PROJECT 1 REPORT

HYBRID ELECTRIC VEHICLES

NAME RAKESH BALACHANDRA

PUID 0030140356

ABSTRACT

In this project, the analysis of the performance of a mild parallel hybrid gas/electric vehicle is performed. In this vehicle, an electric machine is used to propel the vehicle at low speeds with the main engine disengaged. The electric machine boosts the motor to provide high-speed accelerating characteristics. This permits the use of a smaller internal combustion engine without sacrificing overall performance.

In order to analyze the vehicle performance the Simulink model of the parallel hybrid electric vehicle is developed. The input is provided in the form of two drive cycles where one accounts for city driving and the other for highway driving. The different parameters of the vehicle are set for the operation.

INTRODUCTION

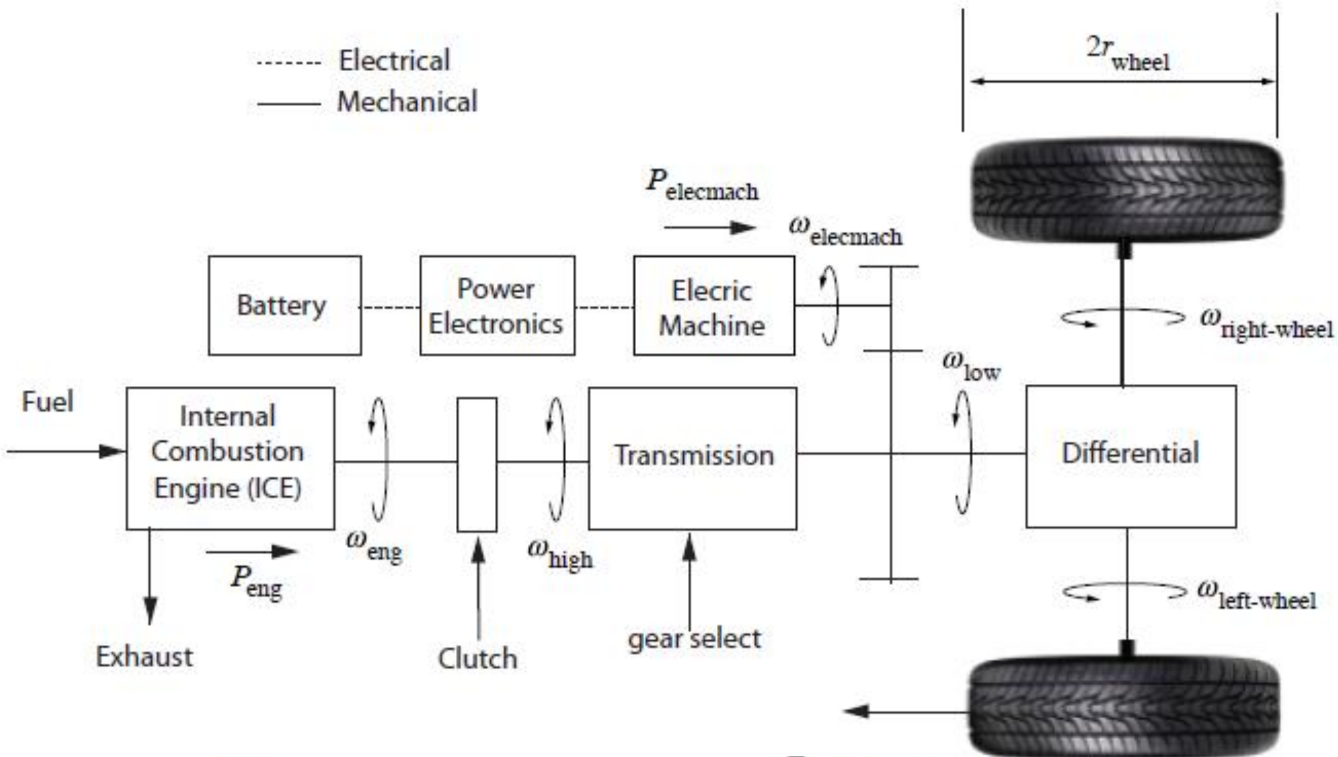
A hybrid electric vehicle is a type of hybrid vehicle and electric vehicle that combines a conventional internal combustion engine system with an electric machine system. The presence of the electric machine system is intended to achieve better fuel economy and lesser carbon dioxide emission than a conventional vehicle. There are two main types of hybrid vehicles 1. Series hybrid vehicle and 2. Parallel hybrid vehicle.

A series hybrid vehicle can receive power only through the electric motor which is run by a battery. But in the case of parallel hybrid electric vehicles the power can be simultaneously provided by both the motor and the internal combustion engine. Thus, a parallel hybrid vehicle can provide more power as compared to a series hybrid electrical.

The basic architecture of the mild hybrid vehicle to be simulated in the project is given below. It mainly contains four parts.

1. Internal combustion engine
2. Transmission system
3. Electric machine system
4. Differential system

The engine and the electric machine modules act as the power sources to the vehicle. The transmission couples the differential module and the internal combustion engine. The clutch connects the engine and the transmission module and disengages the engine when not required. The differential is responsible for the wheel and vehicle speed calculation.



$$\omega_{low} = G_{trans}\omega_{high}$$

$$\omega_{right\text{-}wheel} = \omega_{left\text{-}wheel} = \omega_{wheel} = G_{diff}\omega_{low}$$

$$v_{veh} = r_{wheel}\omega_{wheel}$$

$$\omega_{low} = G_{elecmach}\omega_{elecmach}$$

VEHICLE ARCHITECTURE

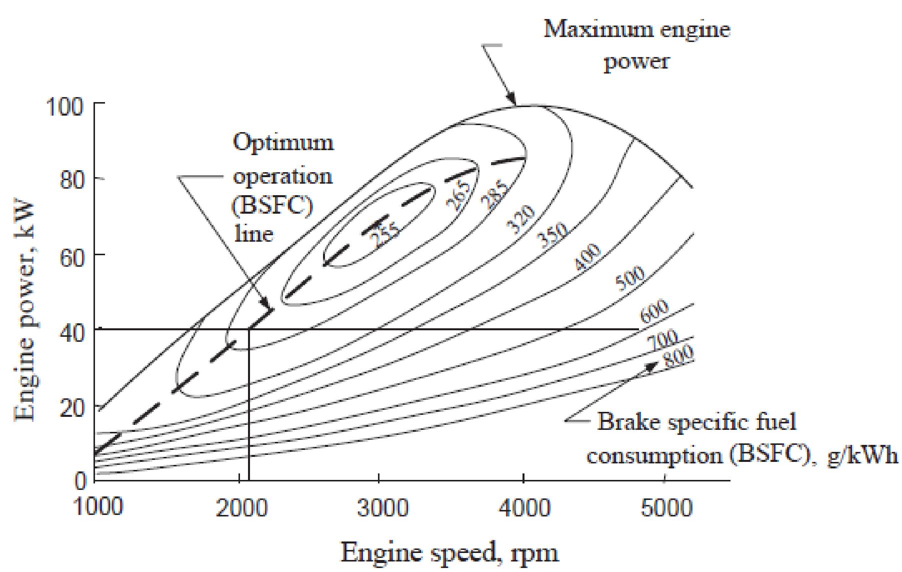
PARAMETERS

Since the various properties determine the performance of the vehicle individually, they are selected beforehand. The main vehicle parameters is given by the following table

Parameter	Symbol	Value
vehicle mass w/o battery, passengers, or driver	M_{veh}	1746 kg
wheel radius	r_{wheel}	0.2794 m
electric machine gear ratio	G_{elecmach}	1
transmission gear ratio (low)	$G_{\mathrm{trans,min}}$	0.3
transmission gear ratio (high)	$G_{\mathrm{trans,max}}$	TBD
differential gear ratio	G_{diff}	0.25
rolling resistance coefficient	C_0	0.015
aerodynamic drag coefficient	C_D	0.35
frontal area	A_F	1.93 m^2
battery capacity in kW-hr	E_{batt}	TBD
battery-and-power-electronics round-trip efficiency	η_{batt}	0.7
minimum engine power	$P_{\mathrm{eng,min}}$	10 kW
maximum engine power	$P_{\mathrm{eng,max}}$	80 kW
initial SOC	$\mathrm{SOC}_{\mathrm{init}}$	0.5
density of gasoline		0.75 kg/liter

BSFC CURVE

The engine of the vehicle is operated along its optimum brake specific fuel consumption (BSFC) characteristic graph. If the vehicle runs based on the BSFC curve then it is having optimal fuel efficiency. The curve is given shown by the figure below.



ENGINE MAP TABLE

The BSFC curve is quantified by the engine map table. It gives the corresponding values of the speed, power and fuel consumed. It is used to the engine speed, total fuel consumption and the mileage of the drive cycles.

Speed (rpm)	Power (kW)	BSFC (g/kW-hr)
1009.3	7.66423	500
1183.18	12.7737	400
1588.89	24.635	320
1936.6	35.7664	285
2318.13	47.6277	265
2612.71	57.2993	255
3371.09	77.7372	255
3685.23	82.8467	265
4014	85.5839	285
4333.26	84.854	310
4657.51	81.0219	350
4919.09	72.8102	410
5108.24	62.0438	500

POWER MANAGEMENT STRATERGY

Given the required net tractive power, the power manager determines how much of the required power is to be supplied by the engine. The remainder is to be supplied by the electric machine. The strategy is to maintain an average SOC of 0.5. That is, the battery is used to provide boost power only in times needed, as opposed to providing a second power source to extend the vehicle range. Other operating strategies/constraints are listed below.

1. If the tractive power is less than minimum engine power (10 kW), the engine is disengaged (Peng = 0) and that a positive tractive power is supplied by the electric machine (making it a motor) while a negative tractive power means that power is supplied to the electric machine (making it a generator). The latter case is known as regenerative braking.

2. If tractive power is greater than maximum engine power (80 kW), assume engine power is equal to the maximum engine power and that electric machine power is the difference between tractive power and maximum engine power

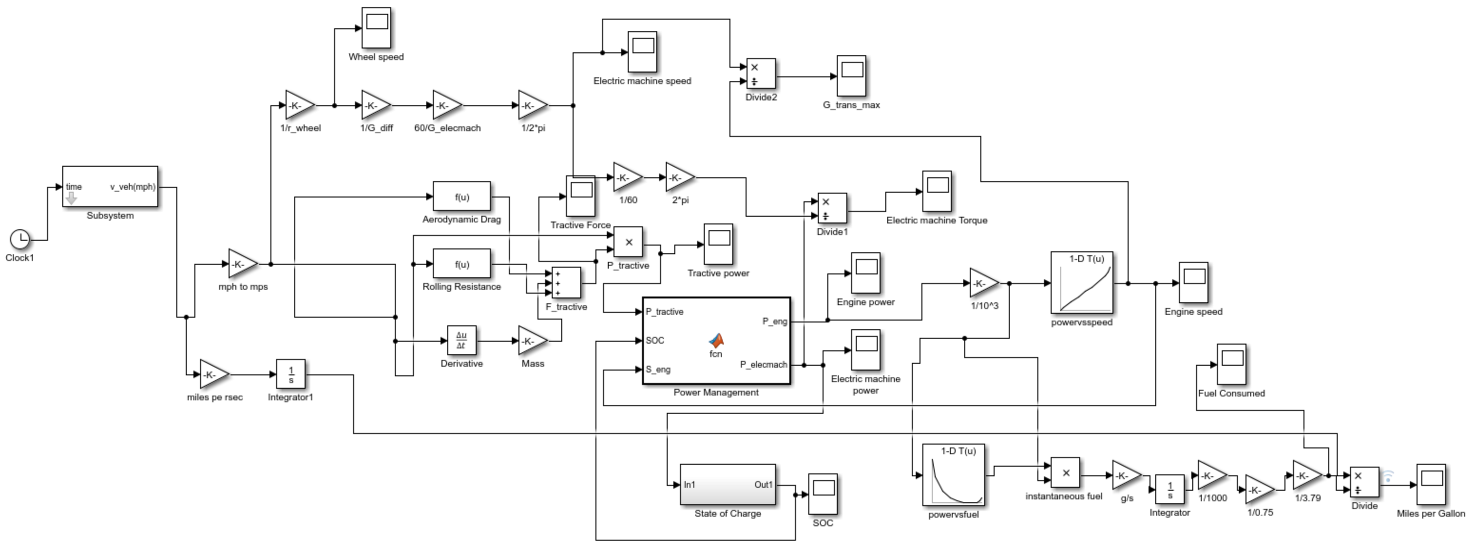
3. The engine is assumed disengaged (Peng = 0) if its speed is below minimum. This occurs at low vehicle speeds and the transmission operating at its lowest gear ratio.

4. Whenever the engine is engaged, its speed is assumed to be on the optimum BSFC line for the calculated power level.

5. Whenever tractive power lies between maximum and minimum engine powers, the excess engine capacity is used to recharge the battery. Initially, we will try electric machine power = − (maximum engine power – tractive power) *(0.5 – State of Charge) and engine power = tractive power – electric machine power.

SIMULINK MODEL

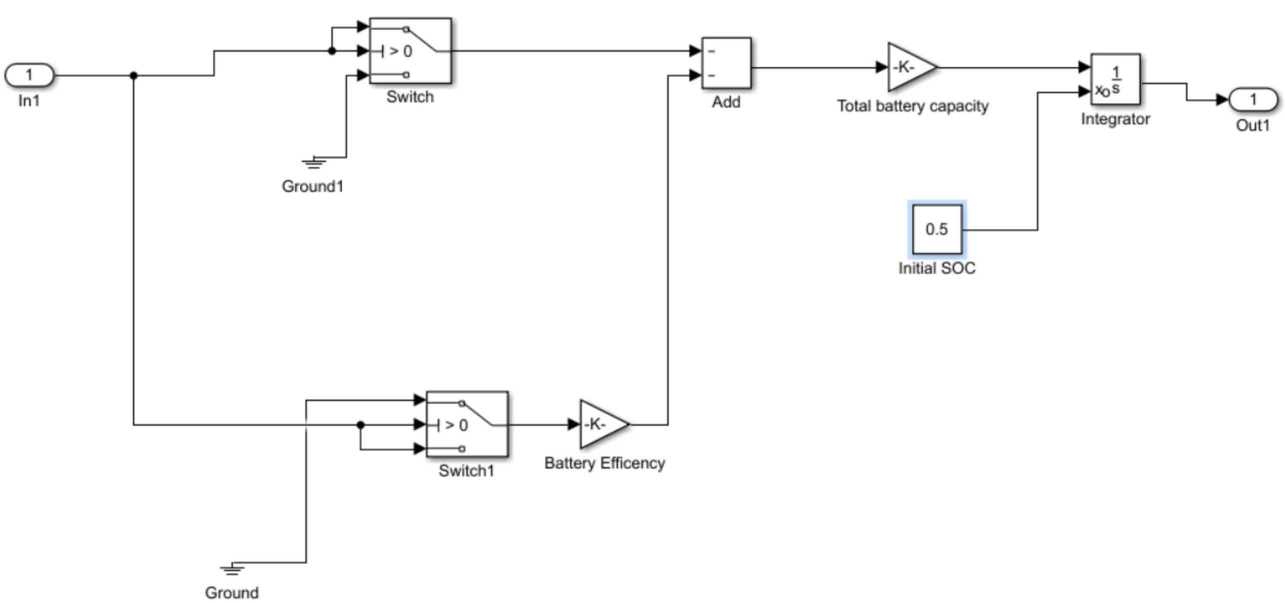
The vehicle performance is simulated in MATLAB Simulink by building its model and testing its various functions. The architecture of the vehicle is represented using the Simulink model as shown below



STATE OF CHARGE SUBSYSTEM

The input to the block is the power of the electric machine and the output is the state of charge. The battery used here has a total capacity of 1 kilo watt hour (kWh) and it weighs 21.73 kg as the gravimetric energy density is 46Wh/kg. Thus the total weight of the car including the mass of the driver and the battery is summed up to 1846 kg. The subsystem for calculation of state of charge is given below.

The state of charge is found out by dividing the electric machine power by the total battery capacity and is integrated over time. The constant is 0.5 which is the initial state of charge.



HIGHWAY AND CITY DRIVE CYCLES

The highway drive cycle HWFET and the city drive cycle NYCC are provided as the inputs to the Simulink model of the vehicle. Different variables of the vehicle are plotted and calculated. The drive cycles are repeated 7 times to get stable values for state of charge, total fuel consumption and the mileage of the vehicle. The time duration for 7 cycles roughly amounts to 5000 seconds. The rest of the parameters are calculated for only 1 drive cycle which is equal to 760 seconds.

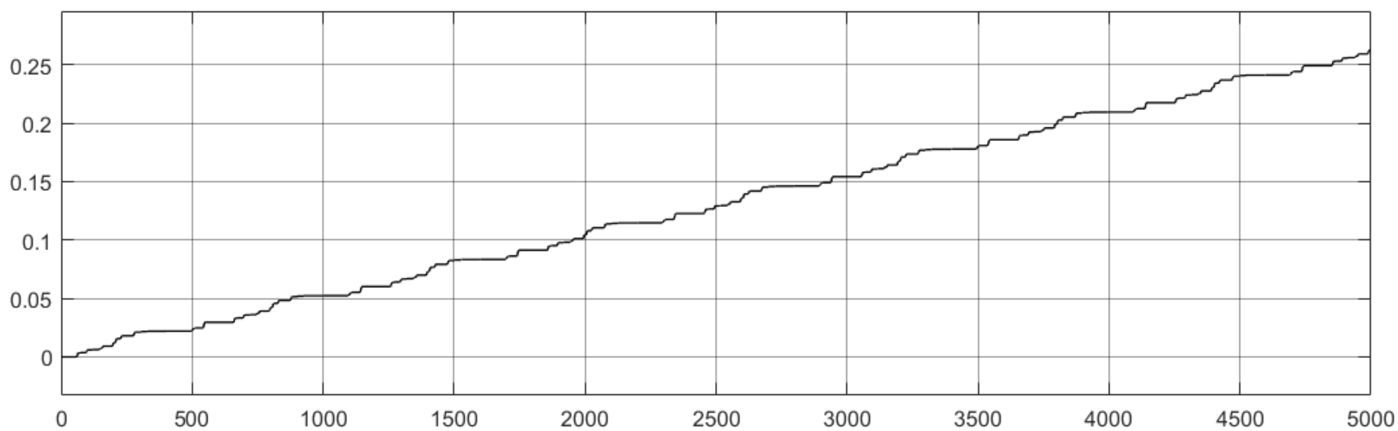
RESULTS

The graphical representations of the required vehicle parameters is presented in this section. The parameters are plotted on the Y axis in their respective units with respect to time in seconds in X axis

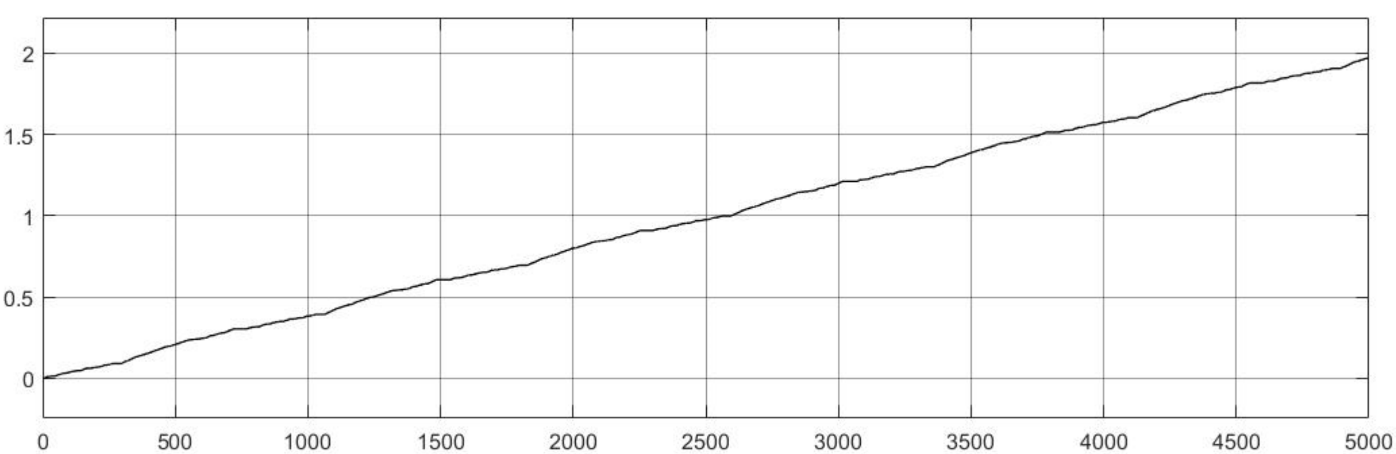
FUEL CONSUMPTION

The fuel consumption gives the total amount of fuel consumed over the entire drive cycle in gallons. The instantaneous fuel is integrated to provide the total fuel consumed. The average miles per gallon is the ratio between total distance travelled and the total fuel consumed. It is calculated in miles per gallons.

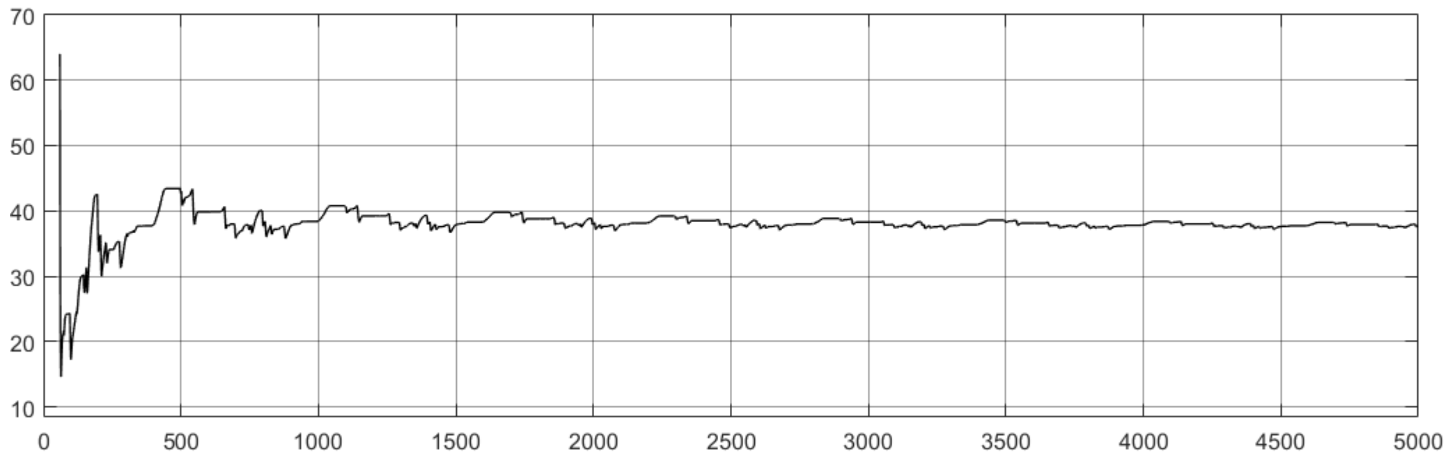
The total fuel consumed and average miles per gallon are graphically presented for both the drive cycles below. The total fuel consumption is 1.973 gallons and the mileage 33.76 mpg for the highway drive cycle. The total fuel consumption is 0.2628 gallons and the mileage 37.61 mpg for the highway drive cycle.



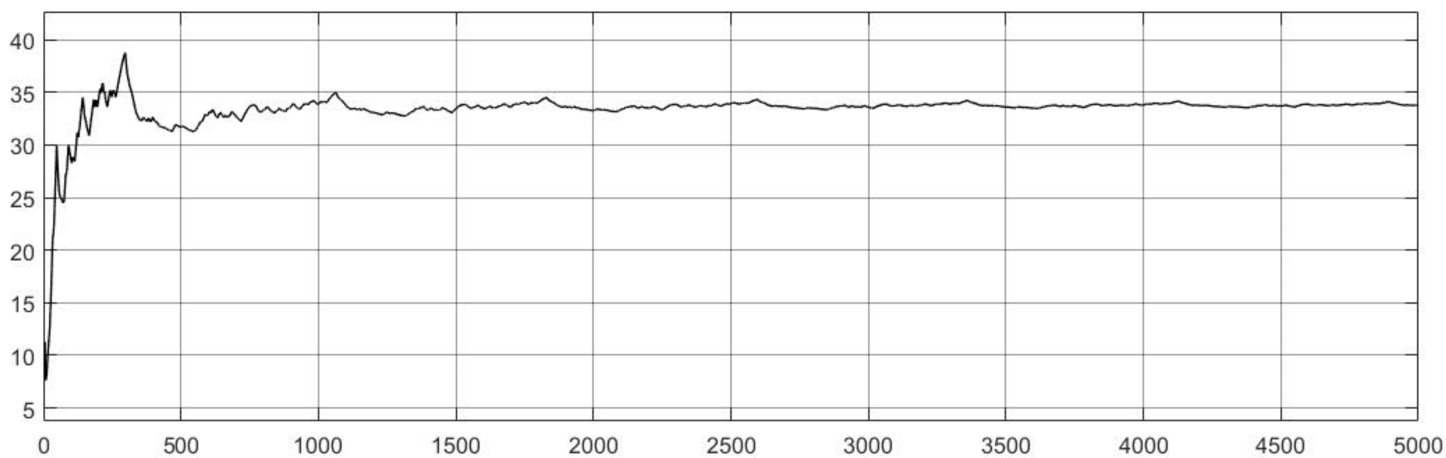
FUEL CONSUMED IN GALLONS VS TIME IN SECONDS (CITY)



FUEL CONSUMED IN GALLONS VS TIME IN SECONDS (HIGHWAY)



MILEAGE IN MILES PER GALLON VS TIME IN SECONDS (CITY)

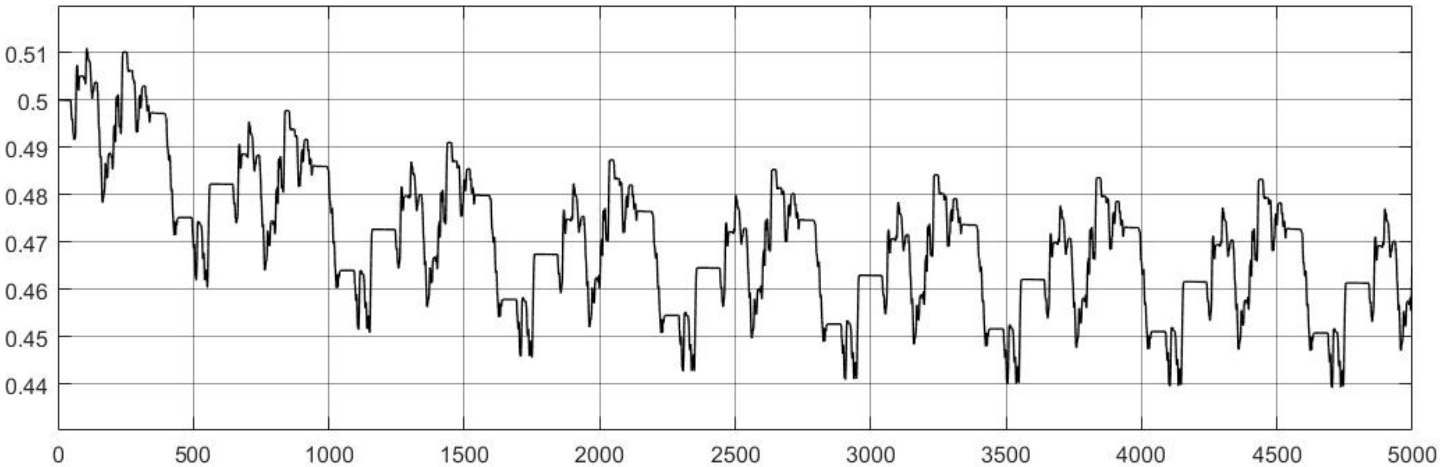


MILEAGE IN MILES PER GALLON VS TIME IN SECONDS (HIGHWAY)

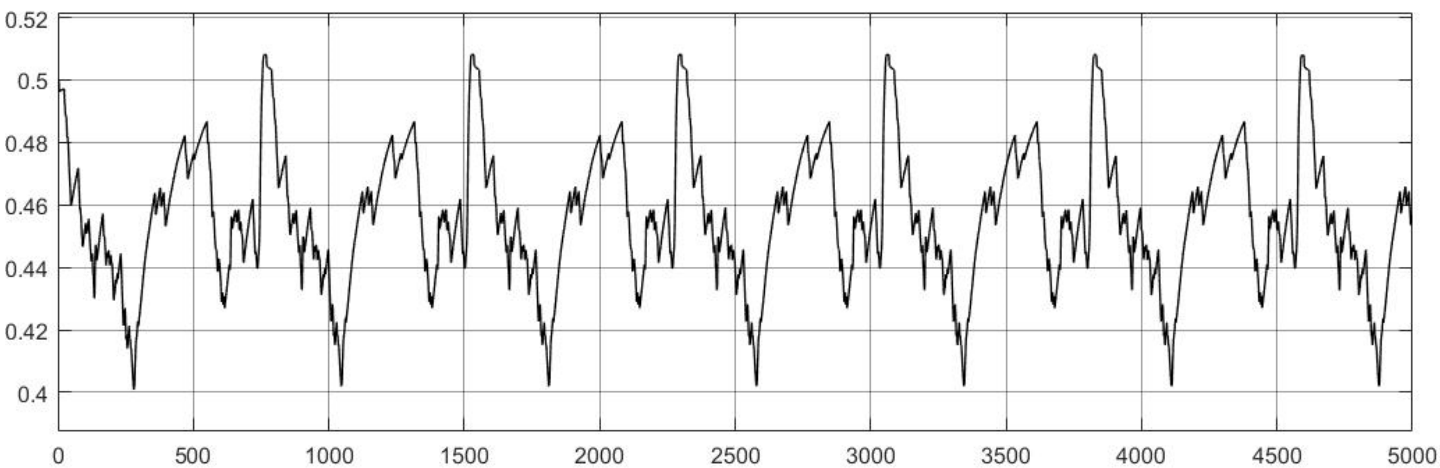
The mileage in the city drive cycle is higher than that of the highway indicating that the performance of the vehicle is more efficient in the city as compared to the highway. This is primarily due to the more number of start/stop activities in the city drive cycle during which the engine remains shut down. The total fuel consumption is more in the highway drive cycle as it is longer as compared to the city drive cycle.

STATE OF CHARGE

State of charge can be defined ratio between the available battery capacity and the total rated battery capacity. In the parallel hybrid vehicle, it is advised to keep the state of charge between 0.2 and 0.8. The ideal value state of charge is 0.5. The graphical depiction of state of charge for both the drive cycles is presented below. The final value of the state of charge at the end of the city drive cycle is 0.465 and for the highway drive cycle is 0.457.



SOC VS TIME IN SECONDS (CITY)



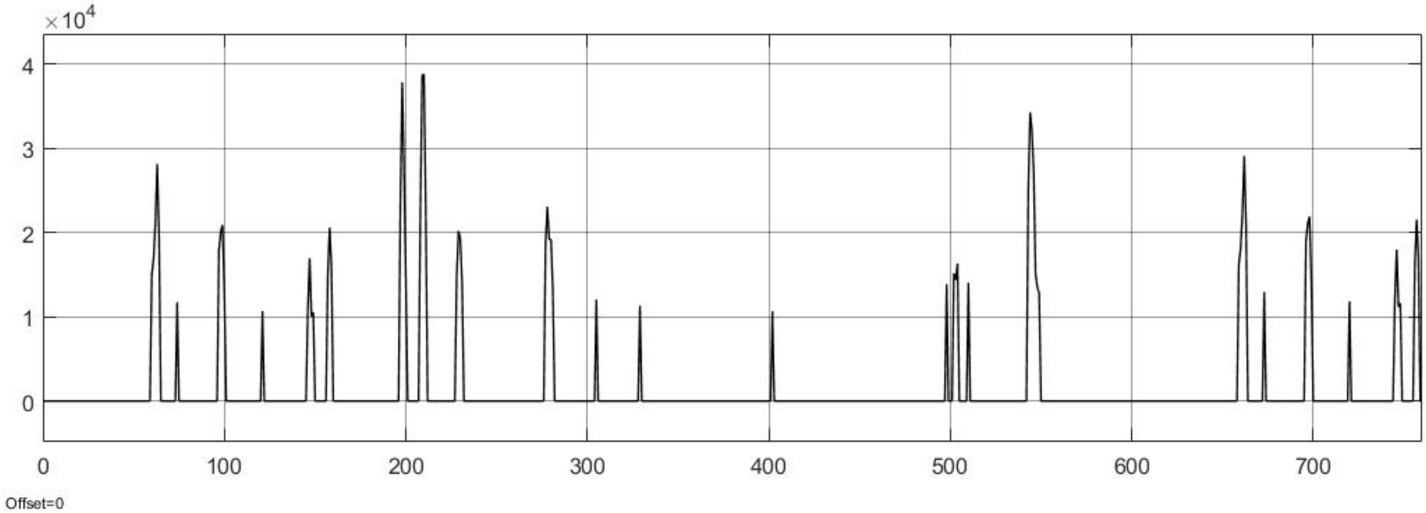
SOC VS TIME IN SECONDS (HIGHWAY)

In both the drive cycles the state of charge falls with the desired range of 0.2 to 0.8 and stabilizes close to the 0.5 ideal mark.

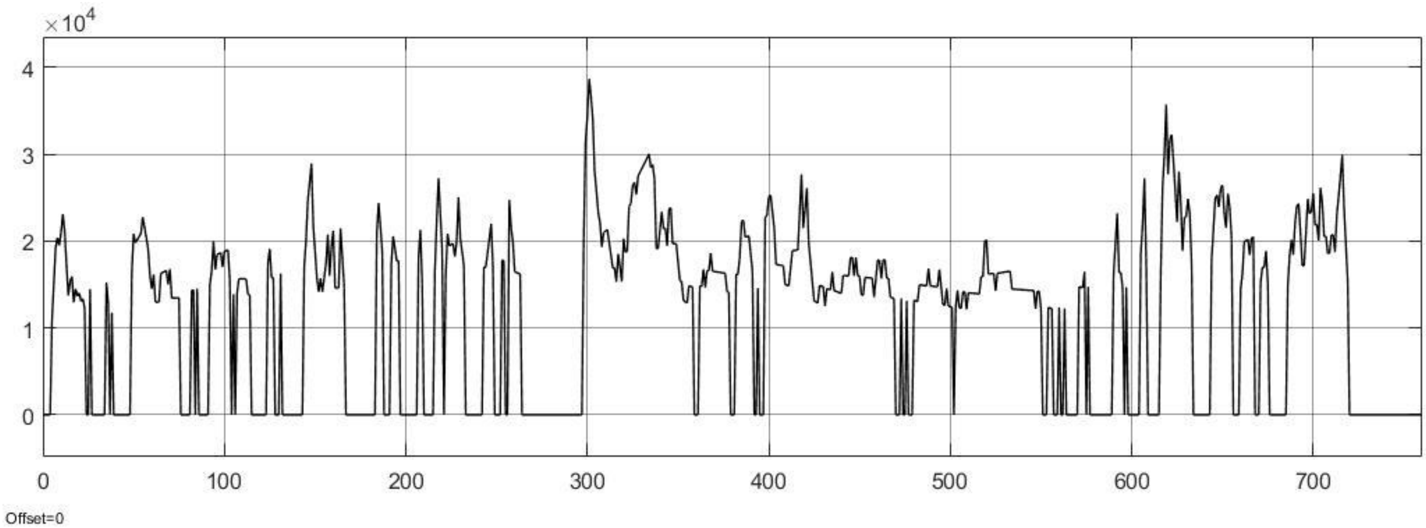
ENGINE POWER

The total power given out by the engine is defined as the engine power. It is determined using the rules followed in the power management strategy and is calculated in kilo watts.

The graphical representation of the engine power for both the drive cycles is given below.



ENGINE POWER IN KILO WATTS VS TIMEIN SECONDS (CITY)



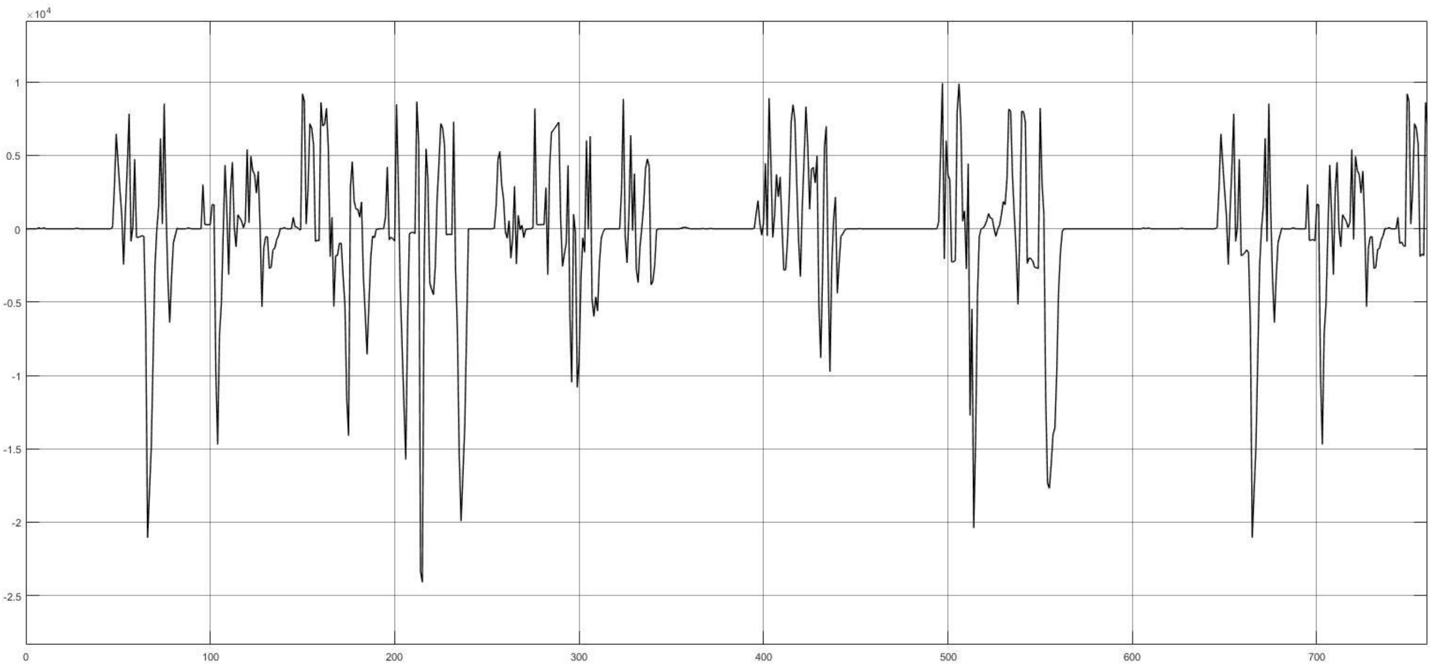
ENGINE POWER IN KILO WATTS VS TIME IN SECONDS (HIGHWAY)

The peak engine power in both the drive cycles is close to 40kW. The engine power required is more in the highway drive cycle sue to higher speed requirements as compared to the city drive cycle.

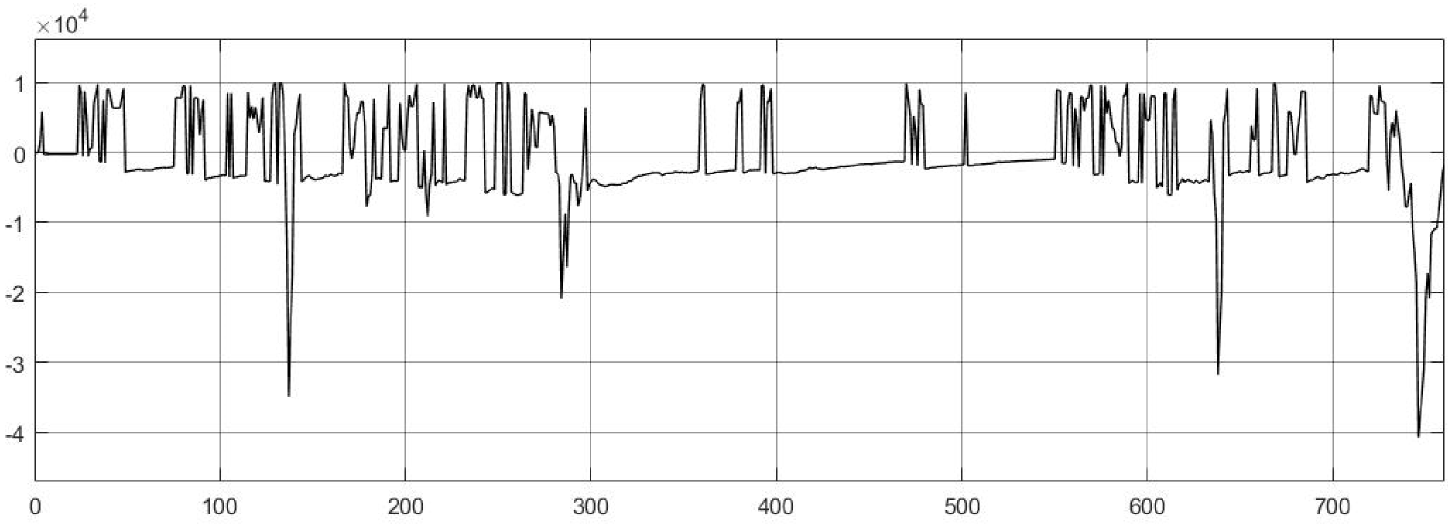
ELECTRIC MACHINE POWER

The total power given out by the electric motor is defined as the electric machine power. It is determined using the rules followed in the power management strategy and is calculated in kilo watts.

The graphical representation of the electric machine power for both the drive cycles is given below.



ELECTRIC MACHINE POWER IN KILOWATTS VS TIME IN SECONDS (CITY)

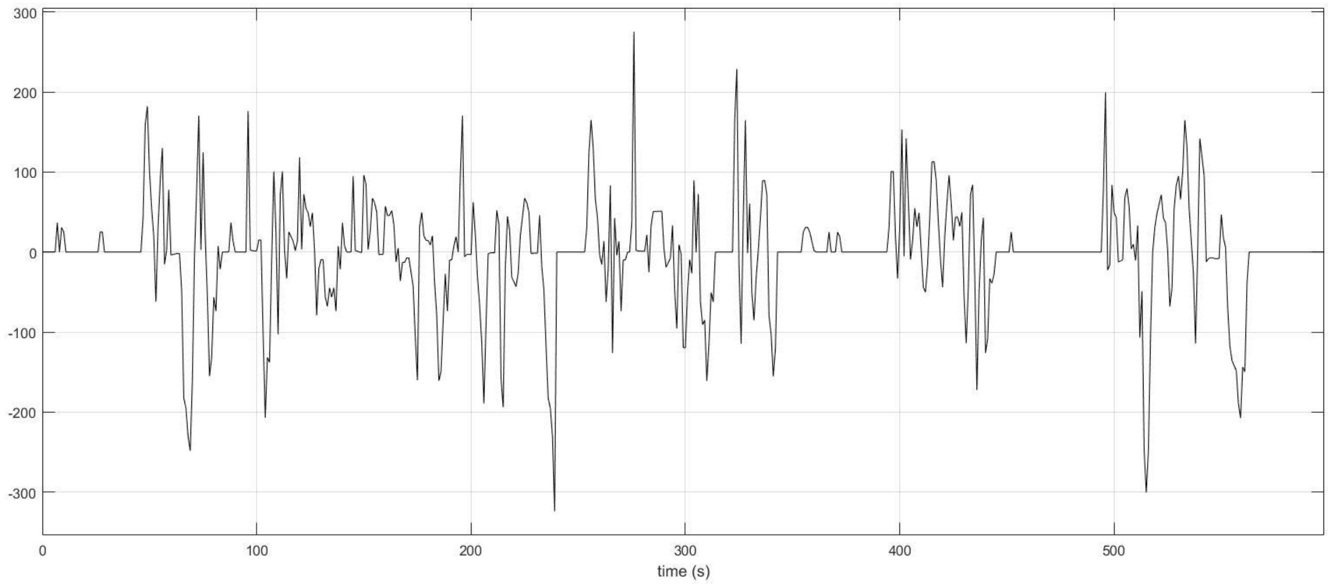


ELECTRIC MACHINE POWER IN KILOWATTS VS TIME IN SECONDS (HIGHWAY)

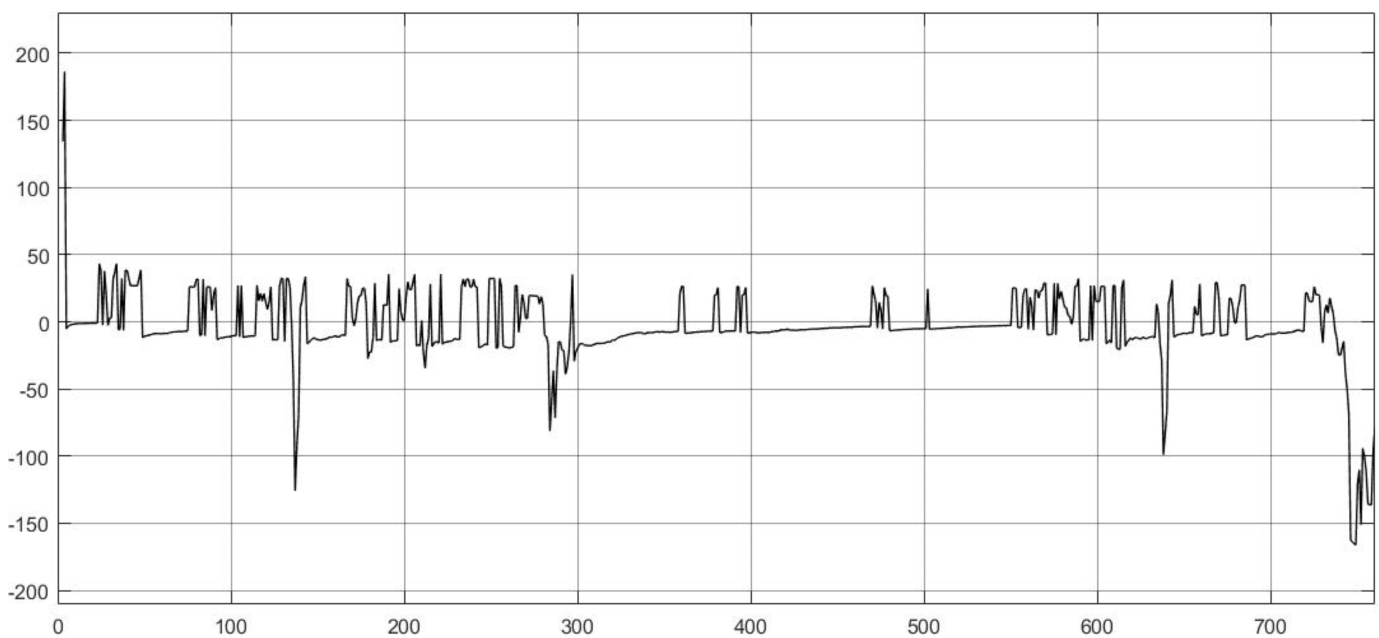
The electric machine power is used during the starting and stopping of the vehicle due to which the hybrid vehicle has a better performance efficiency in the city drive cycle as compared to the highway drive cycle.

ELECTRIC MACHINE TORQUE

Electric machine torque can be calculated by dividing the electric machine power by the electric machine speed. It is calculated in Newton meter (N-m).



ELECTRICAL MACHINE TORQUE IN NEWTON METER VS TIME IN SECONDS (CITY)



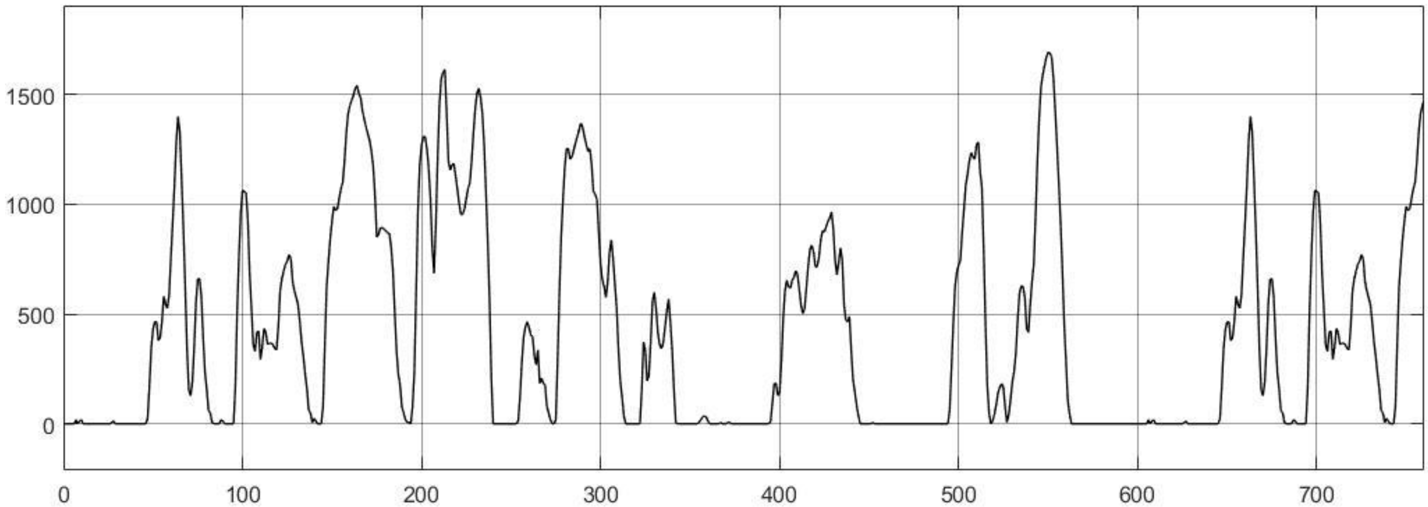
ELECTRICAL MACHINE TORQUE IN NEWTON METER VS TIME IN SECONDS (HIGHWAY)

The electric machine torque is higher in the city drive cycle and reaches a peak value of 280 N-m as compared to the 180 N-m in the highway drive cycle. This is because the vehicle runs at lower speeds in the city.

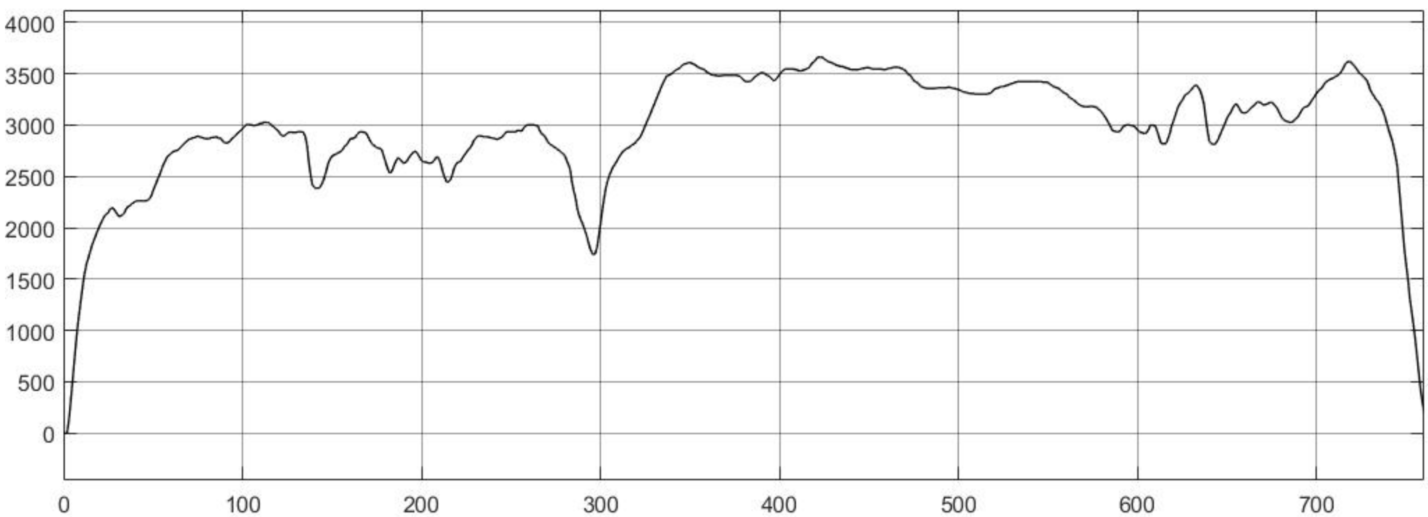
ELECTRIC MACHINE SPEED

The speed at which the electric motor operates is defined as the electric machine speed. It is calculated by dividing the wheel speed by the electric machine gear ratio. It is calculated in revolutions per minute rpm.

The graphical representation of the electric machine speed for both the drive cycles is given below.



ELECTRIC MACHINE SPEED IN RPM VS TIME IN SECONDS (CITY)



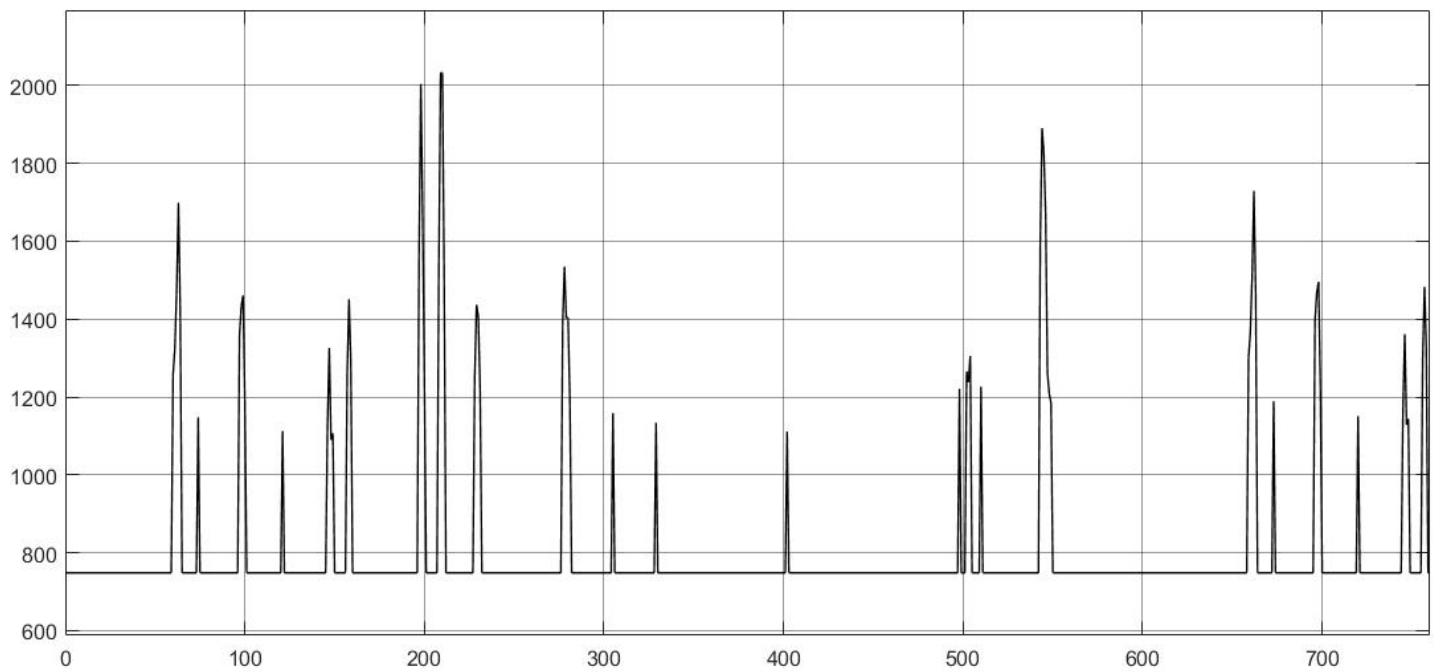
ELECTRIC MACHINE SPEED IN RPM VS TIME IN SECONDS (HIGHWAY)

As there are high speed requirements in the highway drive cycle the electric machine speed is bigger and has a peak value of 3500 rpm in the highway as compared to 1550 rpm in the city.

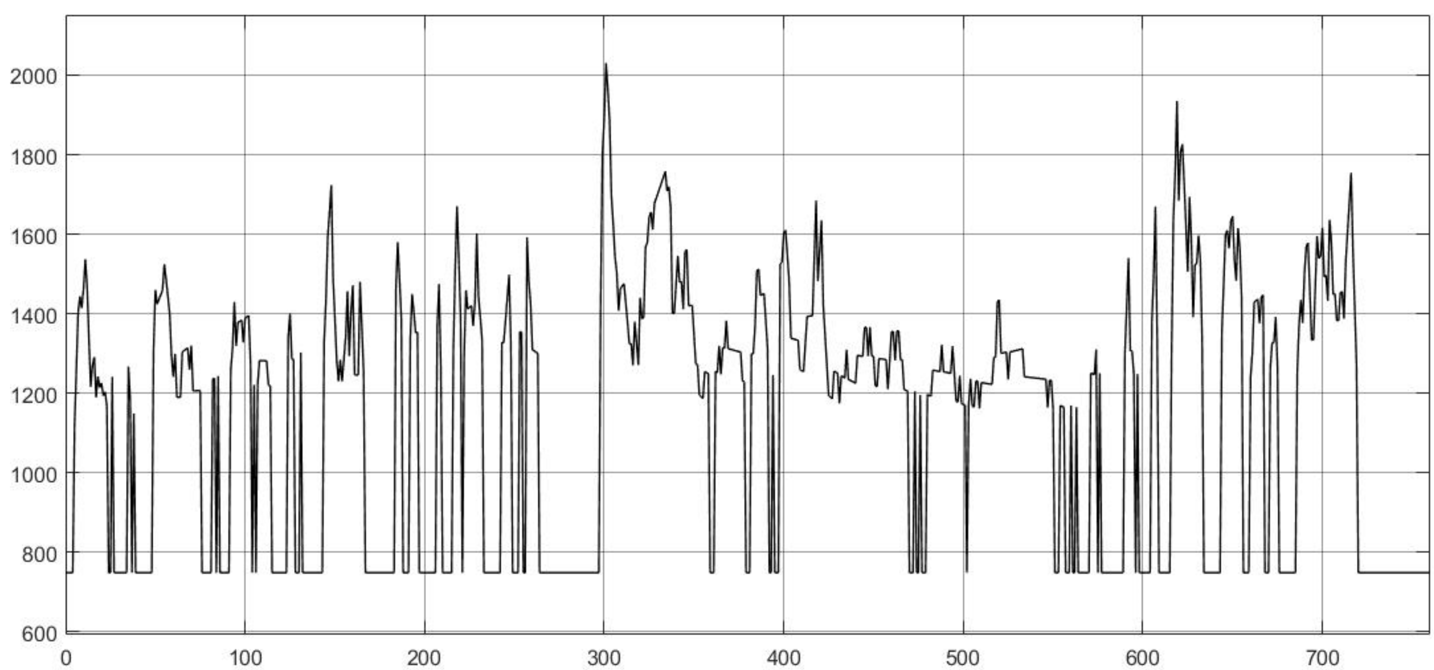
ENGINE SPEED

The speed at which the engine operates is defined as the engine speed. It is calculated through the values present in the BSFC curve. It is calculated in revolutions per minute rpm.

The graphical representation of the electric machine speed for both the drive cycles is given below.



ENGINE SPEED IN RPM VS TIME IN SECONDS (CITY)



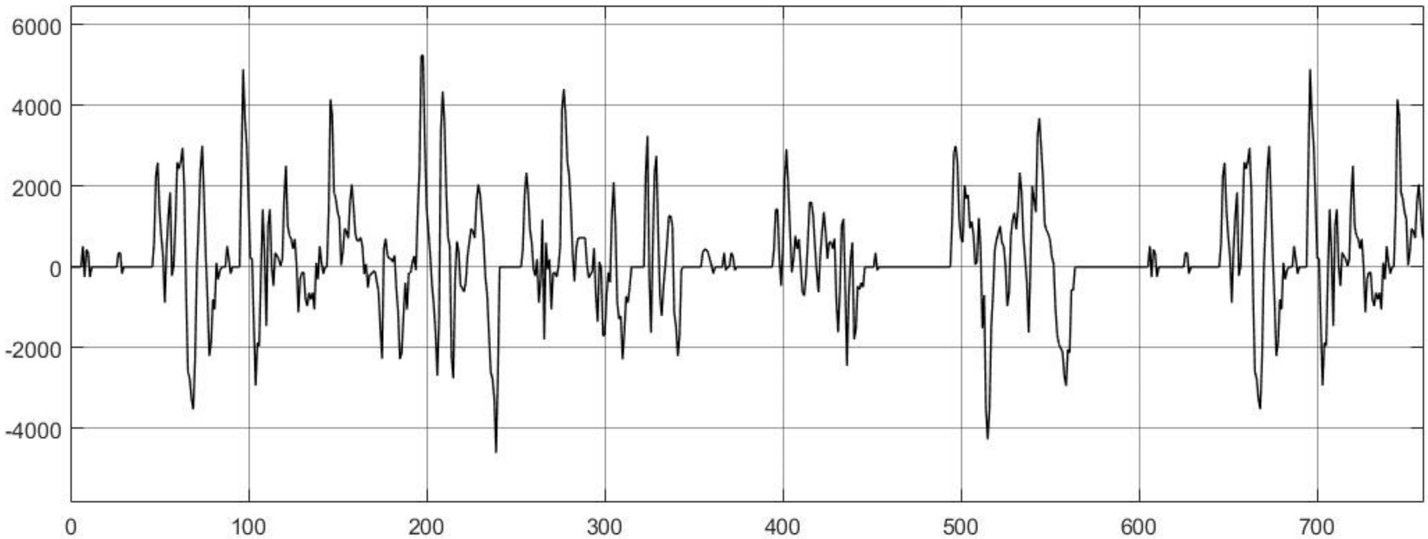
ENGINE SPEED IN RPM VS TIME IN SECONDS (HIGHWAY)

The peak values of the engine speed are nearly similar for both cycles and are around 2000 rpm.

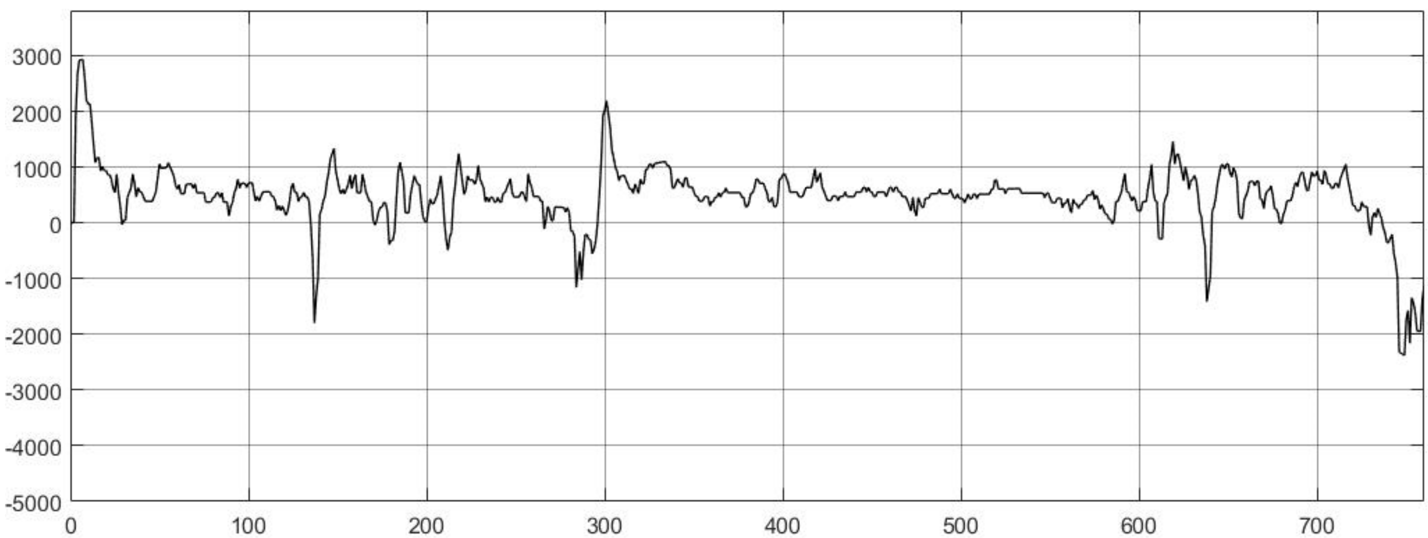
TRACTIVE FORCE

The tractive force can be calculated by adding the aerodynamic drag force, rolling resistance force and the force of acceleration. It is calculated in newtons N.

The graphical representation of the tractive force for both the drive cycles is given below.



TRACTIVE FORCE IN NEWTON VS TIME IN SECONDS (CITY)



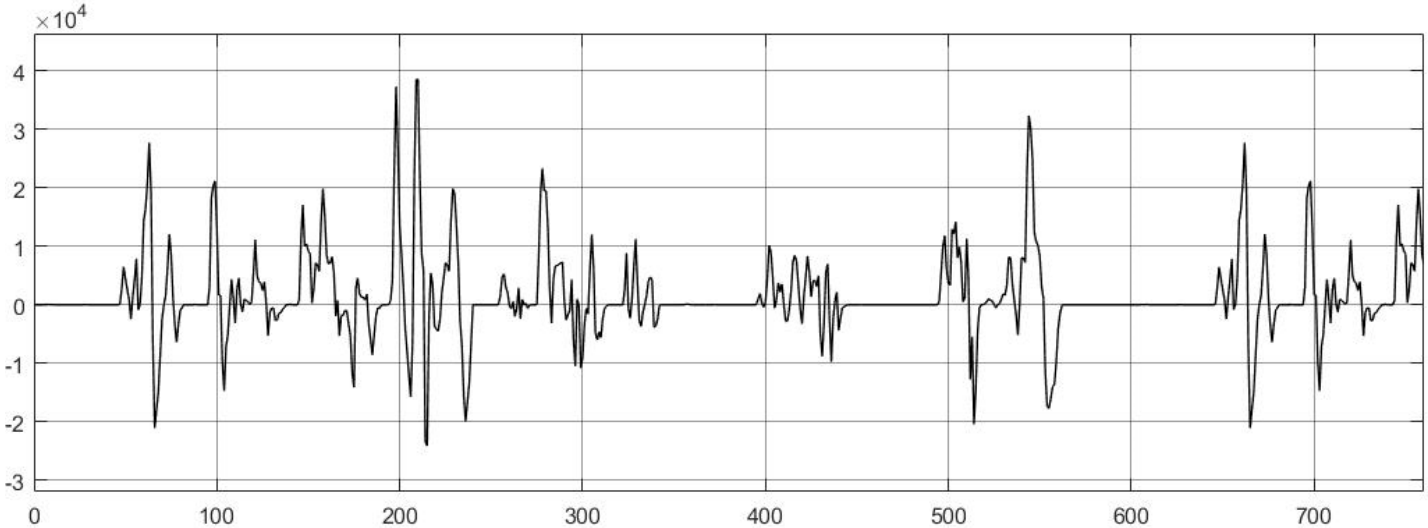
TRACTIVE FORCE IN NEWTON VS TIME IN SECONDS (HIGHWAY)

The peak value of the tractive force for the city drive cycle is 5000 N while that for the highway drive cycle is around 3000 N.

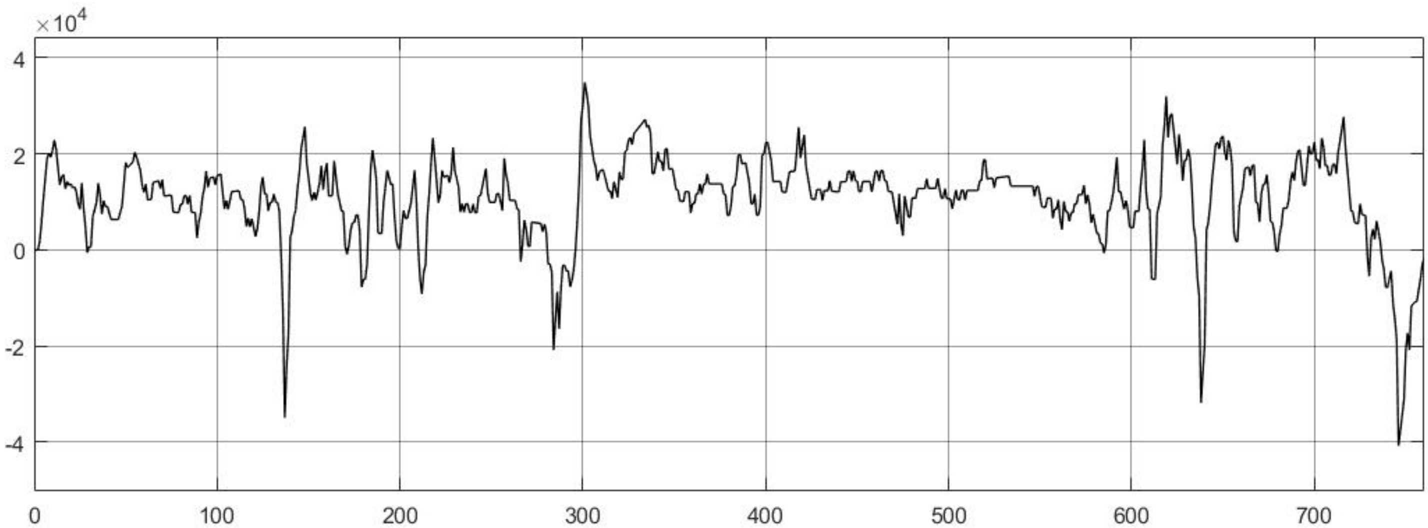
TRACTIVE POWER

The tractive power can be calculated by multiplying the tractive force by the velocity of the hybrid vehicle. It is calculated in kilo watts kW.

The graphical representation of the tractive power for both the drive cycles is given below.



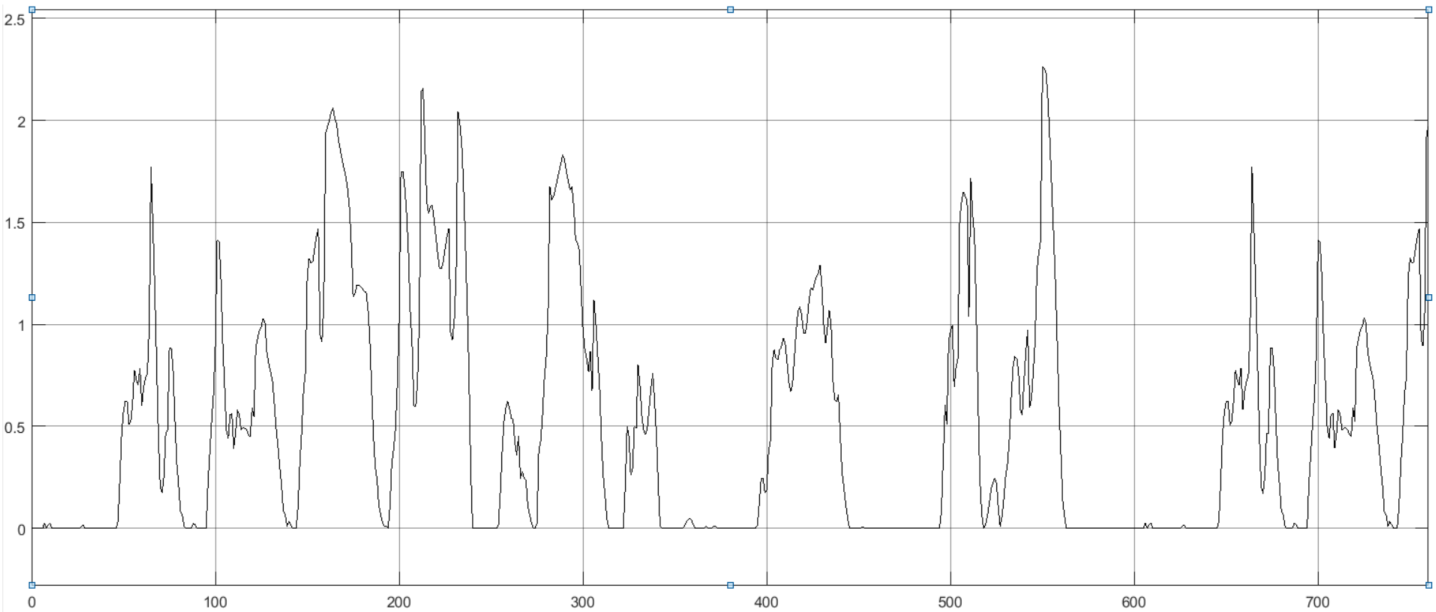
TRACTIVE POWER IN KILOWATTS VS TIME IN SECONDS (CITY)



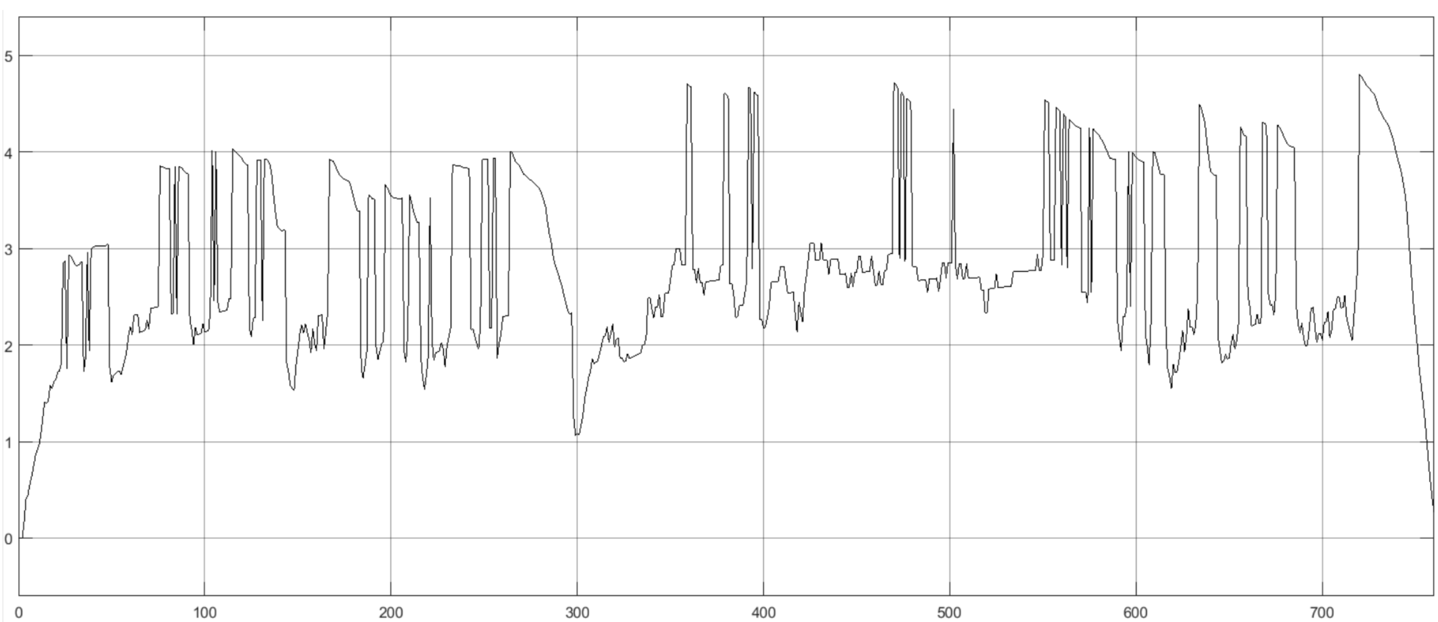
TRACTIVE POWER IN KILOWATTS VS TIME IN SECONDS (HIGHWAY)

CALCULATION OF THE TRANSMISSION GEAR RATIO

The transmission gear ratio is calculated by dividing the electric machine speed by the engine speed. The graphical representation of the transmission gear ratio is presented below.



TRANSMISSION GEAR RATIO VS TIME (CITY)



TRANSMISSION GEAR RATIO VS TIME (HIGHWAY)

If the gear ratio minimum is 0.3 then the ratio between the maximum and minimum transmission gear ratio for the city drive cycle would be 7:1 and 15:1 for the highway drive cycle.

CONCLUSIONS

The performance of the mild parallel hybrid electric vehicle was successfully simulated using the MATLAB Simulink vehicle model. The vehicular parameters were calculated, plotted and recorded. The comparison of the parameters was made between the highway and city drive cycles.