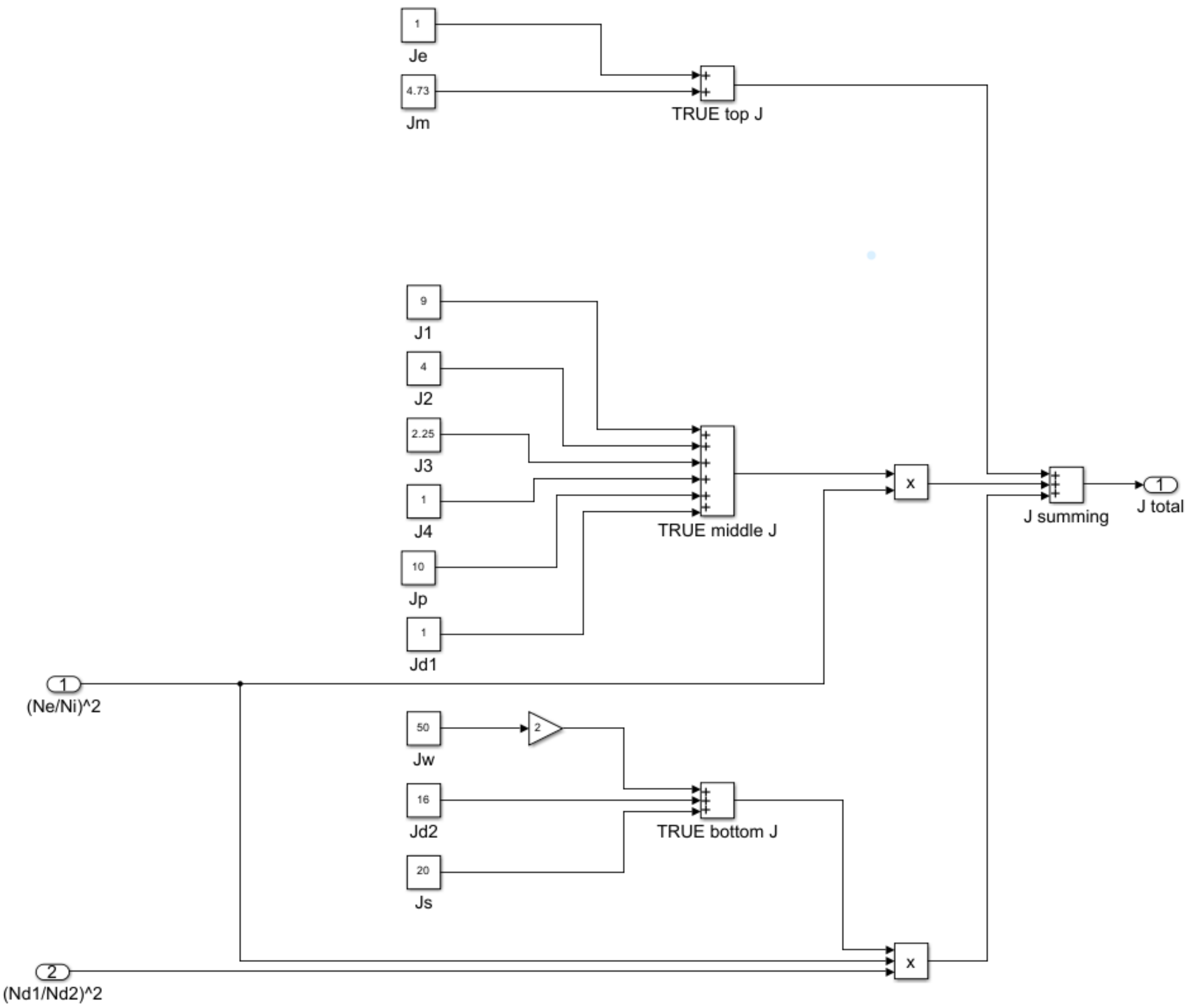


Figure 9 – J total subsystem

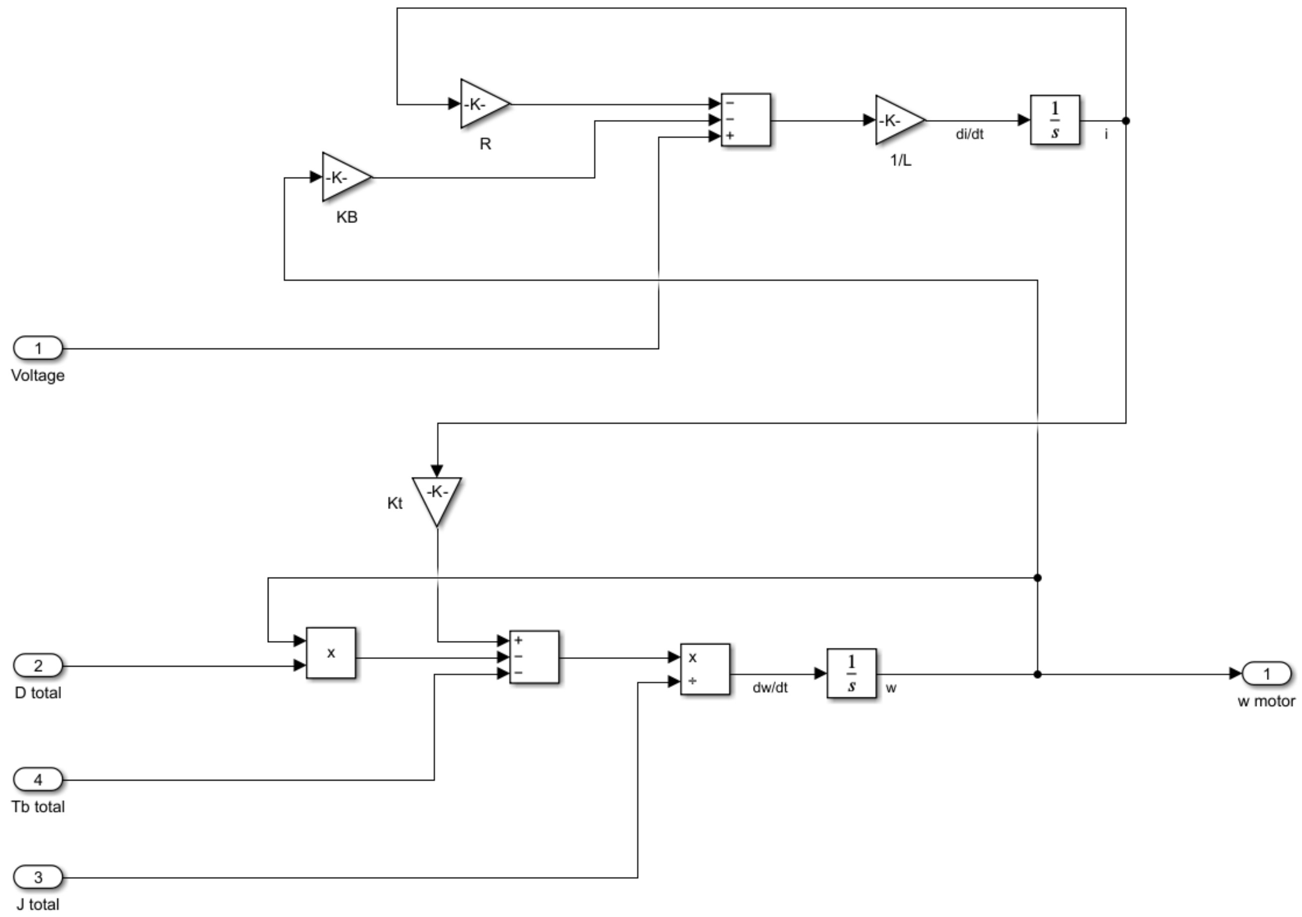


Figure 10 – Motor subsystem

Finally, the wheels subsystem (Figure 11) converts the motor speed (in rad/s) to wheel speed (in RPM).

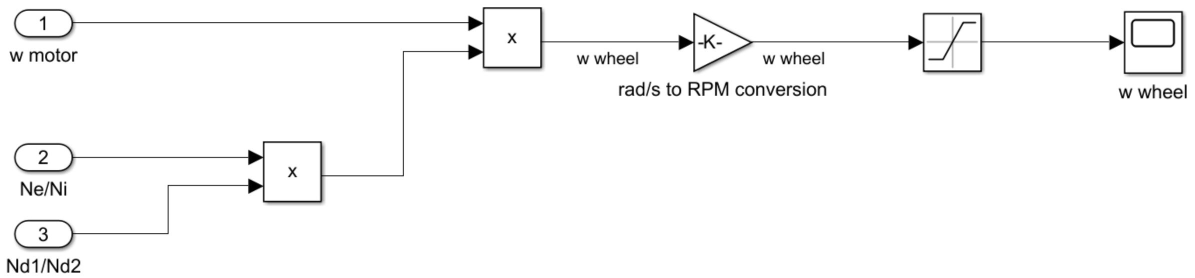


Figure 11 – Wheels subsystem

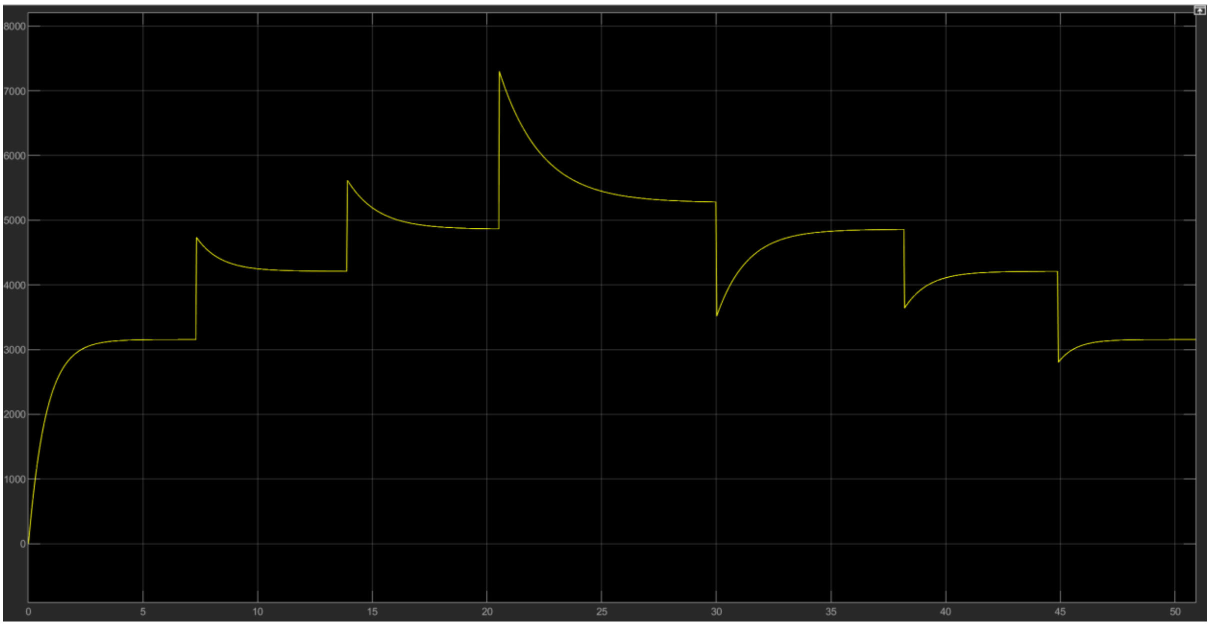


Figure 12 – Graph showing only change in gears

The graph from Figure 12 shows that if the car is shifted up a gear, a sudden spike in wheel speed appears before stabilising to a higher speed. Whereas, if the car is shifted down a gear, a sudden dip in the wheel speed appears before stabilising to a lower speed. In order to produce this result, the electric pedal was fixed at 6% and the brake at zero.

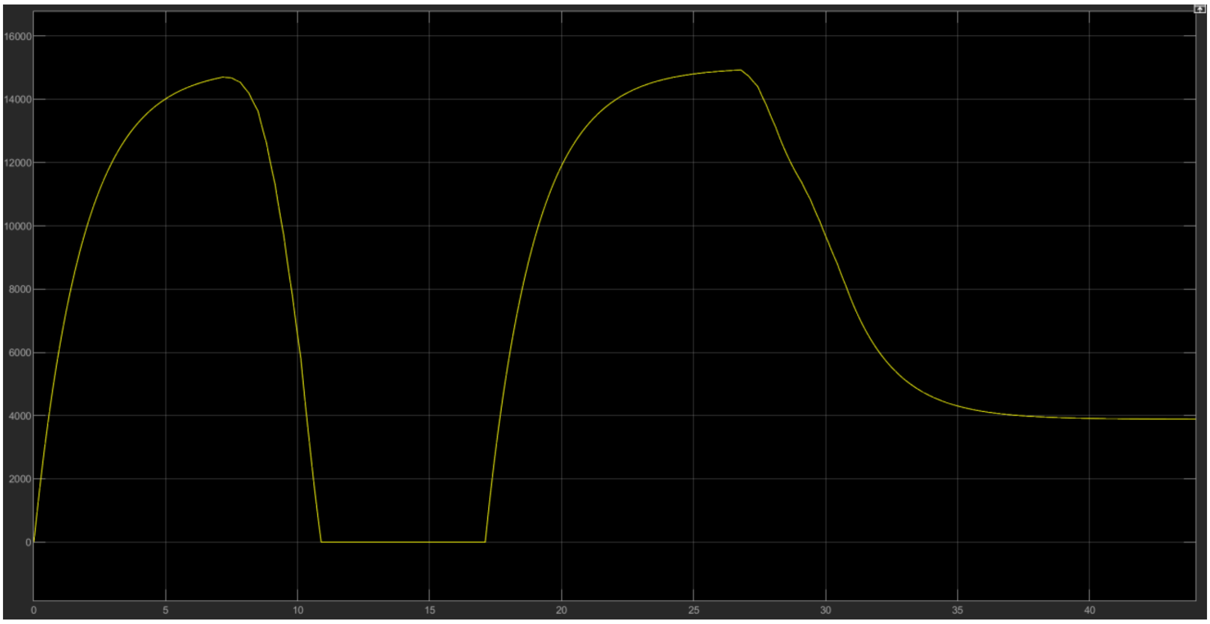


Figure 13 – Graph showing only change in brake pedal

From this graph (Figure 13), the brakes can stop the car if the electric pedal is at a small value such as 20% and in fourth gear. To keep the output speed realistic, a saturation block was added to filter out any negative speeds. Therefore, the car remains at a halt and can speed up again later. The final part of the curve is a flat area where the brake was at a constant value (too small to stop the car).

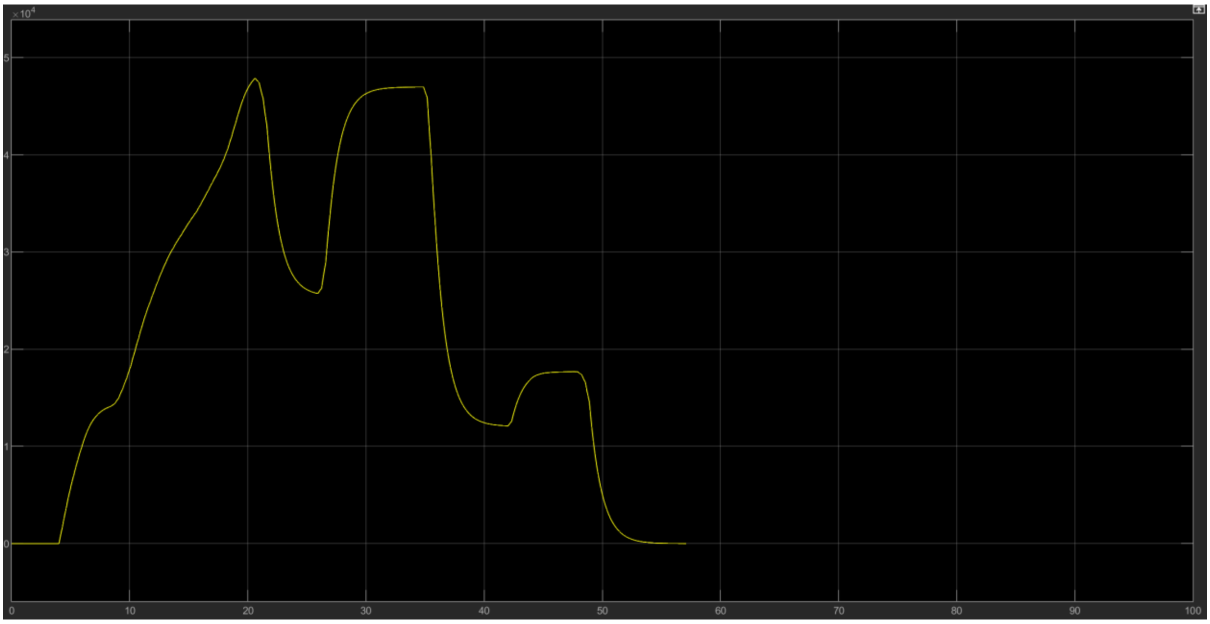


Figure 14 – Graph showing only change in electric pedal

This final graph shows how the car's wheel speed is significantly affected by the electric pedal alone. The flat areas of the graph show that if the electric pedal is set at a fixed value, the wheel speed will eventually stabilise. Moreover, the brake was fixed at zero and the car was in second gear to produce this result.

CONCLUSION

In conclusion, the powertrain of an electric vehicle was successfully simulated using Simulink and some mathematical techniques.

However, the simulation is limited where the braking system does not work entirely as expected due to the placement of the saturation block. The saturation block only hides the negative speeds and does not set the actual speed of the wheels to zero. This means that if the car has been braking for a very long time, the car would not visibly accelerate instantly as it would have to accelerate from an invisible large negative speed.

It would, therefore, be suggested to improve the braking area of the system by correcting this flaw. Furthermore, the gearbox aspect could be further investigated where an automatic transmission could be integrated into the system.