Modeling and Simulation of Series Hybrid Electric Vehicle using MATLAB/Simulink and State flow

by

Prakash Koirala

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Abstract

As the global economy strives towards clean energy in the face of climate change, the automotive industry is researching into improving the efficiency of automobiles. Hybrid vehicle systems were proposed and have demonstrated the capability of reducing fuel consumption while maintaining vehicle performance. Various hybrid vehicles in the form of parallel and series hybrid have been produced by different vehicle manufacturers.

In this project, an overview of series HEV is presented. In fact, we performed a market assessment and analyzed the responses whose average results are quite close to a normal drive cycle. And we aim to introduce modeling of series HEV, and its comparative study between other power train architectures presenting their pros and cons and the reason behind selecting them. The methodology used in this paper is descriptive, library and analytical. The descriptive aspect of this paper is based on identification and definitions and its required materials and information have been complied using related scientific papers.

Objectives

Main Objective:

The main objective of our study is to design and model a series hybrid electric vehicle of the passenger car application.

Specific objectives:

The specific objectives of our study include:

i. Analysis of a Survey and selecting an appropriate driving cycle accordingly.
ii. To create a Simulink model which uses the US06 drive cycle as a reference speed for running.
iii. Comparing different vehicle architectures to determine what would be ideal for the given parameters
iv. To compare it with current hybrid vehicles and conventional engine vehicles available in the market.

Market Assessment and Allowable Cost

We conducted a Survey on 38 candidates living in Greenville area using a Google from created by us, containing several questions asking the user.

We have conducted a market assessment to determine the allowable cost for the vehicle and its powertrain.

We also collected data of the distance their vehicles travel over the course of a day. The average distance travelled was found to be around 16-18 miles and the time that the vehicle runs was found to be an average of around 20 minutes.

The average maximum speed while travelling was around 79 mph.

As a result, from the market survey, it was found that most customer requirements for the vehicle align with the US06 drive cycle. So, we finally decided to use this for powertrain modelling.

From our survey, the maximum number of stops people make while travelling from their residence to workplace was ranging from 5 to 10, which seemed to be reasonable.

Table 0.1 Comparison of parameters between US06 Drive cycle and Market Survey

Parameters	**US06(for single cycle)**	**Market survey data**
Time (in mins)	10	19.2
Distance (in miles)	8	15.5
Average speed(mph)	48	47.22
Top speed(mph)	80	75.77
Number of stops	4	7

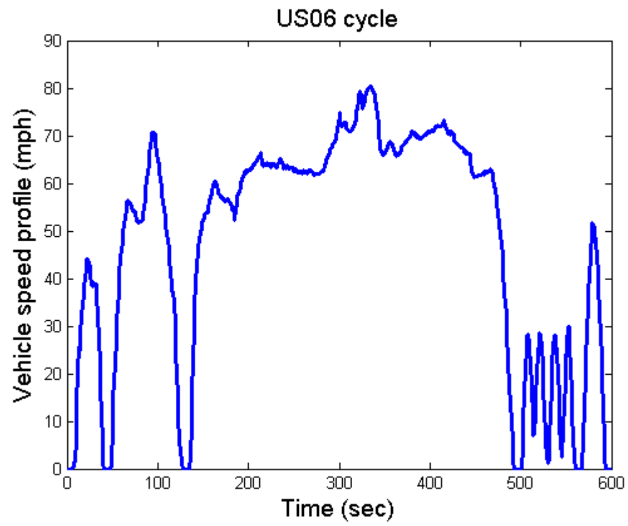

Figure 0.1 US06 Drive Cycle (Source: DieselNet)

The allowable cost of the vehicle and its power train are shown below.

Table 0.2 Allowable cost of vehicle and its powertrain

Parameters	**Specifications**	**Estimated Cost ($)**
Engine	1.5 liters, Inline 4, 60 KW peak power	4,400
Transmission	Single speed	3,500
Battery	150 cells in series	3,000
Electric Motor	111 KW power, Torque = 310 Nm	12650
Braking System	Disc Brakes (front and back)	2,000
Vehicle Electronics	Wiring harness, infotainment, AC system and miscellaneous	3,000
Manufacturing Cost (each vehicle)	Welding, and other metal working processes	5000 (Approx.)
Total		**33,550**

Modeling and Simulation

Overall Modeling

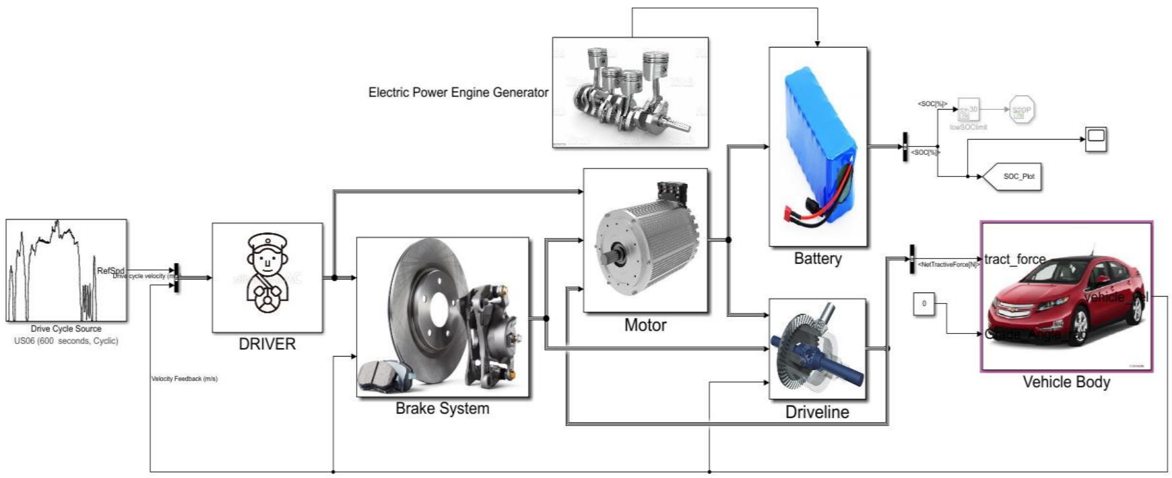

Figure 0.1 Overall Powertrain Model

The US06 Supplemental Federal Test Procedure (SFTP) was developed to address the shortcomings with the FTP-75 test cycle in the representation of aggressive, high speed and/or high acceleration driving behavior, rapid speed fluctuations, and driving behavior following startup.

According to the Google Form, which contains set of questions that ask questions to user that helped us analyze the different driving habits. We noticed that whatever data we have collected was approximately twice the highlights of the drive cycle. And we run the simulation of drive cycle twice. Since we are running it twice the time, so we have taken distance as twice which will be 16 miles.

Powertrain Components

i) Driver

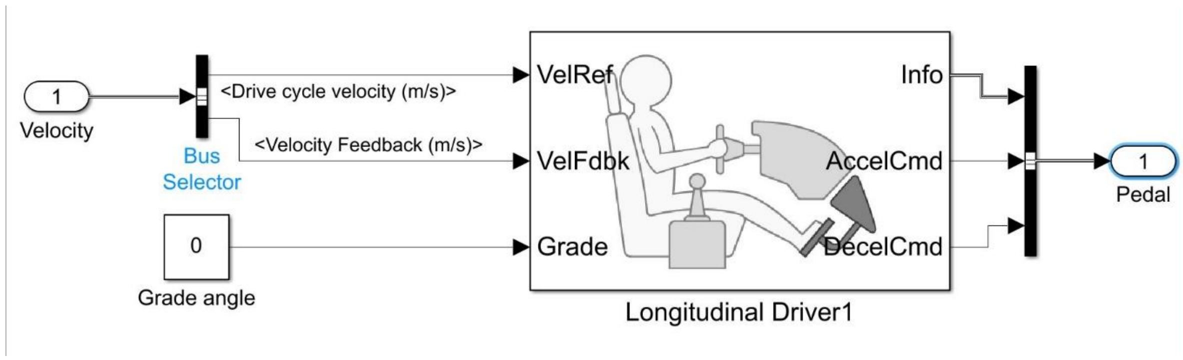

Figure 0.2 Driver Subsystem

The inputs to the driver subsystem are reference drive cycle and vehicle velocity. The outputs from the longitudinal driver (PI) controller are acceleration and deceleration pedal command (0 to 1).

i) Brake subsystem

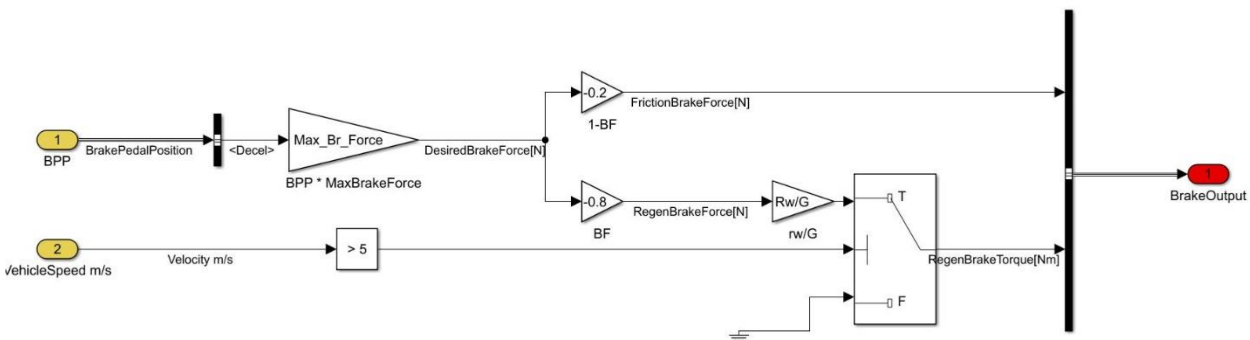

Figure 0.3 Brake Subsystem

ii) Motor

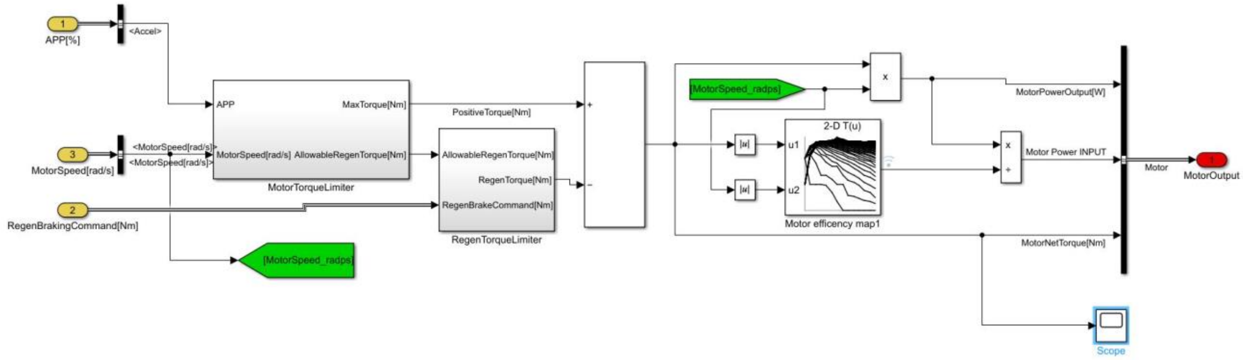

Figure 0.4 Motor Subsystem

Motor Torque Limiter

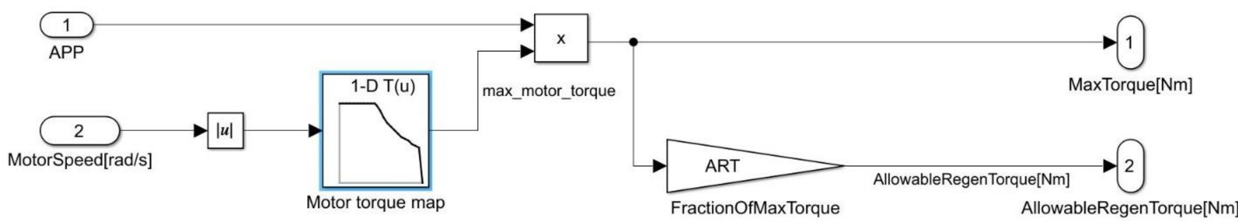

Figure 0.5 Motor Torque Limiter

Regenerative Torque Limiter

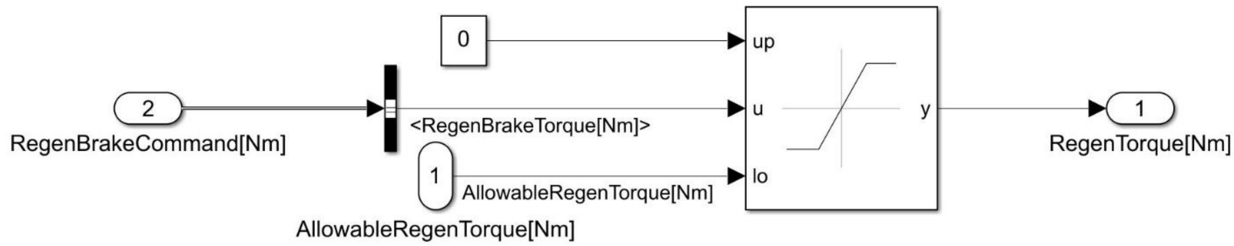

Figure 0.6 Regenerative Torque Limiter

iii) Driveline subsystem

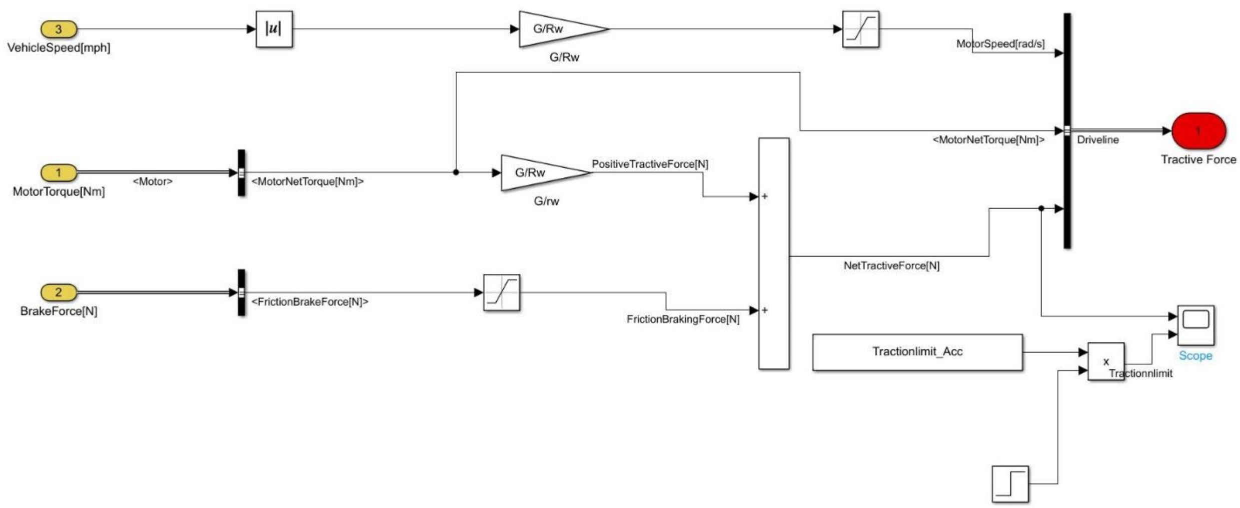

Figure 0.7 Driveline Subsystem

iv) Vehicle Dynamics subsystem

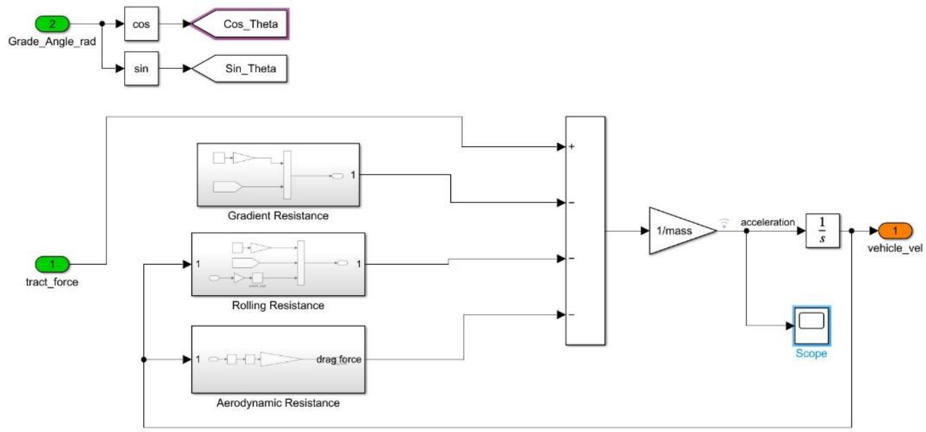

Figure 0.8 Vehicle Dynamics Subsystem

v) Electric Power Generator

Inside this subsystem, engine power map, motor torque map look-up tables, and motor efficiency map are generated from the given parameters from which the electric power generated is taken as output.

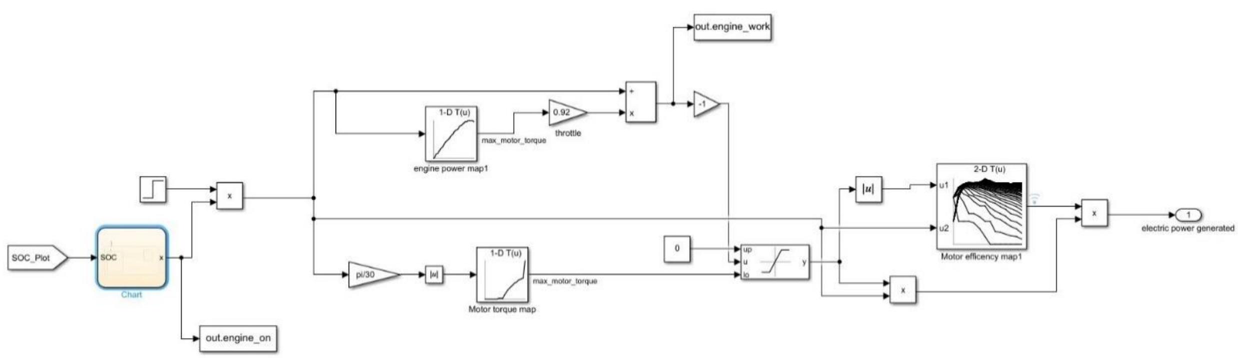

Figure 0.9 Electric Power Generator

1.1.Battery Subsystem

We are considering the motor power consumption and accessory load from which the electric power generation were added and feed into the current calculation subsystem.

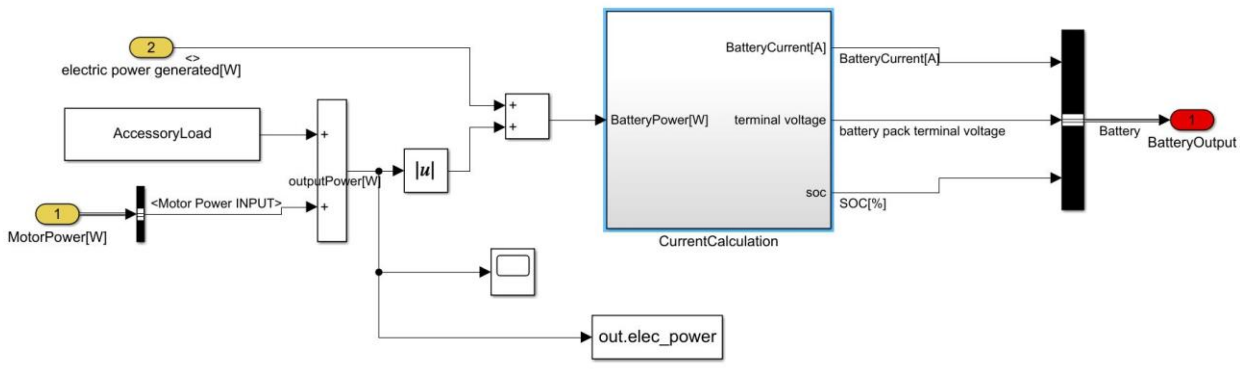

Figure 0.10 Battery Subsystem

<u>Current calculation subsystem</u>

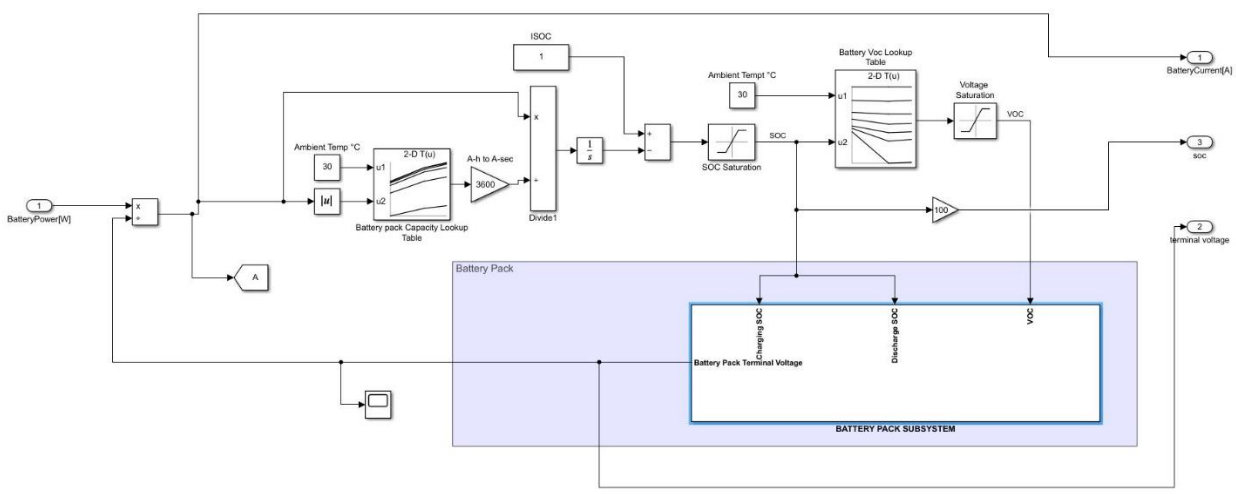

Figure 0.11 Current Calculation subsystem

Battery pack subsystem

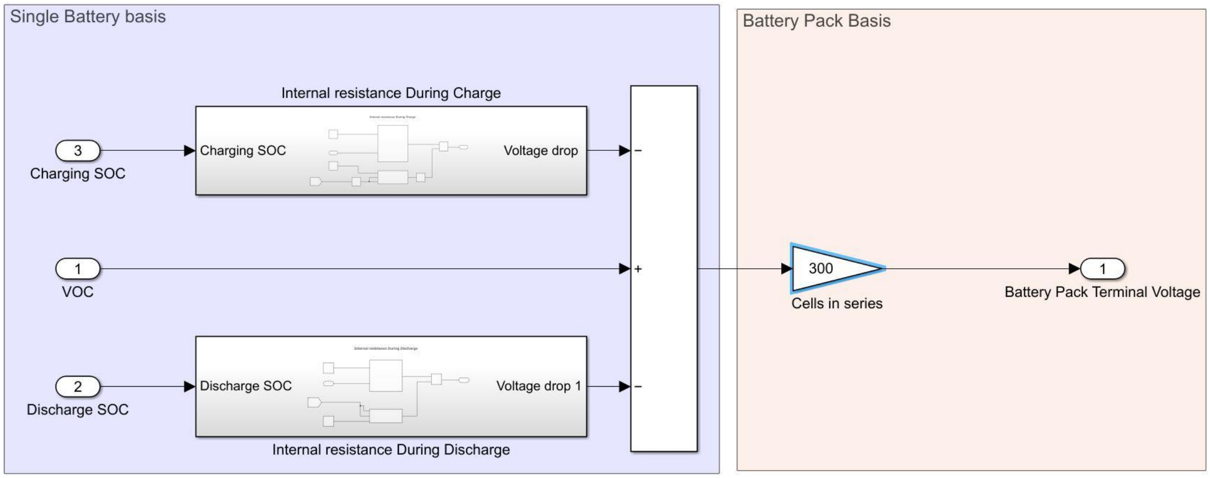

Figure 0.12 Battery pack subsystem

4.4 Control Logic

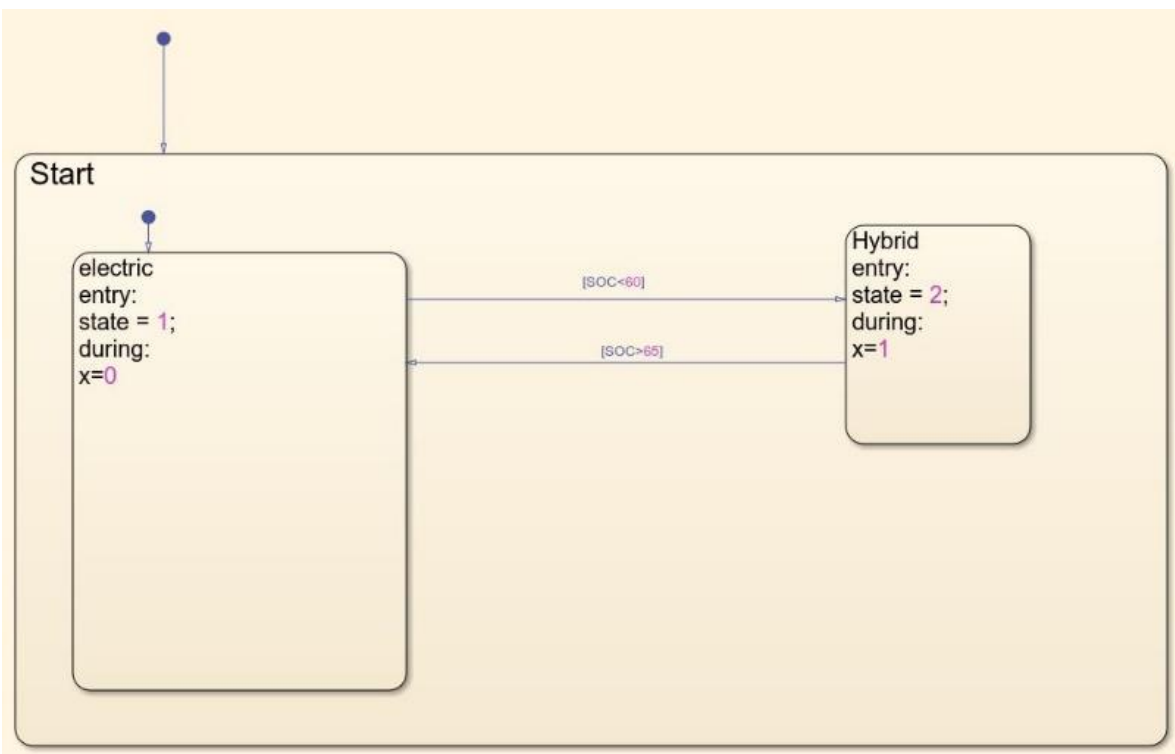

Figure 0.13 State Flow Control Logic

Results and Discussions

The results from the Simulink model are shown below. We have shown the plots of SOC, acceleration, motor torque, power vs time along with vehicle speed and drive cycle.

Vehicle Drive Cycle vs Vehicle Speed:

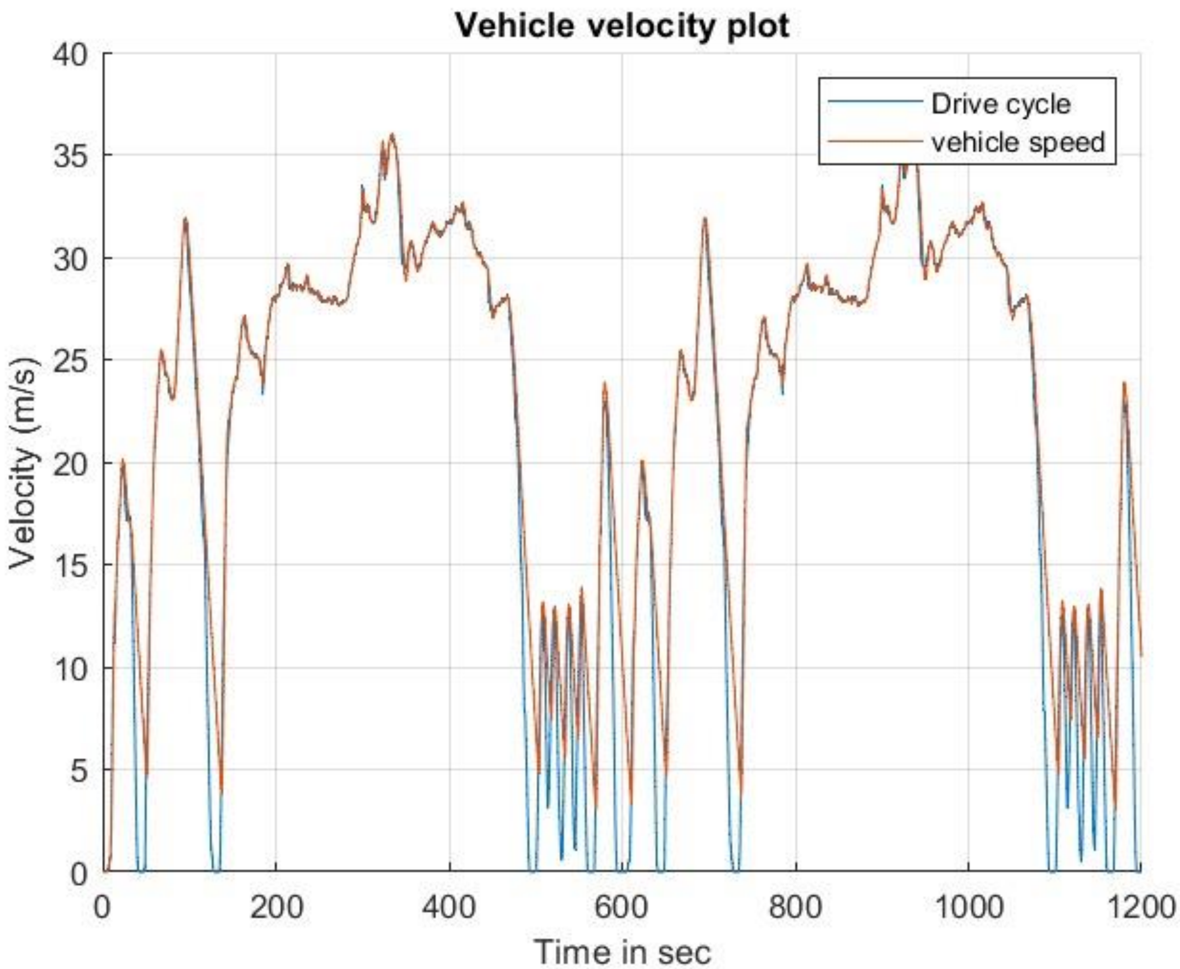

Figure 0.14 Vehicle Speed vs Drive Cycle plot

Acceleration vs Time:

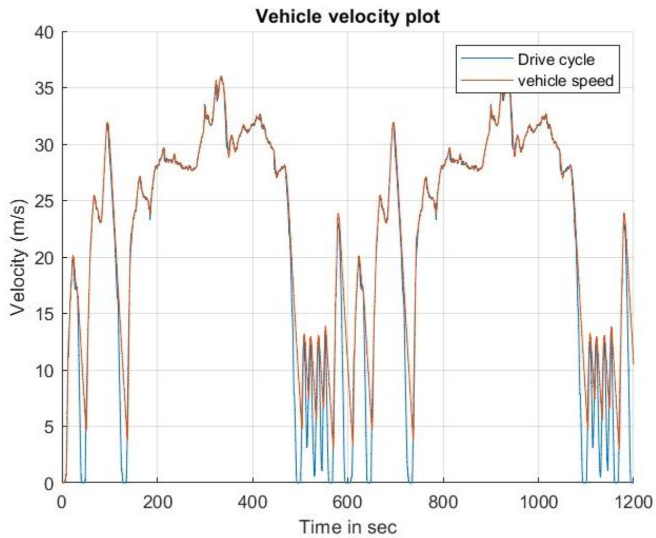

Figure 0.15 Vehicle acceleration vs time

Net Tractive Force, Traction Limit vs Time:

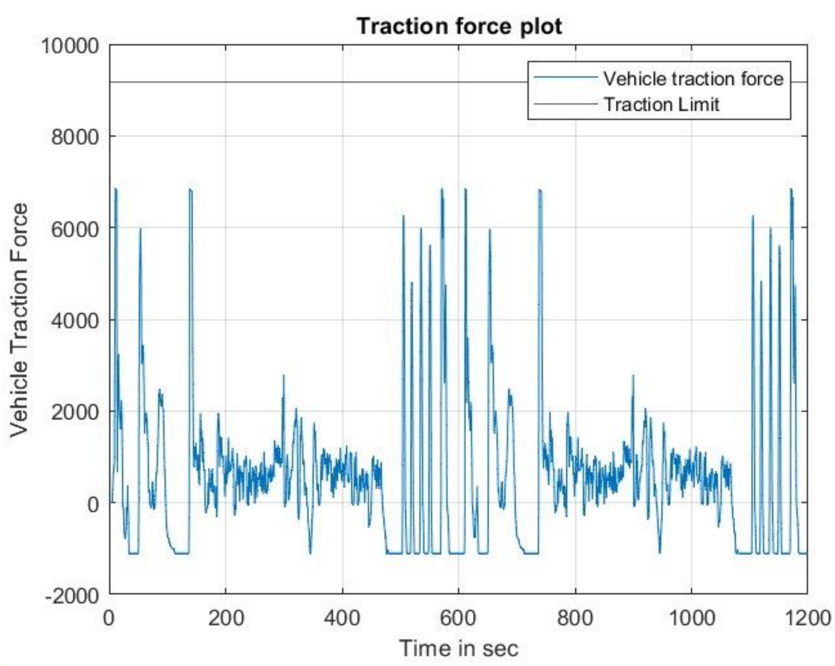

Figure 0.16 Net tractive Force, Traction Limit vs time

Vehicle traction force is below the maximum traction limit. We can see the same nature of the traction force followed by the vehicle in the above plot and the vehicle is not exceeding the maximum traction limit.

Battery SOC vs Time:

The following figure shows the battery SOC for complete EV application (without charging logic with the same Simulink model). Vehicle starts running at 100 % SOC, and after running the vehicle for 1200 seconds (i.e. two complete US06 drive cycle) battery SOC reaches 14 % and it will continue to deplete until it is plugged in for charging.

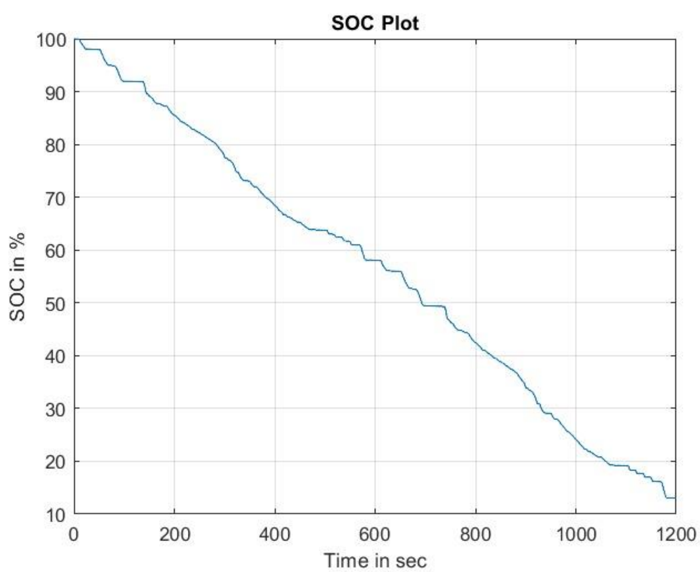

Figure 0.17 Battery SOC vs time without charging

Whereas, in the series application (Simulink model with charging logic) will start the engine as soon the battery SOC reaches 60% and will try to maintain the battery charge between LSL – USL range i.e., 60% - 65%. The following figure shows the illustration graph for the nature of battery SOC throughout the drive cycle.

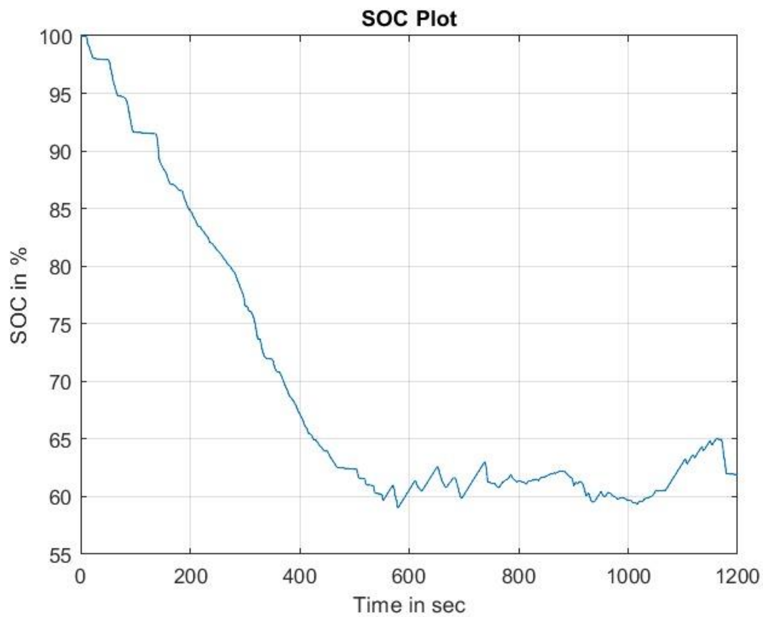

Figure 0.18 Battery SOC vs time with charging

Motor output Power vs Time:

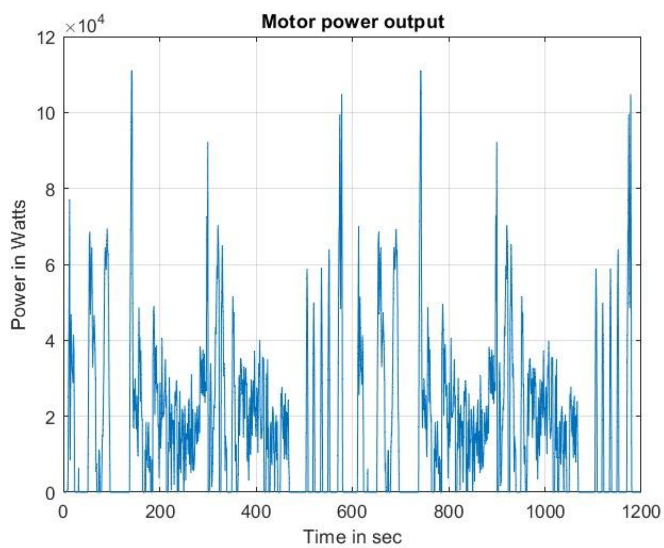

Figure 0.19 Motor Power output vs time

It can be seen from the above plot as per the motor specification motor (110 kW) motor tries to reach its maximum power capacity at some specific region in the drive cycle hence it can be concluded that there are few losses and model is efficient enough to rely.

Motor Torque vs Time:

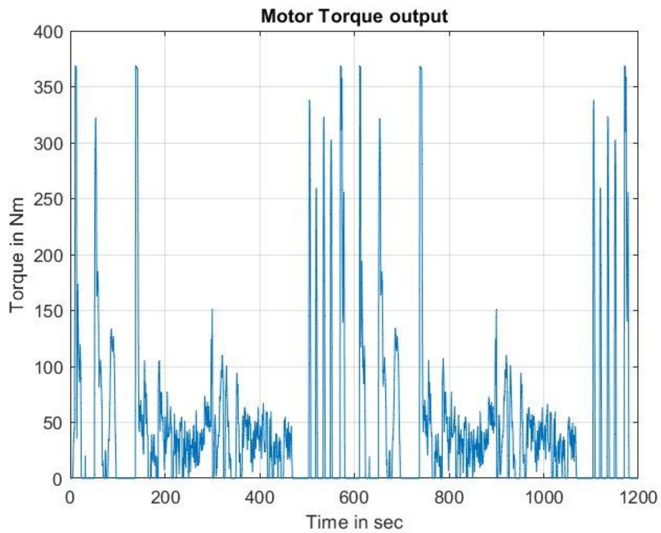

Figure 0.20 Motor torque vs time

In torque vs time plot, we can see that motor produces maximum power output whenever driver demands sudden acceleration at any instant during the complete drive cycle.

Miles per gallon (MPG) calculation

We determined the engine operation time throughout the drive cycle. Here the engine starts at 612.38 seconds and the engine shuts off at 1169.6 seconds.

So, the time difference is 557.22 seconds.

From the live script, we found the fuel flow rate at our operating rpm which is 0.0024523 kg/s.

So, the amount of fuel used throughout the drive cycle is 557.22 * 0.0024523 = 1.416 kg.

Now, the density of gasoline is 730 kg/m^3.

Volume = mass/density = 0.00194 m^3 which is equal to 1.94 liters (the amount of fuel consumed during the drive cycle) = 1.94 * 0.2641 = 0.512 gallons.

The fuel economy for the 0.512 * 16 = 31.25 miles/ gallon

We found the energy consumed by the motor during the drive cycle = Area under electric motor torque demand over drive cycle time

which is equal to 21312497 W-s.
Now, converting it to kWh it comes out to be 5.9 kWh.

This is the energy consumed by the electric motor during drive cycle.

According to Environmental Protection Agency (EPA), 1 gallon of gasoline is equal to 33 kWh of electricity. So, the amount of gasoline equivalence 5.9/ 33 = 0.175 gallons

The total length of the drive cycle is 16 miles.

Miles Per Gallon Equivalent = 16/ 0.175 = 91 MPGe.

The original 2022 MINI Cooper SE Countryman AII4 has electrical equivalence of mileage equal to 73 MPGe and 29 MPG for engine.

Percent difference between electric equivalence of our model and MINI cooper = 106 -102/106 = 3.77 %

Conclusions and Future Scopes

Developing an efficient vehicle powertrain model to meet the market demand and objectives of the product for its application is a difficult task. To start with the hybrid-EV powertrain modeling project we conducted brief market research on the average customer requirements. It is found that application for vehicles with efficient powertrain design is required for the urban driving. Considering the US06 drive cycle to simulate the powertrain model developed by the team to replicate the average urban driving conditions.

Vehicle architecture selection was one of the most difficult tasks of the project, but after finalizing the application it was clear that series hybrid architecture for hybrid EV application is best suited as urban driving conditions consists with multiple stop and start conditions. Whereas, engine working in the best BSFC area only charges the battery rather than driving the complete vehicle and the vehicle itself is driven by electric motor hence no such direct load conditions are applied on the engine. This advantage helped us leverage the design of powertrain model and improve the vehicle MPGe by 24.65 % and MPG by 7.75 % compared to vehicle with the similar powertrain configuration (Mini Cooper SE Countryman).

Finally, having a series hybrid architecture helped the vehicle to maintain the battery SOC within 60% - 65% which will reduce the range discharge-charge fluctuations during operation resulting increase in vehicle battery life. Additionally, as per the customer demand for willingness to pay for a hybrid vehicle for urban use is also satisfied with the vehicle having competitive overall cost with better efficiency and run for a longer range.

Future Scope

Further development of the model for high-speed long-distance application by integrating engine for series-parallel system. Which will help customers who are targeting for a good family vehicle which can be used effectively in the urban as well as long distance applications.

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