HCMC UNIVERSITY OF TECHNOLOGY AND EDUCATION

FACULTY FOR HIGH QUALITY TRAINING

PROCESS REPORT

END-OF-TERM REPORT

Student name:	**HO QUANG HUY**	**19145180**
	DAO DUY KHANG	**19145149**
	BUI TRAN NGUYEN KHOA	**19145192**
	HA PHAN NGOC QUAN	**19145008**

Course: **VEHICLE AUTOMATIC CONTROL SYSTEMS**

Advisor: **M.s NGUYEN TRUNG HIEU**

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THE SOCIALIST REPUBLIC OF VIETNAM
Independence – Freedom– Happiness

Ho Chi Minh City, November 28, 2021

PROJECT ASSIGNMENT

Student name: HO QUANG HUY Student ID: 19145180

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Student name: DAO DUY KHANG Student ID: 19145149

Major: Automotive Engineering Class: 19145CLA1,4

Advisor: M.s NGUYEN TRUNG HIEU Phone number: ________________

Date of assignment: ________________________ Date of submission: _____________

1. Project title: HYBRID ELECTRIC VEHICLE CONTROL

2. Initial materials provided by the advisor: ___________________________________

3. Content of the project: ____

4. Final product: ____

CHAIR OF THE PROGRAM **ADVISOR**
(Sign with full name) *(Sign with full name)*

THE SOCIALIST REPUBLIC OF VIETNAM
Independence – Freedom– Happiness

Ho Chi Minh City, November 28, 2021

ADVISOR'S EVALUATION SHEET

Student name: .... Student ID: ....

Student name: .... Student ID: ....

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Student name: .... Student ID: ....

Major: ....

Project title: …………………………………………………………………….

Advisor: ....

EVALUATION

1. Content of the project:
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   ………………………………………………………………………………
2. Strengths:
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3. Weaknesses:
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   ……………………………………………………………………………...
4. Approval for oral defense? *(Approved or denied)*
   …………………………………………………………………………………….
5. Overall evaluation: (Excellent, Good, Fair, Poor)
   ……………………………………………………………………………
6. Mark: ………………. (*In word*...)

Ho Chi Minh City, November 28, 2021

ADVISOR

(Sign with full name)

ACKNOWLEDGEMENT

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ABSTRACT

A “Gasoline-Electric Hybrid Engine Vehicle” is a vehicle which works on electrical power as well as fuel like petrol. It has many benefits over its predecessors, which developed power using only fuel.

The thought is to design and construct a Hybrid Electric Vehicle (HEV) powered by battery as well as petrol. The vehicle is made dynamic in nature by making use of electrical power from battery and fuel power. It consumes less fuel and creates comparatively less pollution as compared to conventional vehicles.

Hybrid electric vehicles consists of a battery, to drive the electric motor and power system with an IC engine to increase fuel economy reduce harmful emissions from the exhaust. Also, there is a provision for recharging the battery using a generator which is run using a turbine, which runs on the exhaust of the IC engine. In HEV, the battery single handedly provides power for driving at low speeds where the efficiency of IC engine is least. In cruising and high load conditions like moving up the hill, the electric power assists the engine by providing additional power. Thus, the HEV is the best alternative in areas with high traffic like urban metropolitan cities.

In this project, we will study the theoretical basis of hybrid vehicles including 3 types: Series Hybrid, Parallel Hybrid, and especially is Complex Hybrid which is the type we focus on learning with the model available on the Simulink application. The next step, we test the model on Simulink using the available drive cycle and finally put the parameters of a Toyota Prius into the model and compare it with reality.

TABLE OF CONTENTS

ABBREVIATIONS

HEV: Hybrid Electric Vehicle

ICE: Internal Combustion Engine

RPM: Rounds per Minute

MPG: Miles per Gallon

FTP75: EPA Federal Test Procedure

HWFET: Highway Fuel Economy Driving Schedule

TABLES

FIGURES

REFERENCES

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[2]. A. Galip Ulsoy, Huei Peng, Melih Cakmakcı, Automotive Control System, Cambridge University Press, 2012

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CHAPTER 1

PROJECT REPORT: HYBRID ELECTRIC VEHICLE CONTROL

1. OVERVIEW ABOUT THE PROJECT

The reason for choosing the project.

In Vietnam's current economic development conditions, one of the issues that is always concerned is the demand for travel and transportation, which is also the reason for the development of our country's automobile industry.

Decades ago, cars were merely a tool to serve the needs of traveling or transporting goods with low productivity; however, after years of continuous economic development, cars have gradually upgraded and met other human needs such as saving fuel costs, meeting air emission standards, or simply operating smoothly with high capacity.

Previously, cars powered by gasoline engines were a very familiar symbol to the world in general and the automotive industry in particular; however, limited aspects of emissions to the environment, too expensive to repair, or high fuel consumption are the reasons leading to the development of a more optimal vehicle to replace it in the future.

One of the vehicles created to meet new human standards is the hybrid. Hybrid cars, with their unique combination of traditional internal combustion engines and strong currents, bring us even more exciting new discoveries for the automotive industry. This is also why the topic of Hybrid vehicles was chosen. Let's start looking into this project to better understand the hybrid vehicles.

2. INTRODUCTION ABOUT THE HYBRID

2.1. Hybrid cars: The History

Hybrid cars combine a conventional internal combustion engine (ICE) with a battery-powered electric motor. At low speeds, the car is powered by electricity alone. As speed increases, the engine takes over. Under certain conditions, the engine and electric motor work together to provide more power or recharge the batteries.

The first hybrid car appeared at the start of 1900s, designed by Ferdinand Porsche, who later achieved some success with cars bearing his name. The technology was developed throughout the 20th Century, but it wasn’t until the 1990s that Toyota perfected it, launching the first Prius in 1997.

Sales outside Japan started in 2000, it was little more than a curiosity until the second-generation version was launched in 2004, becoming a massive sales hit around the world. More than six million and counting have now been sold.

Other manufacturers followed Toyota’s lead, launching their own hybrids. They chose their timing well. In the early 2000s, concerns were growing about increasing carbon dioxide emissions causing climate change. Thus, legislators started giving tax breaks to cars with low CO2 emissions, which particularly favored hybrids. Since the UK launched its CO2-based Road tax regime in 2004, most hybrids have been tax-free. That alone prompted many people to switch to hybrids, especially company car drivers and fleets who can save thousands of pounds a year on their tax bill. Anyway, enough scene-setting. Let’s dig into how a hybrid-powered car actually works.

2.2. How does a Hybrid car work?

Hybrid-powered cars use two energy sources: fuel powering a conventional diesel or petrol engine, and a battery powering an electric motor. Exactly which energy source the car uses at any given moment depends on the situation.

When trickling along in stop-start traffic, the car may run on battery power alone. This not only saves fuel, but it also means the car isn’t producing any tailpipe emissions – particularly desirable when stuck in city center congestion. As an added bonus, the car will be pretty much silent, as well.

The electric element of a hybrid car’s powertrain is optimized for low-speed running, thus the petrol or diesel engine takes over as speed increases. At that point, the car behaves like any other conventional car.

The petrol or diesel engine and electric motor can work together to provide extra power. The engine can also work as a generator to recharge the battery. Regenerative braking recovers energy that would otherwise be lost while slowing down and feeds it back to the batteries. Some hybrid cars have other energy recovery systems and, of course, some can be plugged into a socket to recharge, as well.

Driving a hybrid car, you need to do nothing more than, err, drive it. The car’s immensely clever technology works out exactly which energy source or combination thereof is best at any given moment. However, most of the latest hybrids do give you the option of specifying which power source is used at the press of a button.

3. GENERAL KNOWLEDGE ABOUT HYBRID VEHICLE

A hybrid electric automobile is any model that basically contains an electric motor in addition to an internal combustion engine, in other words, these models have two sources of power. Hybrid electric vehicles take advantage of the characteristics of their power sources for most driving conditions. The drawback to conventional engines, both large and small, is that they are not as efficient as low engine speeds as they are at high engine speeds. In contrast, electric motors produce higher torque, which is what enables car to move stronger from a stop, at a very low speed. This characteristic means that motors can be used to provide initial motion to a hybrid electric vehicle and then, once the vehicle is moving, the engine can take over as the primary power, thus lowering emissions and increase fuel efficiency.

Traditionally, HEVs were classified into two basic kind - series and parallel. Recently, with the introduction of some HEVs offering the feature of both the series and parallel hybrid, the classification has been extended to three kinds - series, parallel and series parallel. It is interesting to note that some newly introduced HEVs cannot be classified into three kinds. Hereby, HEVs are newly classified into three kinds:

3.1. Series Hybrid system

[1] The series hybrid is the simplest kind of HEV. Its ICE mechanical output is first converted into electricity using a generator. The converted electricity either charges the battery or can bypass the battery to propel the wheels via the same electric motor and mechanical transmission. Conceptually, it is an ICE-assisted electric vehicle that aims to extend the driving range comparable with that of the ICE vehicle. Due to the decoupling between the engine and the driving wheels, it has the definite advantage of flexibility for locating the ICE generator set. Although it has an added advantage of simplicity of its drivetrain, it needs three propulsion devices, the generator, and the electric motor. Therefore, the efficiency of series HEV is generally lower. Another disadvantage is that all these propulsion devices need to be sized for the maximum sustained power if the series HEV is designed to climb a long grade, making series HEV expensive. On the other hand, when it only needs to be sized for maximum sustained power if the series HEV expensive. On the other hand, when it is only needed to serve such short trips as commuting to work and shopping, the corresponding ICE generator set can adopt a lower rating.

Figure 1.1 illustrates how the components work in a Series Hybrid System, the power from Engine move to the Generator, from generator to Inverter and continue move to the Battery for charge. Then, from the Battery follow back to the Inverter, to Motor and finally drive the wheels after moving to the Transmission

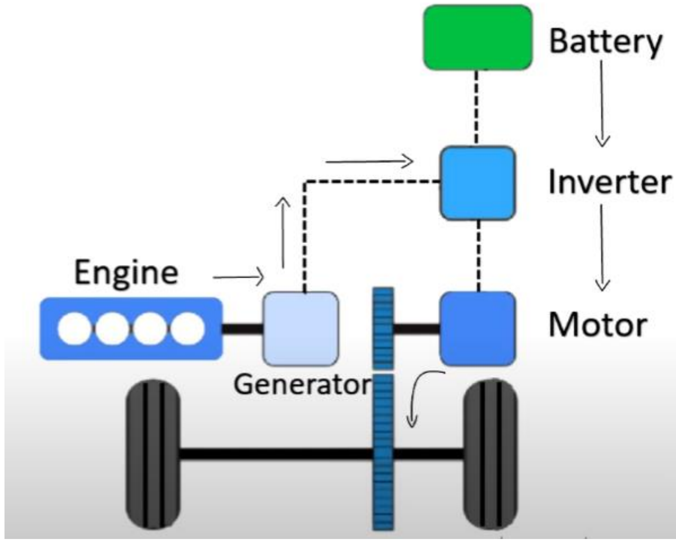

Figure 1.1: The diagram of Series Hybrid System

3.2. Parallel Hybrid System

[1] Differing from the series hybrid, the parallel HEV allows both the ICE and electric motor to deliver power in parallel to drive the wheels. Since both the ICE and electric motor are generally coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by the ICE alone, by the electric motor or by both. Conceptually, it is inherently an electric assisted ICEV for achieving lower emissions and fuel consumption. The electric motor can be used as a generator to charge the battery by regenerative braking or absorbing power from the ICE when its output is greater than that required to drive the wheels. Better than the series HEV, the parallel hybrid needs only two propulsion devices the ICE and the electric motor.

Another advantage over the series case is that a smaller ICE and a smaller electric motor can be used to get the same performance until the battery is depleted. Even for long trip operation, only the ICE needs to be rated for the maximum sustained power while the electric motor may still be about a half.

Figure 1.2 illustrates how the components work in a Parallel Hybrid System, the power from Engine move to Transmission and drive the wheels. And then from Battery to Inverter, to Motor and finally is drive the wheels.

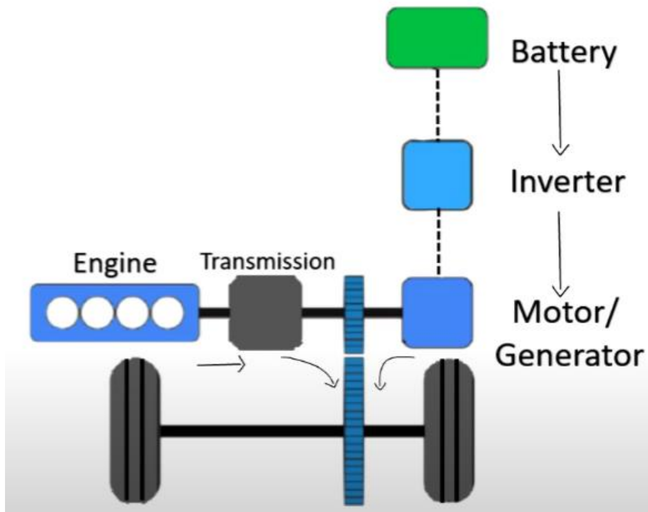

Figure 1.2: The diagram of Parallel Hybrid System

3.3. Power-split Hybrid System

[2] The third type of hybrid vehicle is the power-split type. These hybrid systems use a planetary gear(s) as the power-summation device as well as to provide torque ratios. Two electric machines (i.e., the motor and the generator, although both can have either role) are used as the secondary power sources to sustain favorable operating conditions for the ICE as well as to augment the engine-driving torque to satisfy a driver's demand. In the case of the original.

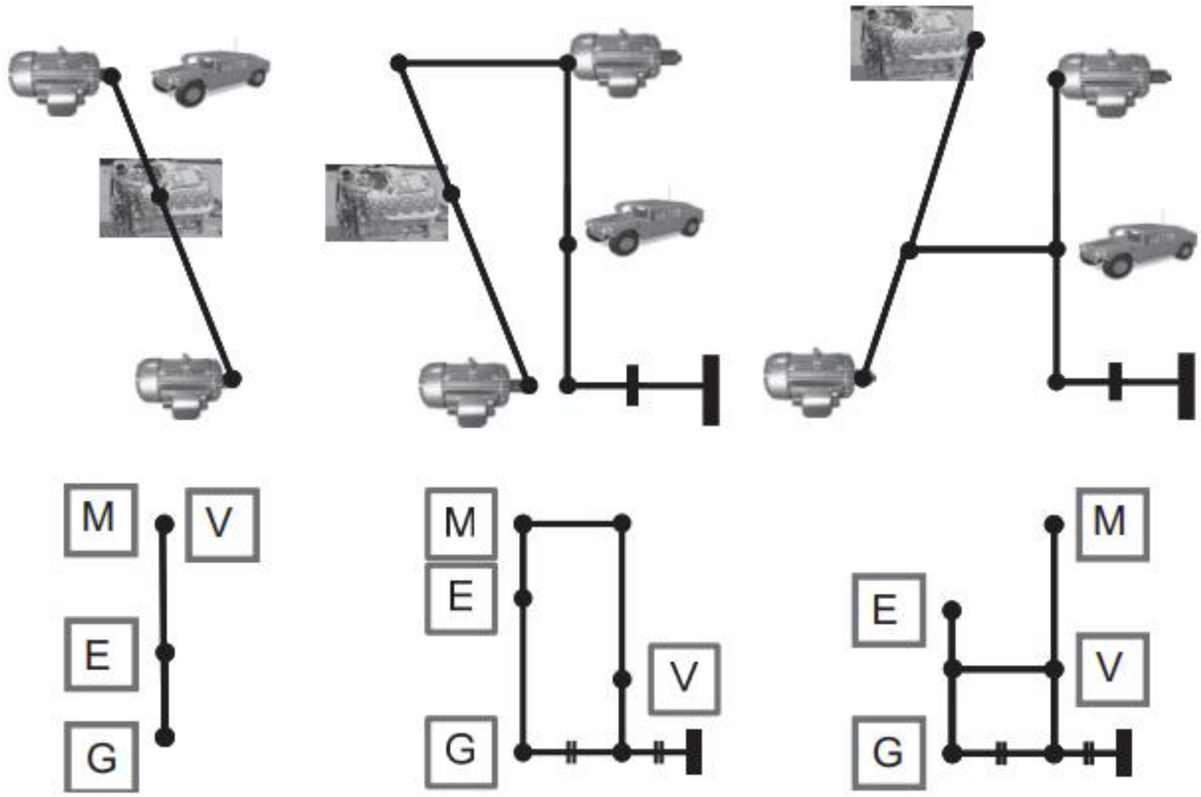

Figure 1.3: Examples of split hybrid vehicles (Left: original Toyota Hybrid System, Center: original General Motors Design, Right: A Timken design)

Toyota Hybrid Design, one planetary gear is used, whereas in the original General Motors design, two planetary gears are used. Figure 1.3 shows three examples of split hybrid designs, all of which are patented. They are represented in the lever-diagram form in which each "stick" represents a planetary gear with three nodes: sun gear, carrier gear, and ring gear. The small icons connected to the nodes represent the vehicle (V), engine (E), motor (M), and generator (G).

The planetary gear typically is very compact (i.e., only slightly larger than a soft drink can), has high torque capacity, has simple and robust mechanical design, has very high efficiency, and potentially can have multiple operation modes if clutches are used. However, because it is inherently a mechanical transmission, it is not suitable for certain types of hybrid vehicles. For example, it does not make sense to have a fuel-cell split hybrid. All existing split vehicles use two electric machines and, because of the torque balance on the planetary gears, they are inherently strong hybrids with two sizable electric machines. Therefore, it is more challenging to design a low-cost split hybrid vehicle. Because of the existence of three power sources, the associated sizing and control problem is more complex than for series and parallel hybrids.

Figure 1.4 illustrates how the components work in a Power-split Hybrid System, the Power from Engine move to the Power Split device to drive the wheels and also from Engine to Generator, to Inverter and to the Battery. Then the Battery follow back to the Inverter, to Motor and finally is move to Transmission for drive the wheels.

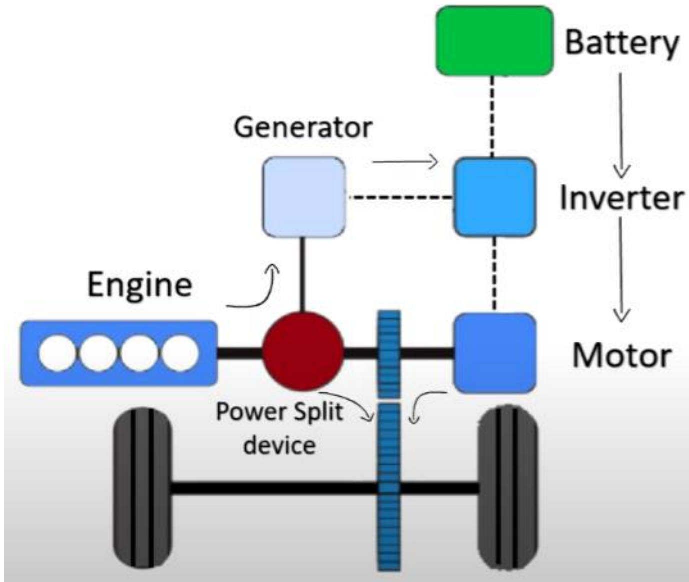

Figure 1.4: The diagram of Power-split Hybrid System

4. INVESTIGATION ON COMPLEX HYBRID SYSTEM.

4.1. Simulink model

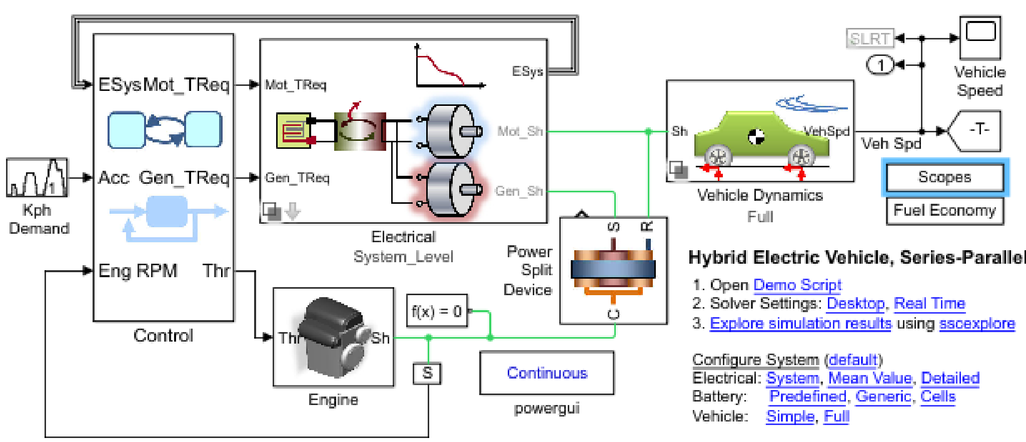

Figure 1.5: Power-Split Hybrid Model

In this research, we investigated a Simulink Based Power-split Hybrid System (Figure 1.5). The model has six parts: Kph Demand, Control, Electrical, Engine, Power-split and Vehicle Body. The Electrical subsystem includes a Battery connecting with a DC-DC Converter, a Motor and a Generator respectively connecting to the sun and ring connections of the Power-split device, and the carrier connects with an internal combustion engine.

4.2. Kph Demand Subsystem

The Kph Demand Subsystem (Figure 1.6) is considered as the input where Drive Cycles are processed and send the Reference Speed command, together with the Vehicle Speed from the Vehicle body, to the Vehicle Speed Controller Subsystem (Figure 1.7) in order to process and calculate the Acceleration demand and Brake Pedal input for vehicle body.

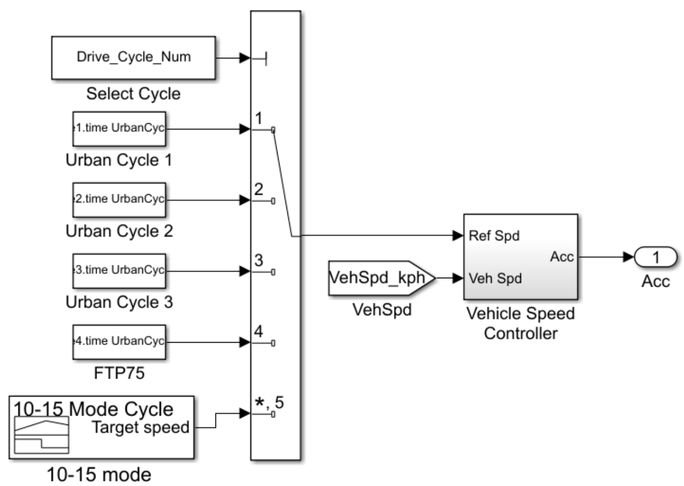

Figure 1.6: Kph Demand

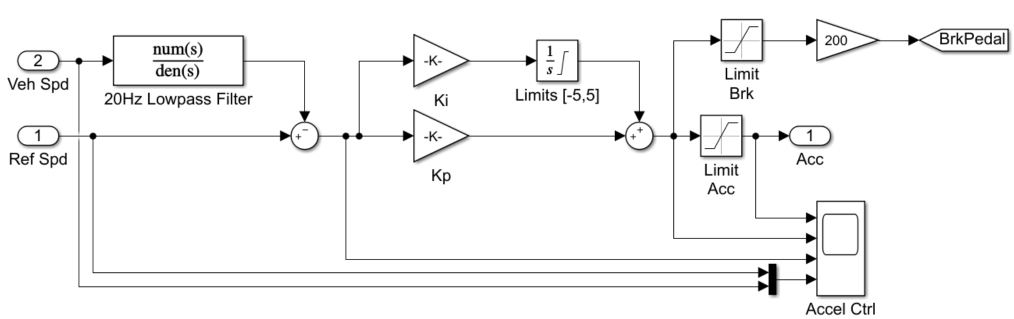

Figure 1.7: Speed Controller Subsystem

4.3. Model's Control Strategy

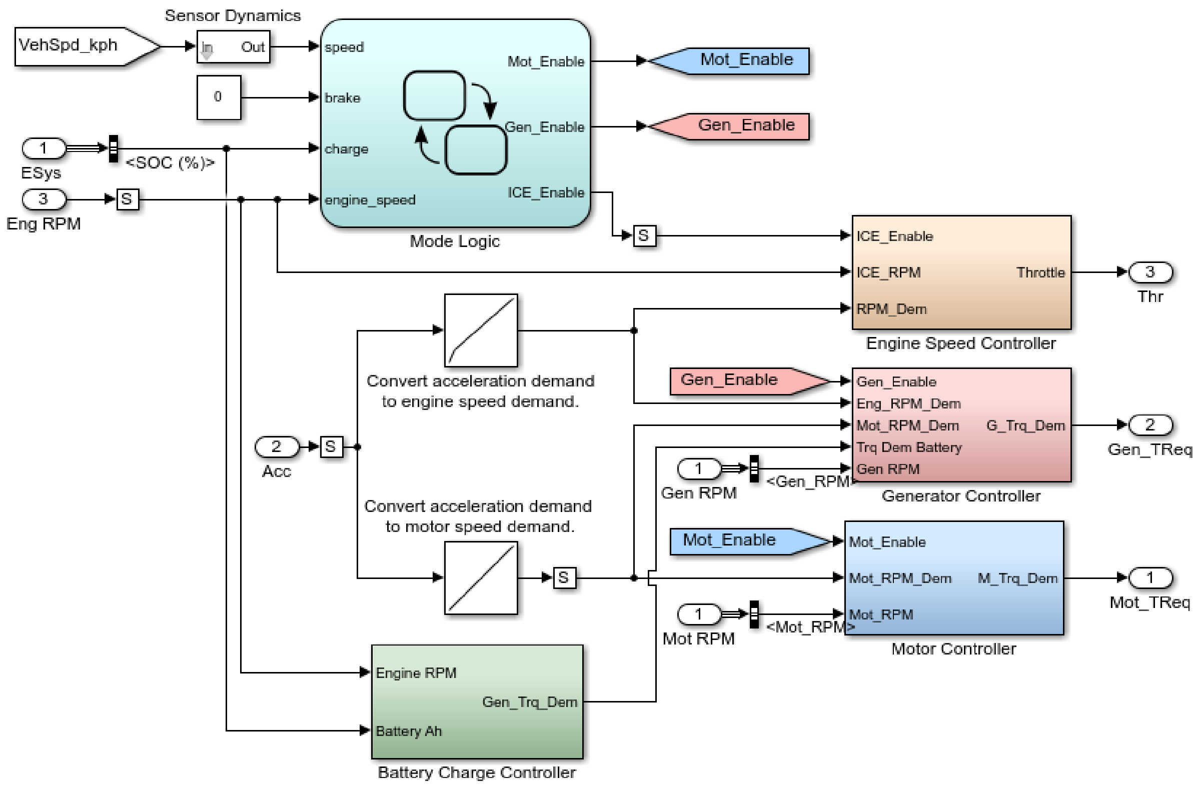

Figure 1.8: Control

The Control Subsystem is where the Speed Demands of Motor, Generator and Engine are processed according to the inputs from Kph Demand and from the given Mode Logic State Flow.

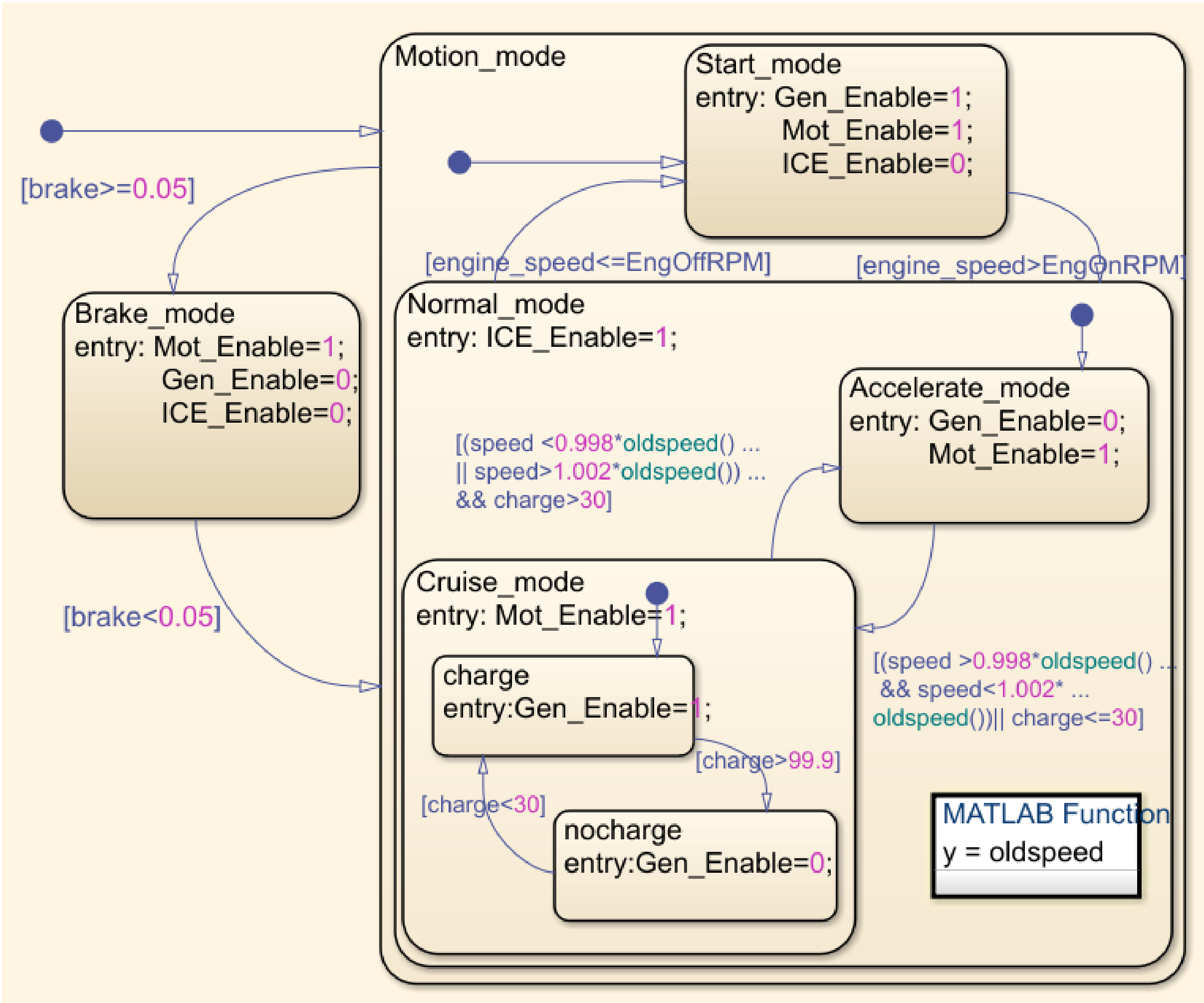

Figure 1.9 Mode Logic State Flow

The Mode Logic (Figure 1.9) indicates how the components of the model work during many driving conditions such as Start Mode, Accelerate Mode, Cruise Mode, Brake Mode. When the engine gets above a certain threshold the vehicle enters normal mode where the engine is used to drive the vehicle and to charge the battery. If the driver wishes to accelerate, the motor can be used to drive the vehicle even faster and the generator is turned off so that all of the engine’s torque can be used to accelerate the vehicle.

When the vehicle is in cruise mode the generator may be used to charge the battery there are also transitions to go back to acceleration mode and to start mode if the driver applies the brakes, then the motor is used via regenerative braking to charge the battery.

In this model Generator torque demand has been set so that at the starting condition the combustion engine is providing just enough power to keep the vehicle moving at constant speed, and hence battery power is close to zero. The engine RPM demand is set to 2000 rpm for good efficiency.

4.4. Components

Following below are the main components of the Simulink Power-split Hybrid Vehicle model

- Planetary gear

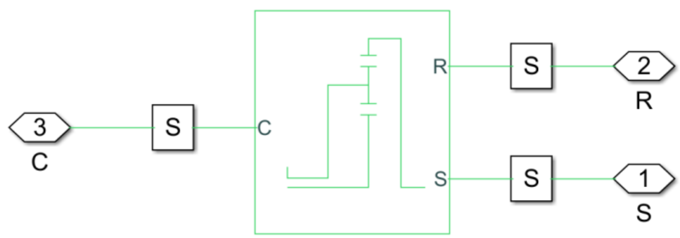

Figure 1.10: Power-split device

The Planetary Gear is a power-split device with connections C, R and S, which are mechanical rotational conserving ports associated with the carrier, ring, and sun shafts, respectively. In this model, the Generator is connected with S port, the Motor is connected with R port while the Engine is connected with the remaining.

- Battery

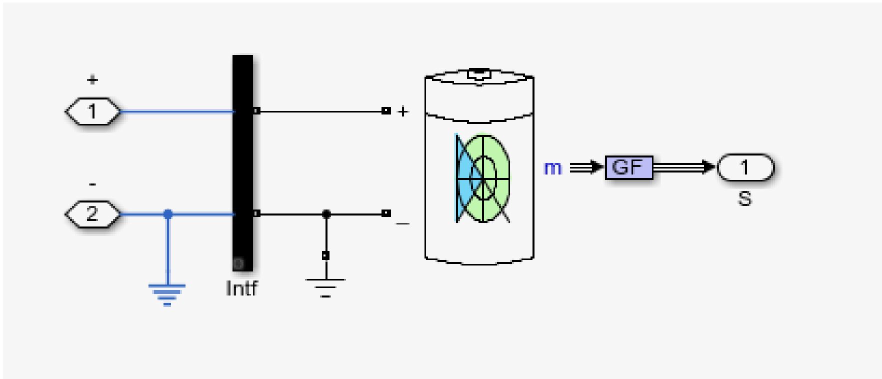

Figure 1.11: Battery

The Predefined Battery, whose use is to serve as the storage of energy for the model, has parameters such as Nominal Voltage, Rated Capacity, Initial State-of-Charge, and Response time. The Ports (+) and (-) are connected with corresponding ports from DC-DC Converter, the output (m) contains the Battery SOC as one of the inputs for Mode Logic Subsystem.

- DC-DC Converter

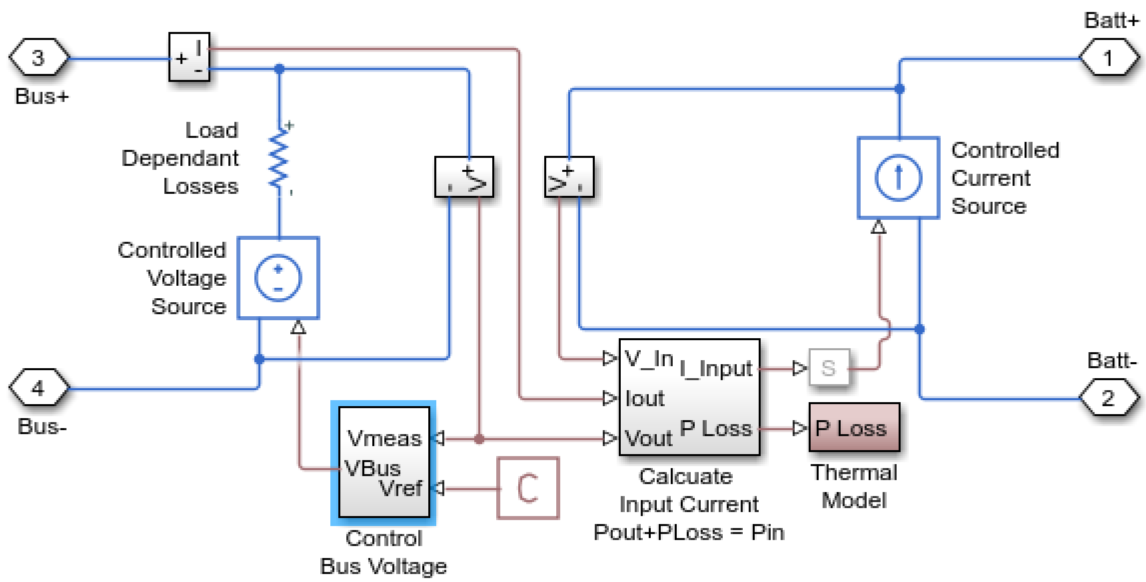

Figure 1.12 DC-DC Converter

The DC-DC Converter, whose use is to boost the voltage from the battery into required voltage to drive the motor. The inputs which are from the battery go through a process which contains firstly an ideal voltage sensor to converts voltage measured between any electrical connections into a physical signal proportional to the voltage. The Signal then travel to a calculation subsystem to estimate the output current and voltage which shall be processed as the outputs of the Converter. The device also contain a thermal model to estimate the temperature during driving.

- Generator and Motor

Both the Generator and Motor contains a Simplified PSPM Drive, this block represents servomotor and drive electronics operating in torque-control mode, or equivalently current-control mode. The motor's permissible range of torques and speeds is defined by a torque-speed envelope. The mechanical connection (R) allows connection with the mechanical drivetrain of the vehicle. The inputs which are from the Control Subsystem (TReq) and DC-DC Converter (Vcc, Gnd) travel through different types of sensors and are processed in the PMSM Drive.

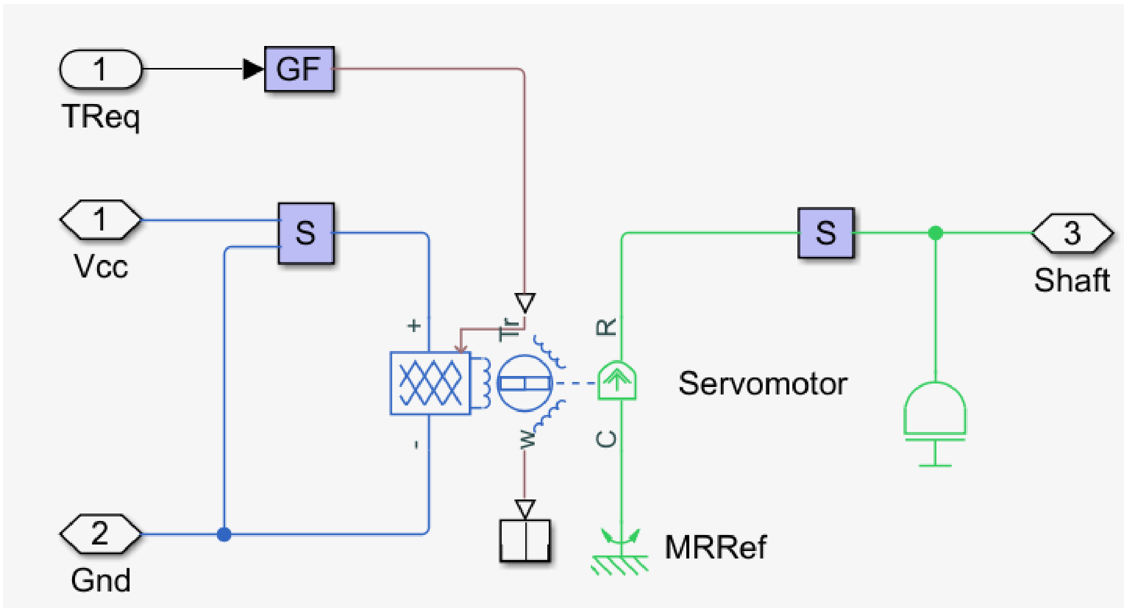

Figure 1.13: Generator

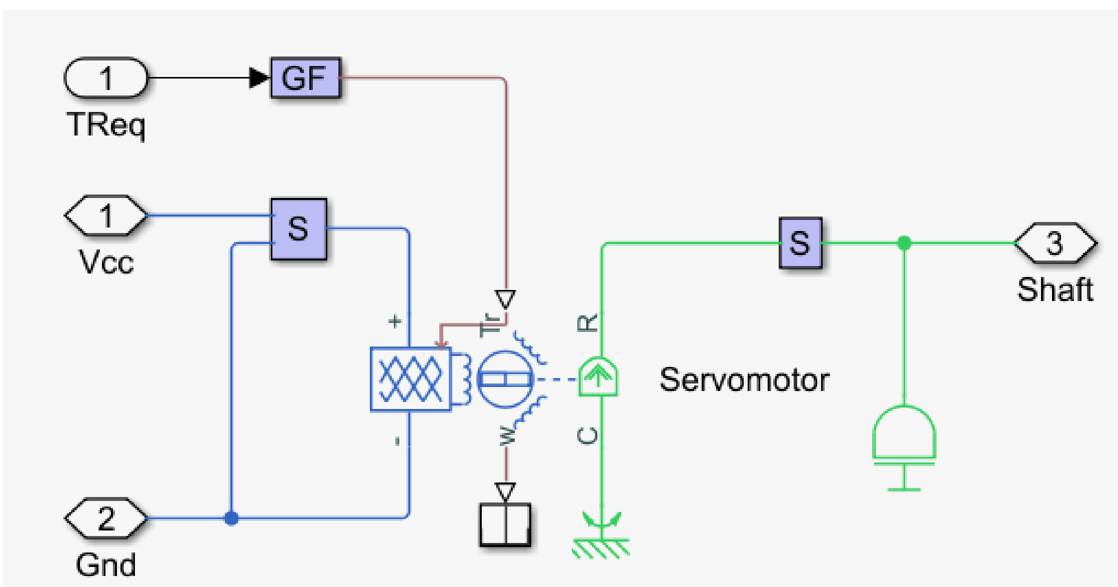

Figure 1.14: Motor

- Engine

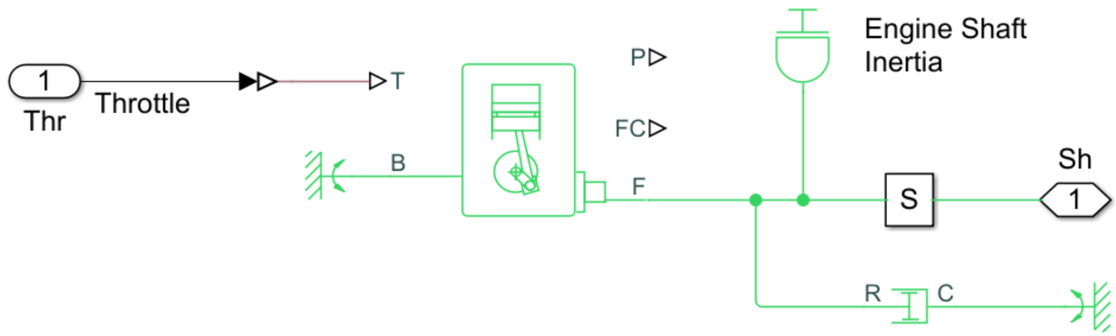

Figure 1.15: Engine

The Engine block in this model consists of a generic engine with port T as the throttle input signal which lies between zero and one and specifies the torque demanded from the engine as a fraction of maximum possible torque. The Engine shall receive throttle signal from Control Subsystem. Connection F and B are mechanical rotational conserving ports associated with the engine crankshaft and engine block, respectively. Connection P and FC are physical signal output ports through which the engine power and fuel consumption rate are reported. Vehicle Body

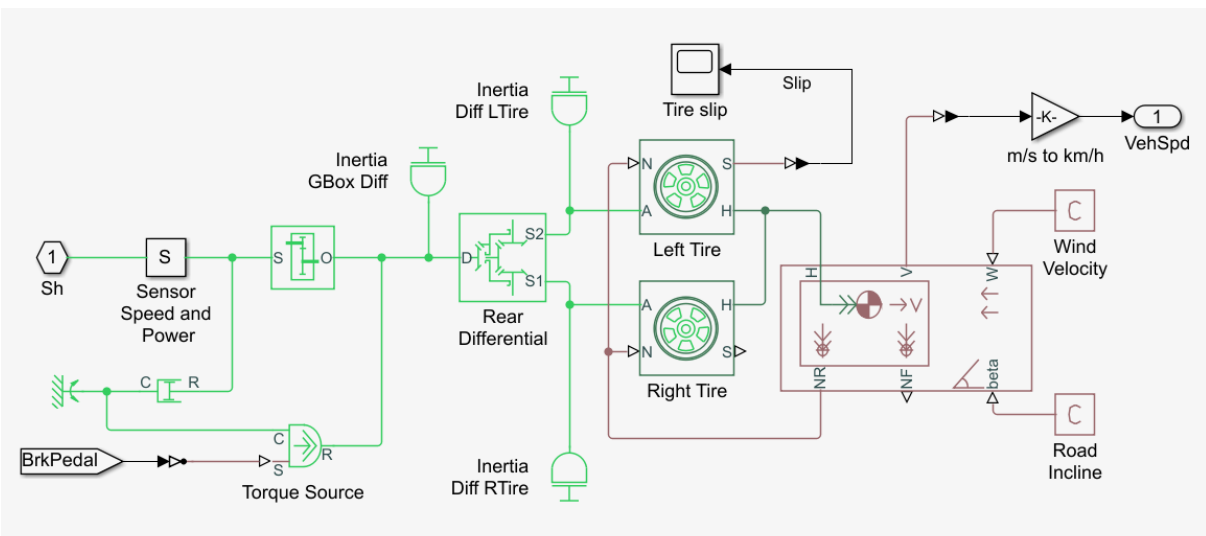

Figure 1.16 Vehicle Body System

The Vehicle Body contains Right Tires and Left Tires, both of which receive input signals in connection A and N. The connection A is the mechanical rotational conserving port for the wheel axle while connection N is a physical signal input port that applies the normal force acting on the tire. The force is considered positive if it acts downwards. The outputs of the Tires are in connection H, which is the mechanical translational conserving port for the wheel hub through which the thrust developed by the tire is applied to the vehicle. Moreover, the connection S is a physical signal output port that reports the tire slip.

Another component is the Vehicle body where the Vehicle Velocity is processed. The output from the tires connect to connection H in this block, which is the mechanical translational conserving port associated with the horizontal motion of the vehicle body. In the block, Connections V, NF, and NR are physical signal output ports for vehicle velocity and front and rear normal wheel forces, respectively. Connections W and beta are physical signal input ports corresponding to headwind speed and road inclination angle, respectively.

4.5. Fuel Economy

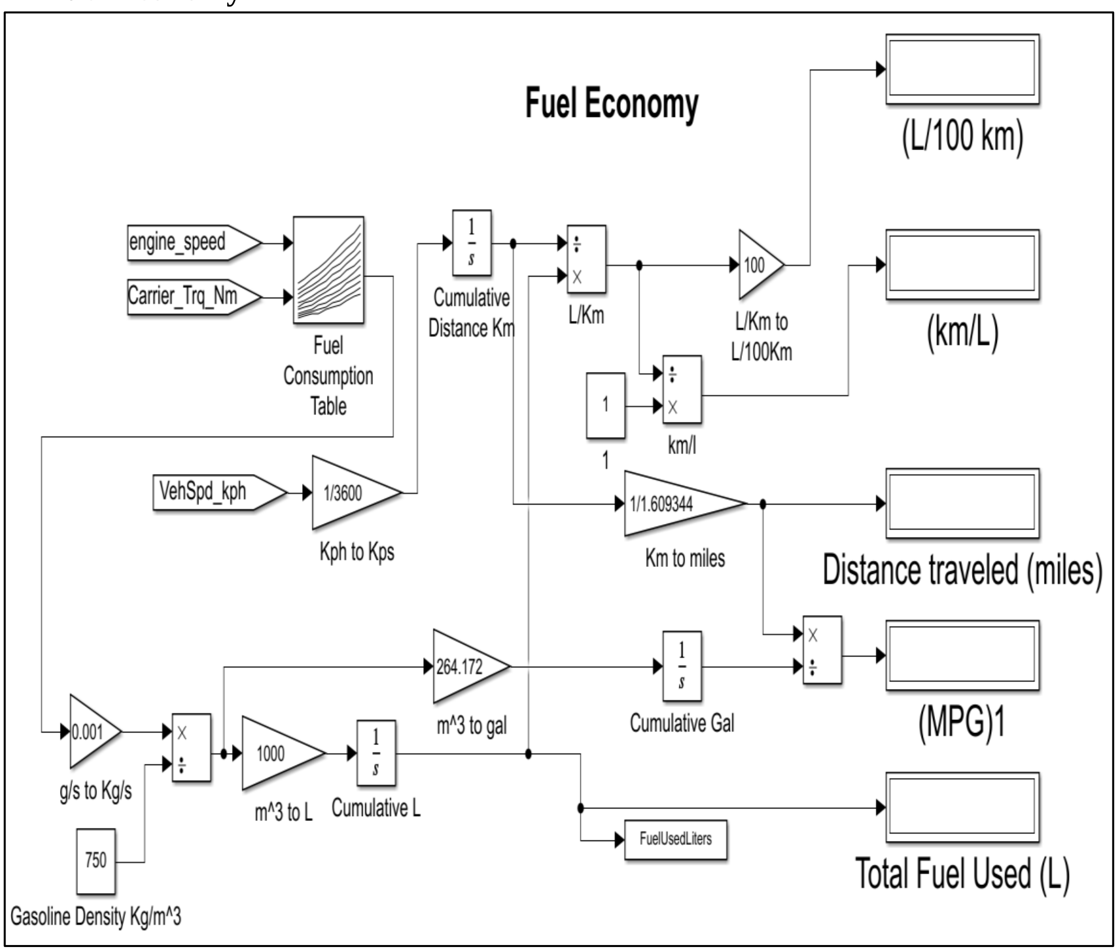

Figure 1.17: Fuel Economy Calculation Block sets

The Fuel Economy is calculated with Vehicle Speed (km/hr.) and Fuel Consumption (g/s) as the inputs, the outputs are Distance Travelled (Miles), Fuel Economy in MPG, L/100km, km/L, and Total Fuel Used (L)

4.6. Model's output Figures

4.6.1. Vehicle Speed

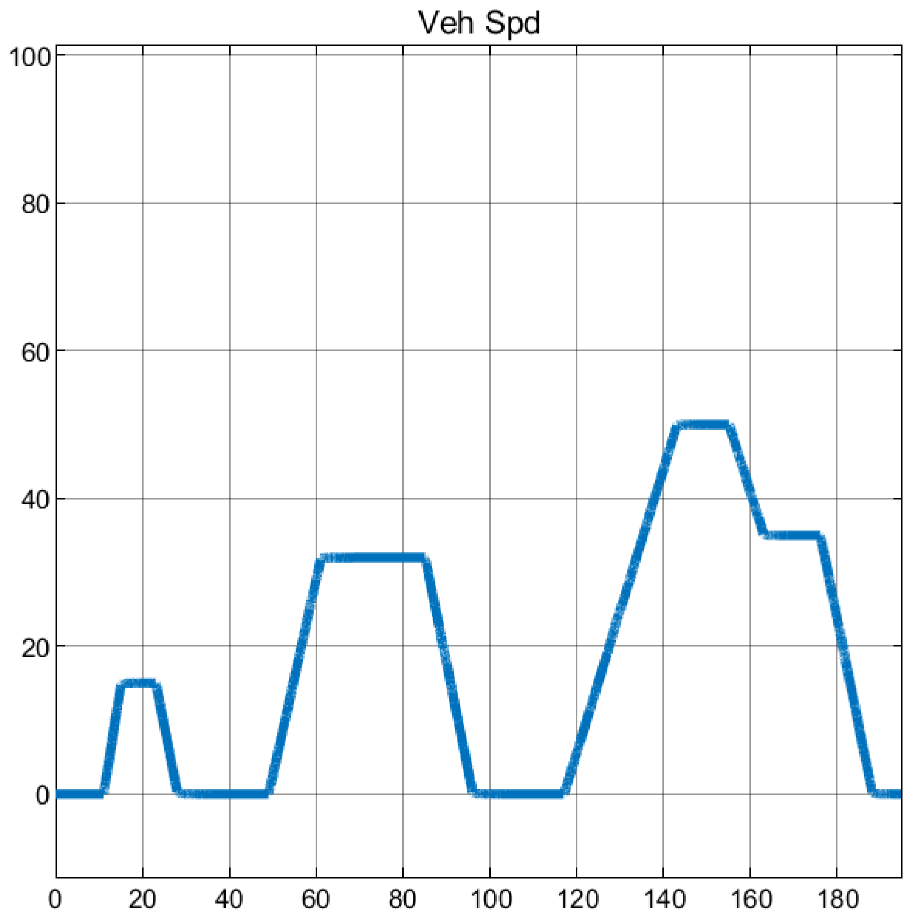

Figure 1.18: Vehicle Speed (Km/h)

According to Figure 1.16, at starting, the vehicle speed is approximately 0 km/h and stabilize for approximately 10 seconds. From t=10s, the vehicle accelerates and reach the speed of over 14.98 km/h at t=15s. The Vehicle Speed stays unchanged for about 8 seconds and steadily decelerate thence. At t=50s, the vehicle speed accelerates again and peak at 32 Km/h for 25 seconds and then decelerates to 0. At t=143s the vehicle reaches the highest speed of 50km/h and after over 10 seconds, it lowers the speed and stays at 35km/h for 12 seconds before reaches 0 speed and end the 195-second duration.

4.6.2. Mode Logic

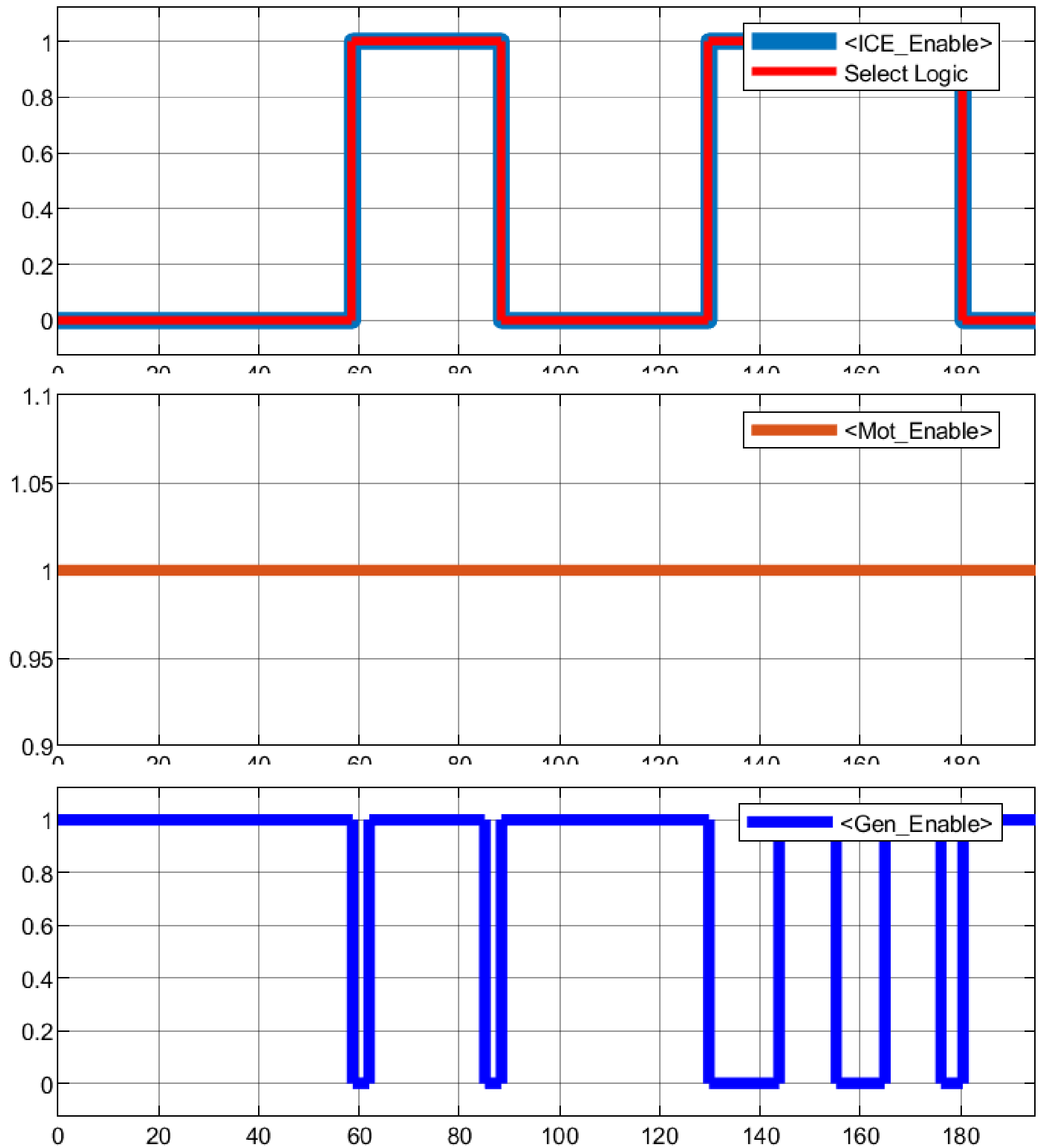

Figure 1.19: Mode Logic

According to the mode logic, the enable signal of the three devices is ‘1’. Therefore, it is immediate that while the car is at start mode, the Generator is enabled with the Motor. When accelerating, only the ICE and Motor are enabled while at braking mode when the car decelerate the ICE and Generator are disabled. Finally, during cruise mode, ICE is off for generator to charge.

4.6.3. RPM Speed

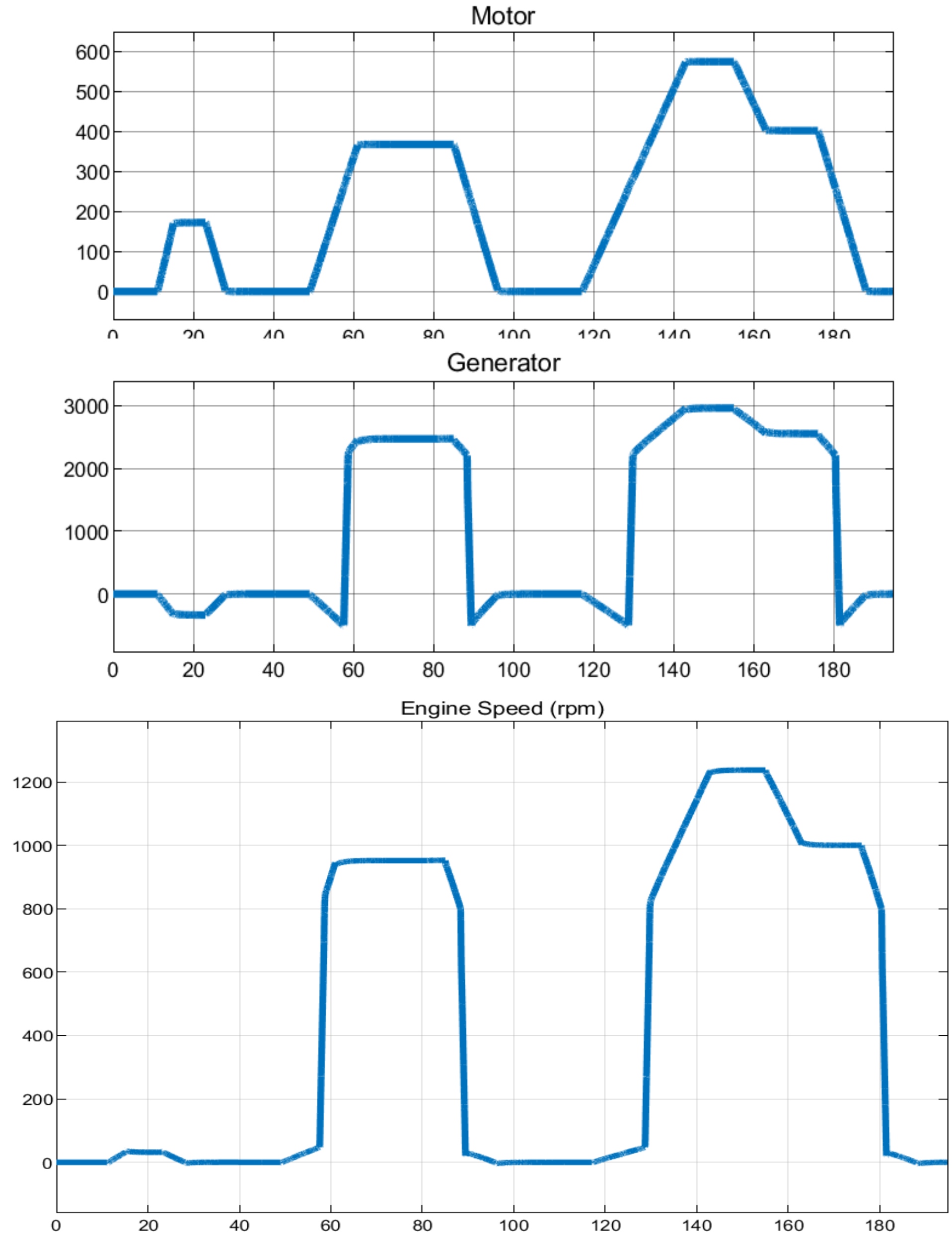

Figure 1.20: Components’ Speed (RPM)

Obviously, the speed of the devices works perfectly according to the speed of the vehicle, they raise when the car is accelerating and decrease when the car slows down.

4.6.4. Powers

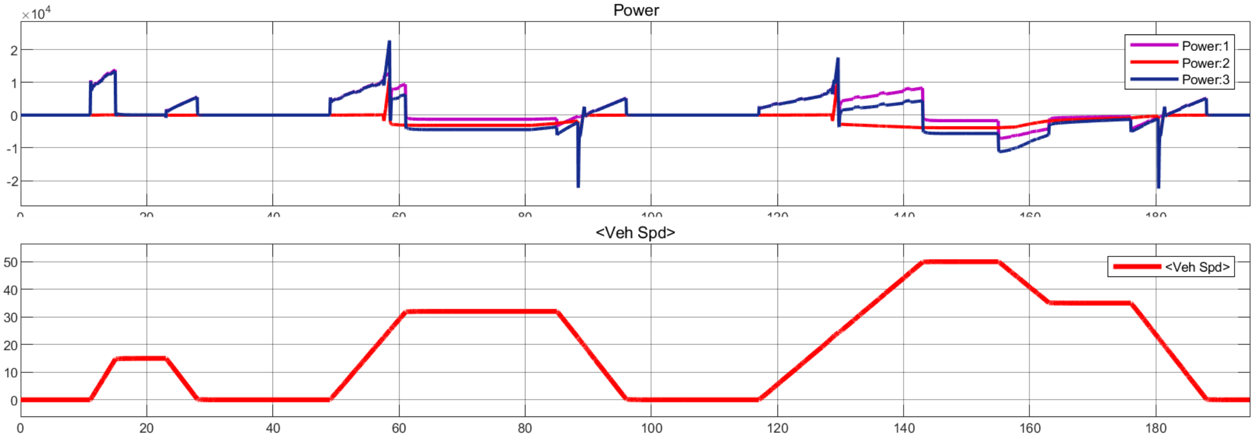

Figure 1.21: Powers (W) and Vehicle Speed: Power 1: Motor, Power 2: Generator, Power 3: Battery

According to Figure 1.21, when the car drives at constant speed, the Power of the components does not fluctuate much. The Generator supplies the DC network with a constant flow of power drawn from the engine, hence the Power of Generator and Engine stay nearly constant. However, the Power of Motor and Battery sees significant changes when the vehicle speed varies.

Specifically, when the vehicle accelerates, the Power of both devices considerably boom up. The trend of the Power of Motor and Battery also decreases as the car decelerates, touch the smallest value of about -20 kW. After that, when the car stabilizes again, the Power of the two devices raise and remain stable at 0.

4.6.5. ICE Scopes

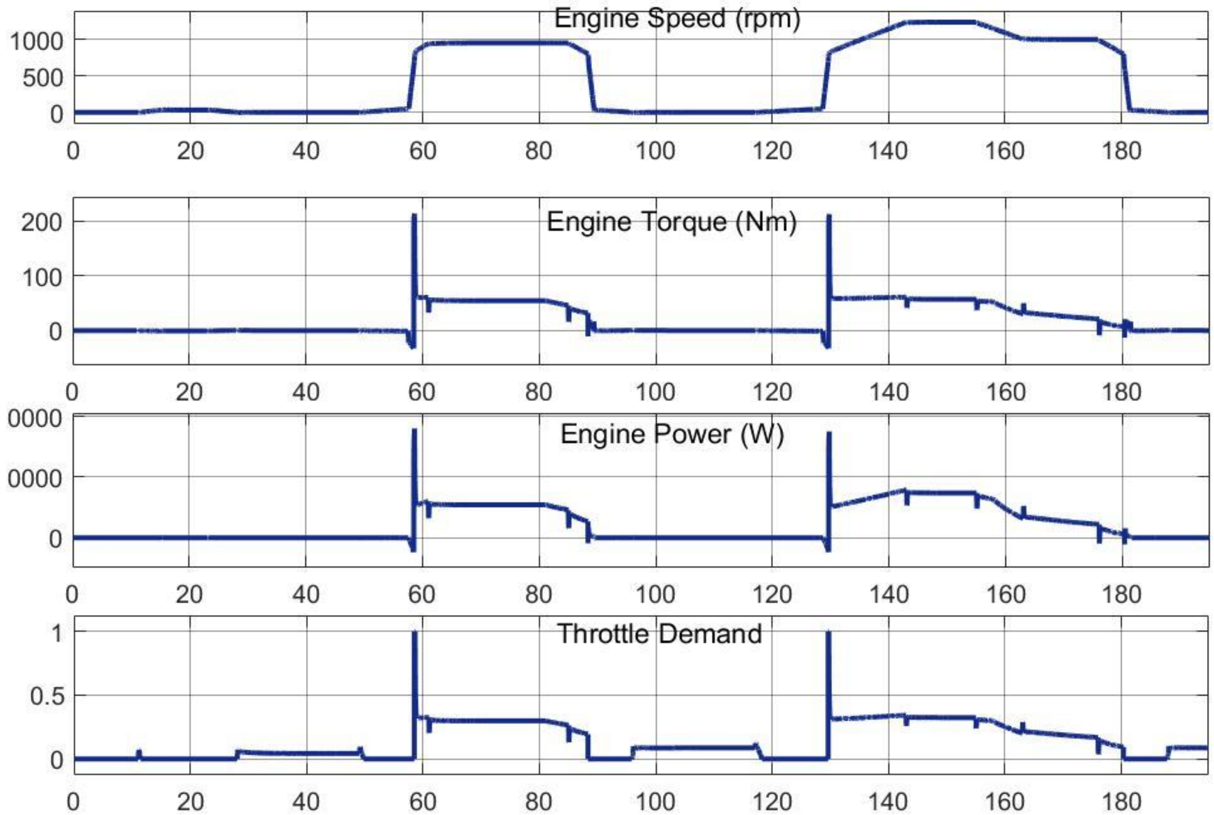

Figure 1.22: ICE Scopes

It is obvious from the graph that when the car is accelerating, all other parameters increase and then decrease as the car stabilized and decelerates.

4.6.6. Battery Voltage

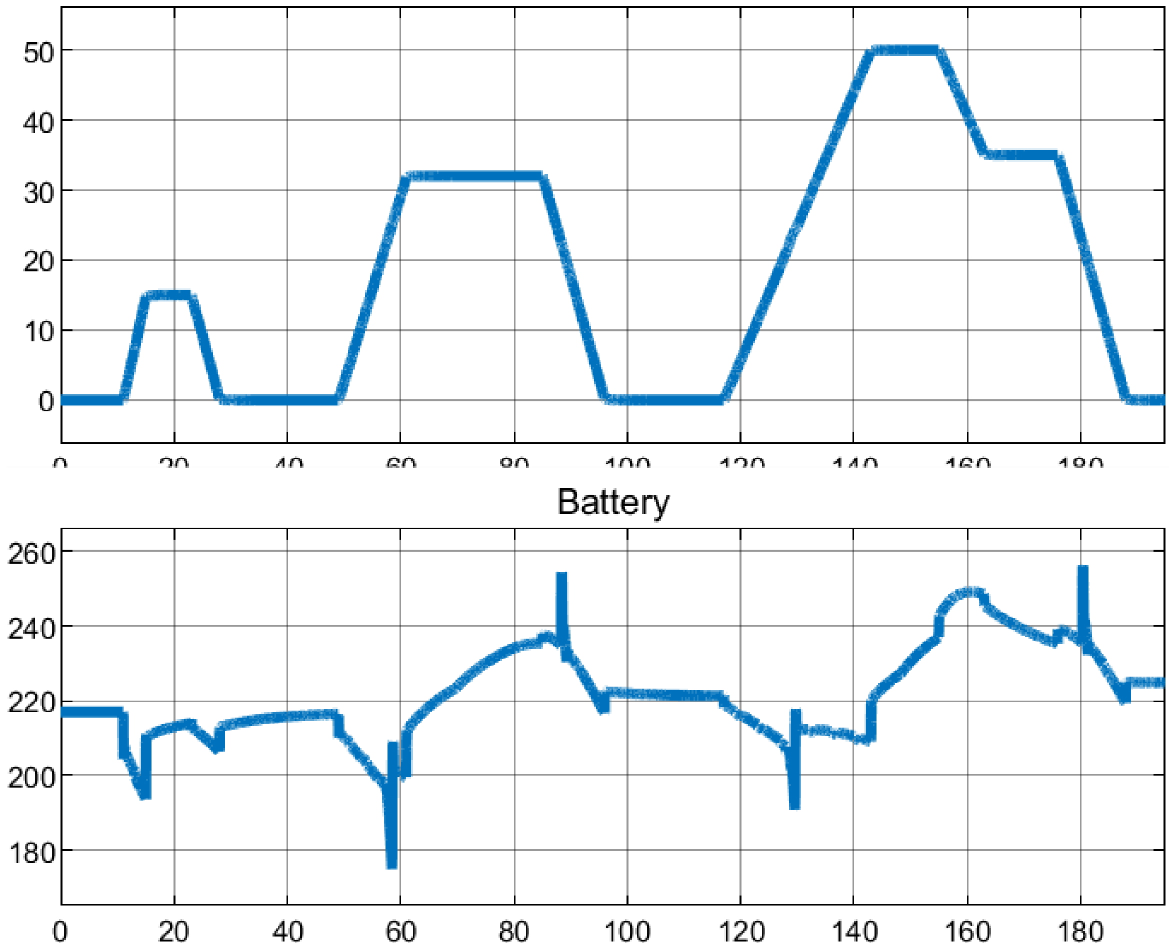

Figure 1.23: Voltage of Battery during driving

According to the graph, the battery voltage tends decline while accelerating but booms up during stable mode or decelerating.

4.6.7. DC-DC Temperature

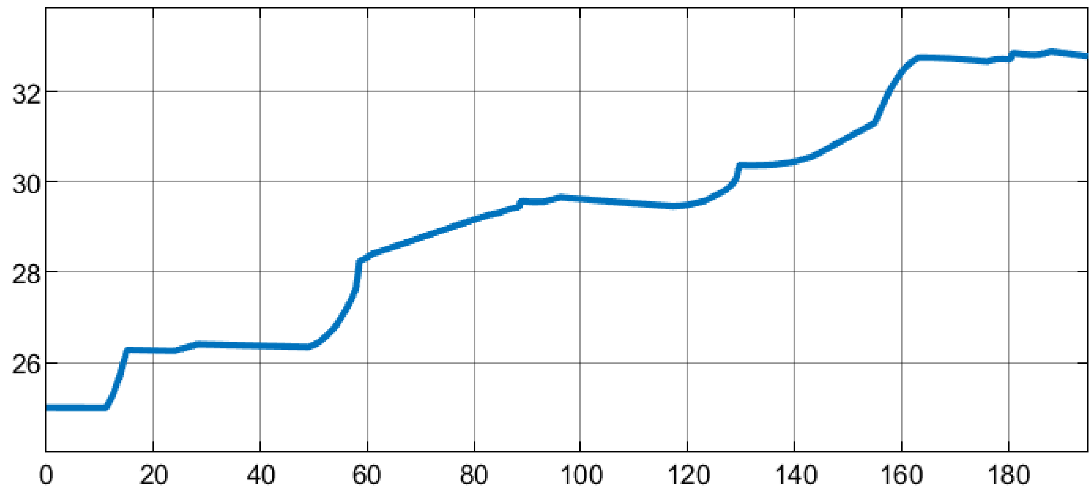

Figure 1.24: DC-DC Temperature

The Temperature of DC-DC Converter has overall upward trend during driving but unstable. The trend tends to rise stronger while the vehicle is accelerating and remain calm while the car is at stable mode.

4.6.8. Fuel Economy

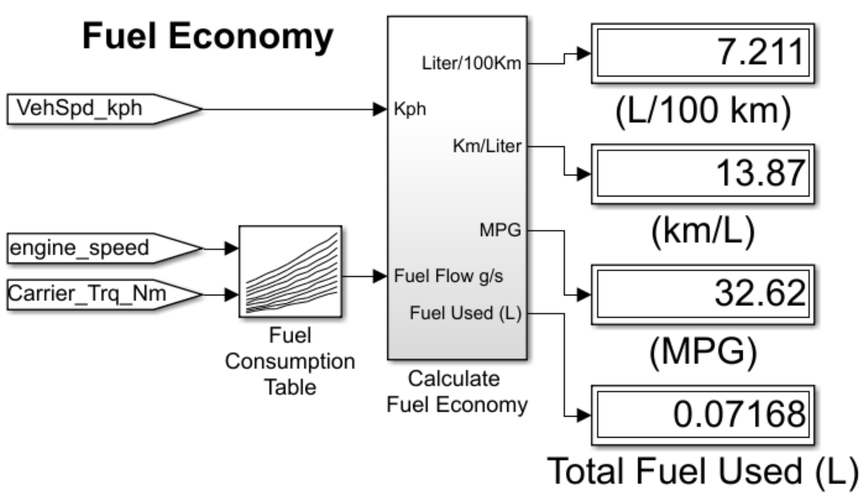

Figure 1.25: Fuel Economy

After 195-second duration, the EPA Fuel Economy of the vehicle is 32.62 MPG with the total fuel used during the time is 0.07168 L

5. CASE STUDY

In this case study, we would like to observe and compare the simulation results using the specification of the model Toyota Prius by changing several parameters but drive cycle. The achieved results are fuel consumption of the Toyota Prius model. After calculations, the fuel economy of the model will be estimated (city/highway/combined MPG).

Moreover, in order to minimize the error between Vehicle Speed and Reference Speed, investigation, and adjustment about the Kp, Ki, and Kd in PID-controller are carried out. The aim is to improve the precise Vehicle Speed to meet with the demands of the given Drive Cycle.

5.1. Toyota Prius Specification

To investigate a Toyota Prius Hybrid model, we use the available Power-split HEV model. However, some specifications have to be changed so as to make a replica of Toyota Prius on Simulink.

Following below are some specifications of a 2021 Toyota Prius LE-Edition Vehicle:

Table 1: Toyota Prius Specifications [3]

Subassembly	Specification	Value
Vehicle	Weight	1378.921 kg
	CG height above ground	5.1 inches
	Drag coefficient	0.24
	Tire Size (Rolling Radius)	0.3175 m
	Frontal Area	4012.47 square inches
Engine	Maximum Power	96 horsepower
	Speed at maximum power	5200 rpm
	Maximum speed	6000 rpm
Battery (Lithium-Ion)	Constant Voltage	207.2 V
	Battery Cells	56 cells
	Capacity	3.6 Ah
DC-DC Converter	Output Voltage	600 V

5.2. Drive cycle

After changing the specifications of the model. The simulation will be investigated, the result will be the fuel consumption during highway and city conditions.
During city condition, the drive cycle FTP75 is used with the characteristic as follow:

- Distance travelled: 17.77 km (11.04 miles)
- Duration: 2474 seconds

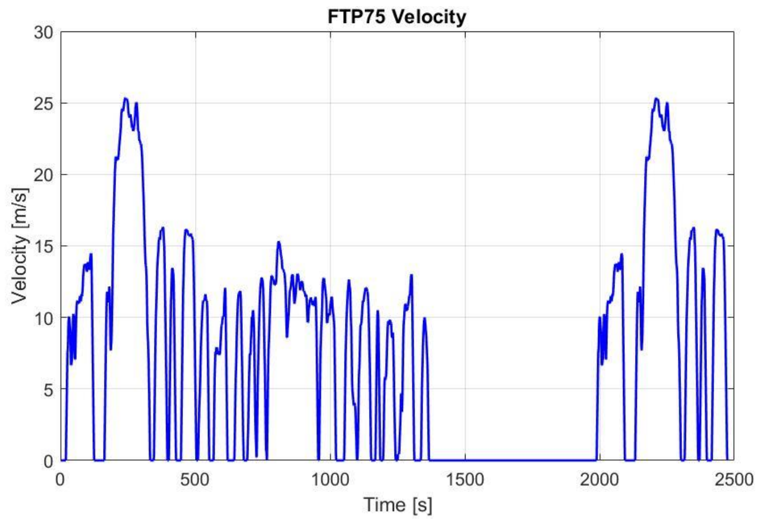

Figure 1.26: FTP-75 Driving Cycle

During highway condition, the drive cycle HWFET is used with the characteristic as follow:

- Distance travelled: 16.45 km (10.26 miles)
- Duration: 765 seconds

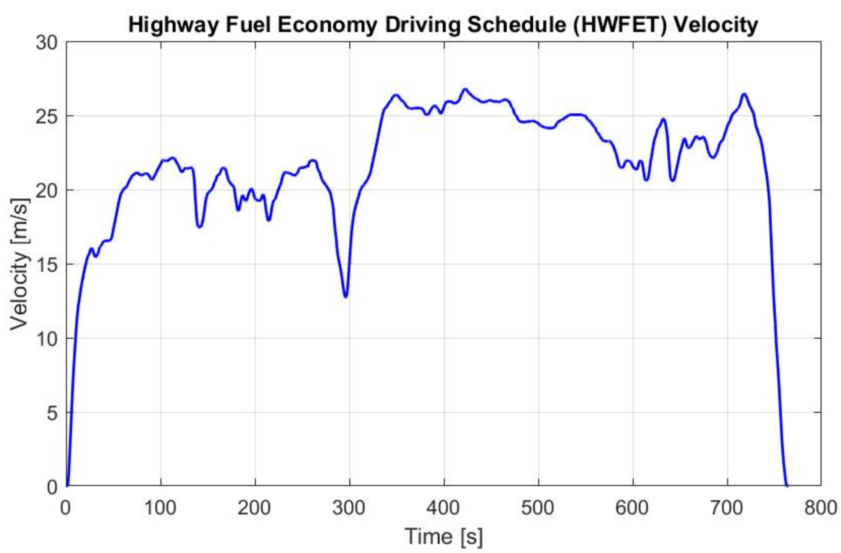

Figure 1.27: HWFET Driving Cycle

5.3. Results and Conclusion

Below are the Results for the two mentioned Driving Cycle:

- **FTP – 75:**

In this drive cycle, the PID controller has been changed from the default value Kp = 0.02, Ki = 0.04, Kd = 0 to Kp = 0.12, Ki = 0.0042, Kd = 0. The vehicle speed approximated to the reference speed.

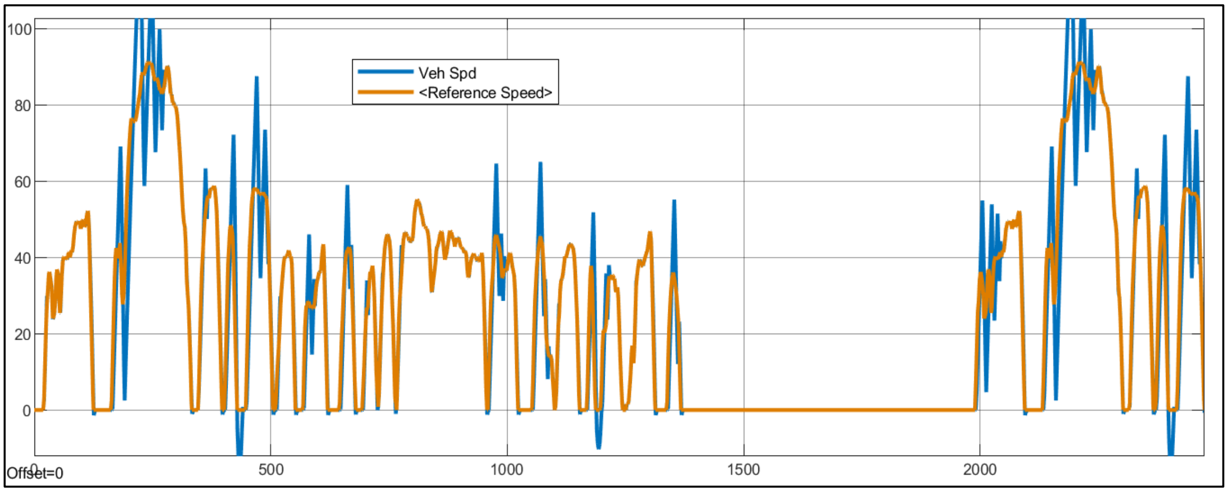

Figure 1.28: Vehicle Speed and Reference Speed (FTP-75) (Before adjustment)

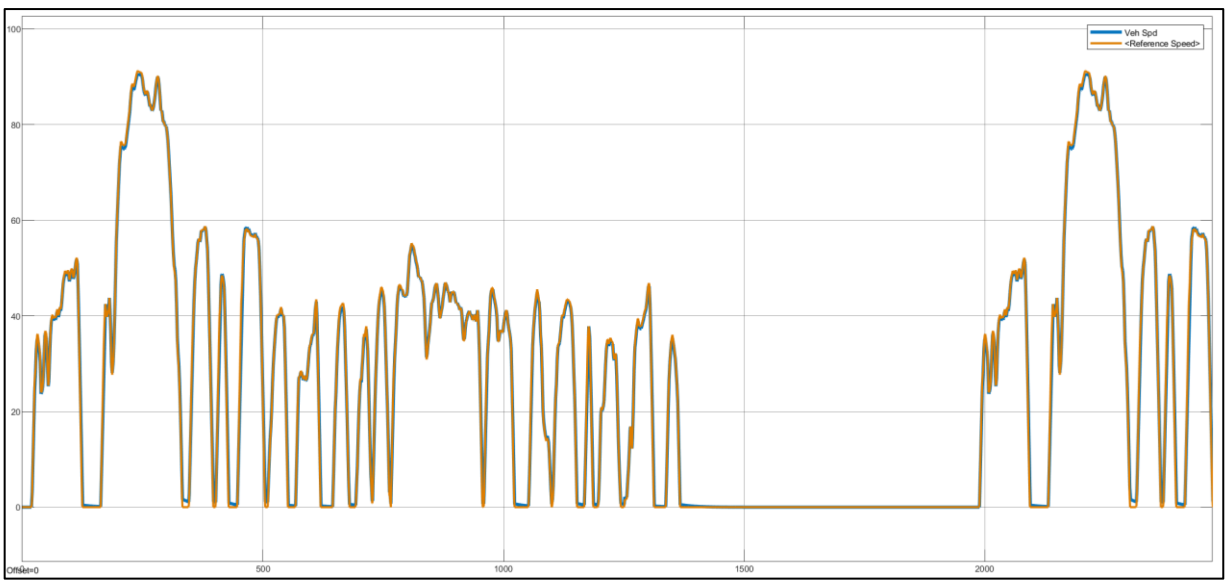

Figure 1.29: Vehicle Speed and Reference Speed (FTP-75) (After adjustment)

- **HWFET:**

In highway condition, the value of PID controller is adjusted to Kp = 0.05, Ki = 0.0042 and Kd = 0

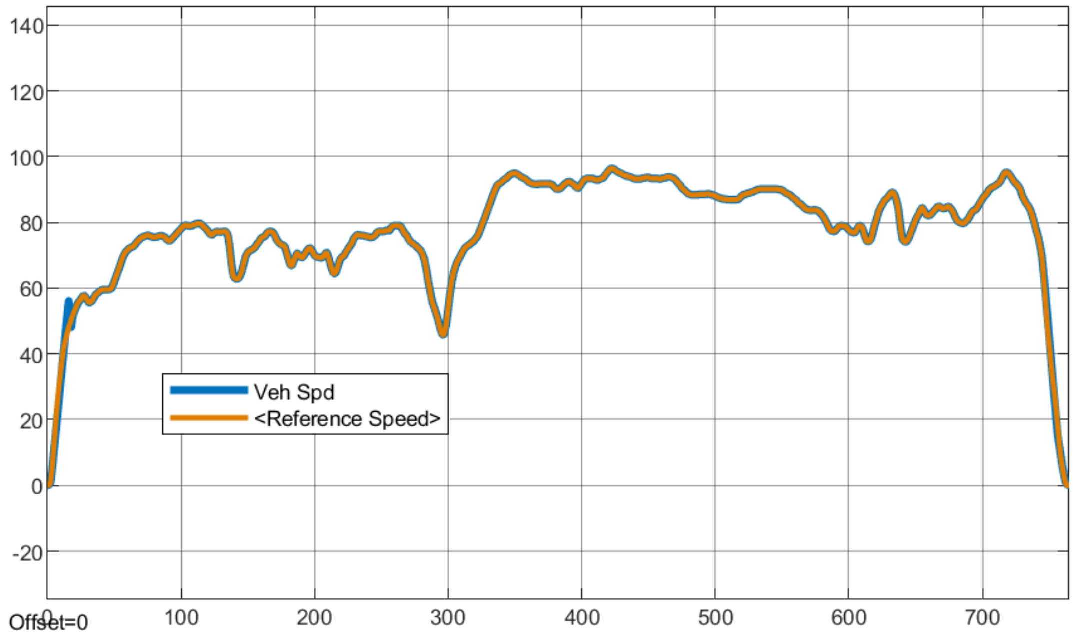

Figure 1.30: Vehicle Speed and Reference Speed (HWFET) (Before adjustment)

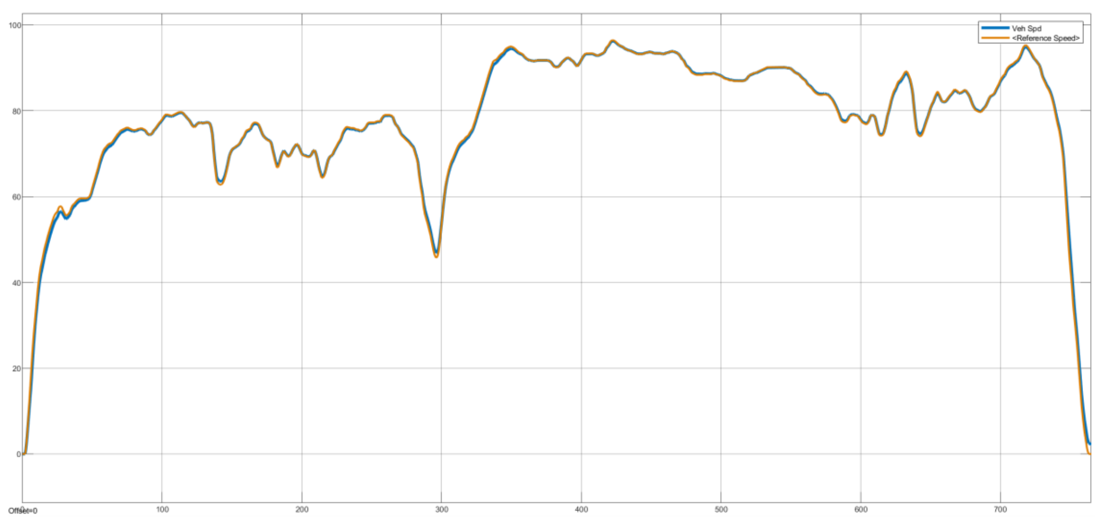

Figure 1.31: Vehicle Speed and Reference Speed (HWFET) (After adjustment)

- **Fuel Economy Result**

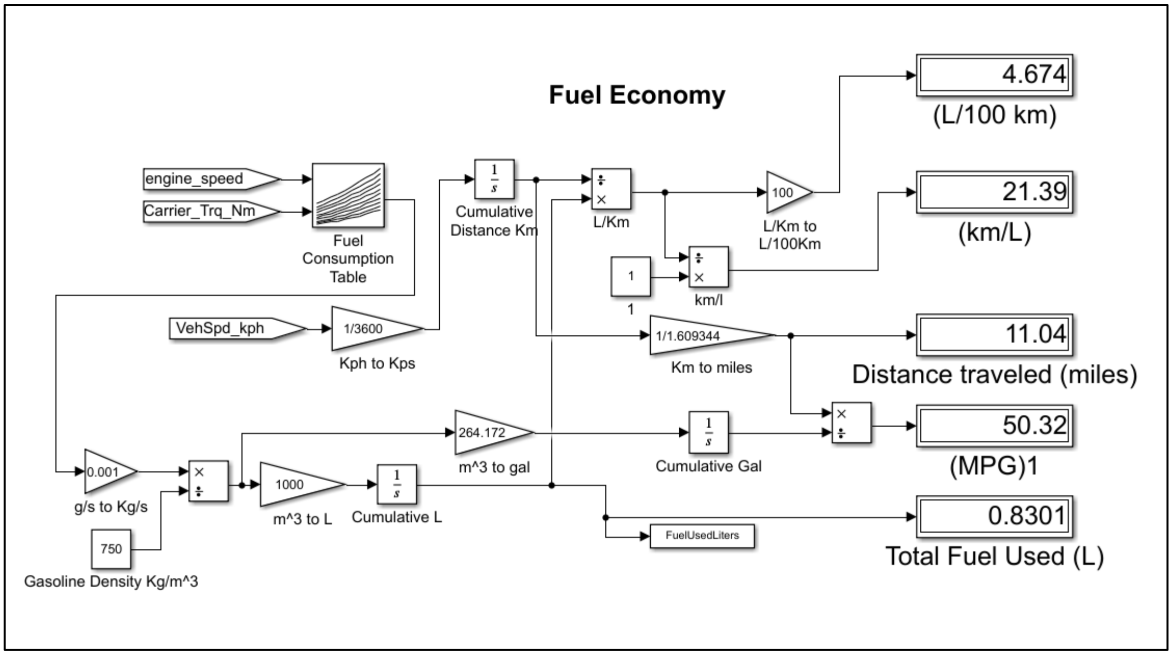

Figure 1.32: Fuel Economy (FTP-75)

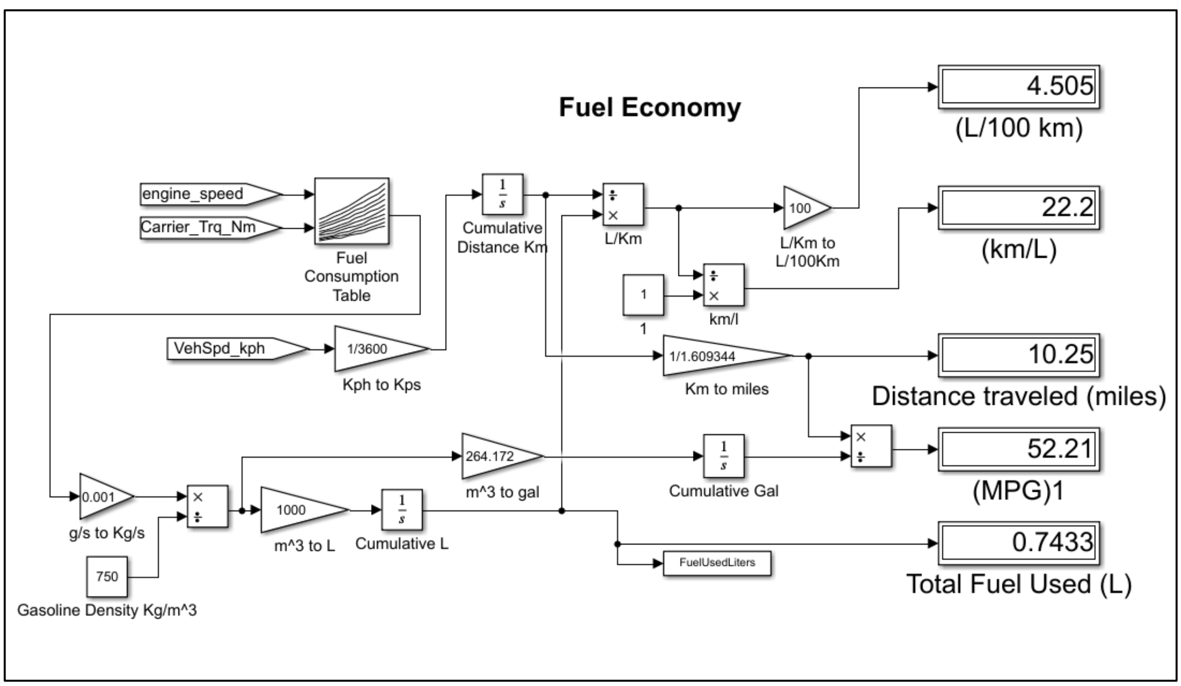

Figure 1.33: Fuel Economy (HWFET)

- **Conclusion:**

After changing the value Kp, Ki, Kd for each situation, the error is reduced significantly during both cycles, hence the Vehicle speed followed the demand speed better during process

The estimated fuel economy shall be compared with the Estimated EPA Fuel Economy in MPG:

Table 2: Compare estimated fuel economy with estimated EPA fuel economy in MPG

	City (FTP-75)	Highway (HWFET)	Combined
EPA Fuel Economy	54	50	52
Processed Fuel Economy	50	52	51

In Conclusion, the Replica Toyota Prius model closely reach the Fuel Economy demand of 2021 Toyota Prius LE-Edition.

CHAPTER 2
ASSIGNMENT 1: CLOSED LOOP AND OPEN LOOP SYSTEM

1. What are the differences between Open Loop and Closed Loop?

1.1. Definition

A Control System which doesn't have any feedback connected to it is called as Open Loop System. These types of systems don't depend upon its output i.e., in open loop systems, output is not used as a control variable for the system, and it has no effect on the input. an open-loop control system utilizes an actuating device to control the process directly without using feedback.

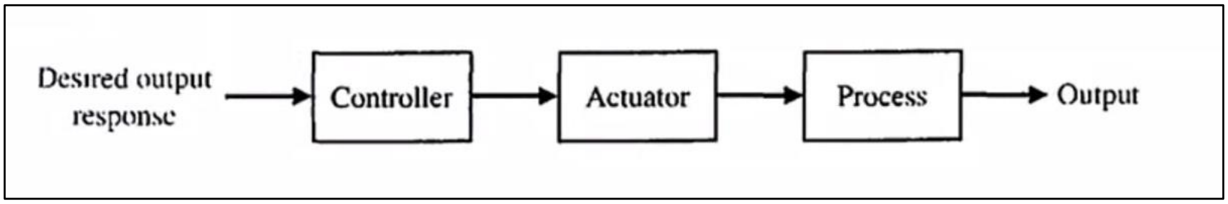

Figure 2.1 Open-loop System

A control system with feedback loop is called “closed loop control system”. In other words, the control system which uses its feedback signal to generate output is called” closed loop control system”. In these control systems, the input is controlled by the feedback signal from input so that it can correct the errors occurred. Closed loop control systems are two-way signal flow systems.

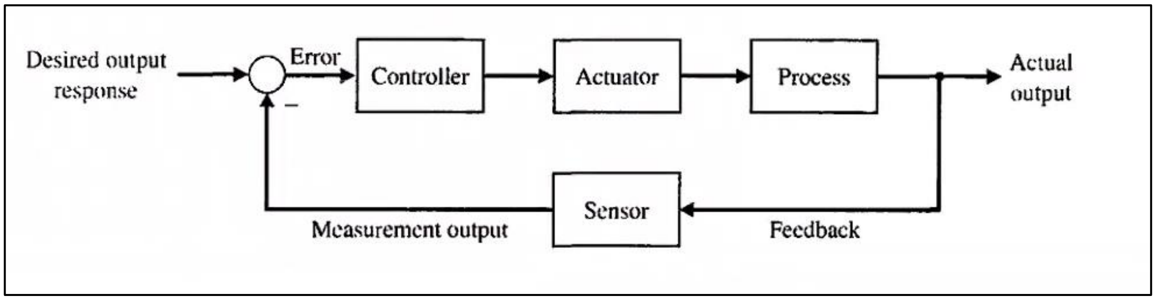

Figure 2.2 Closed loop system

1.2. Differences

- Closed loop receives feedback signal through sensor and sends this signal to the controller while Open loop control system does not have feedback

- Closed loop control system has ability to self-correct while open loop system does not

- In Open loop control system, the controlled action is free from the output

- In the closed-loop system, the output mainly depends on the controlled act of the system.

- The construction of open loop system is simple while closed loop is complex

- The optimization of the open loop is impossible while that of Closed loop is possible

- Closed-loop systems have the obvious advantage of greater accuracy than open-loop systems.

- It is easy to calibrate the Closed loop system than Open loop system

1.3. Advantages and disadvantages of Open loop and Closed loop

1.3.1. Open loop system

❖ **The main advantages:**

- Open Loop Control Systems are very simple and easy to design.
- These are considerably cheaper than other types of control systems.

- Maintenance of an open loop control system is very simple.
- Generally, open loop systems are stable up to some extent.
- These types of systems are easy to construct and are convenient to use.

❖ **The disadvantages:**

- The bandwidth of open loop control system is less.
- The non-feedback system doesn't facilitate the process of automation.
- Open loop systems are inaccurate in nature and unreliable.
- If their output is affected by some external disturbances, there is no way to correct them automatically as these are non-feedback systems.

1.3.2. Closed loop system

❖ **Advantages:**

- As the closed loop control systems have feedback signal to control the output, these are very accurate and less error prone.
- They can automatically correct the errors by means of the feedback signal.
- Closed loop systems are very accurate.
- Band width of open loop system is very large than closed loop system.
- They can support automation.
- As they have very high noise margin, they are less affected by noise.

❖ **Disadvantages:**

- They are very complex and complicated to design.
- Economically they are very costlier.
- High maintenance is required.
- Sometimes the feedback signal causes the system to oscillate, which will give oscillatory response.
- More time and efforts are needed to design a stable closed loop system.

2. Example:

2.1. Open loop system:

Windscreen washer system

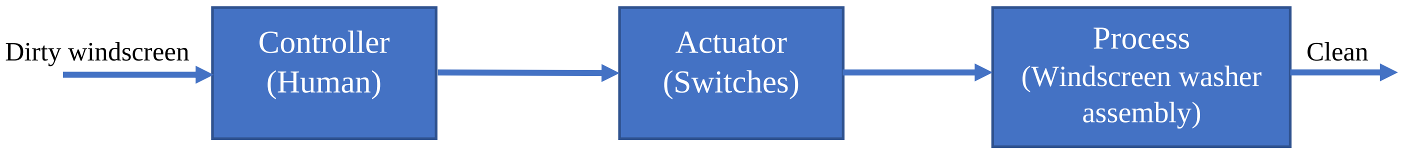

Figure 2.3 Block system for Windscreen washer system

2.2. Closed loop system

Cooling system

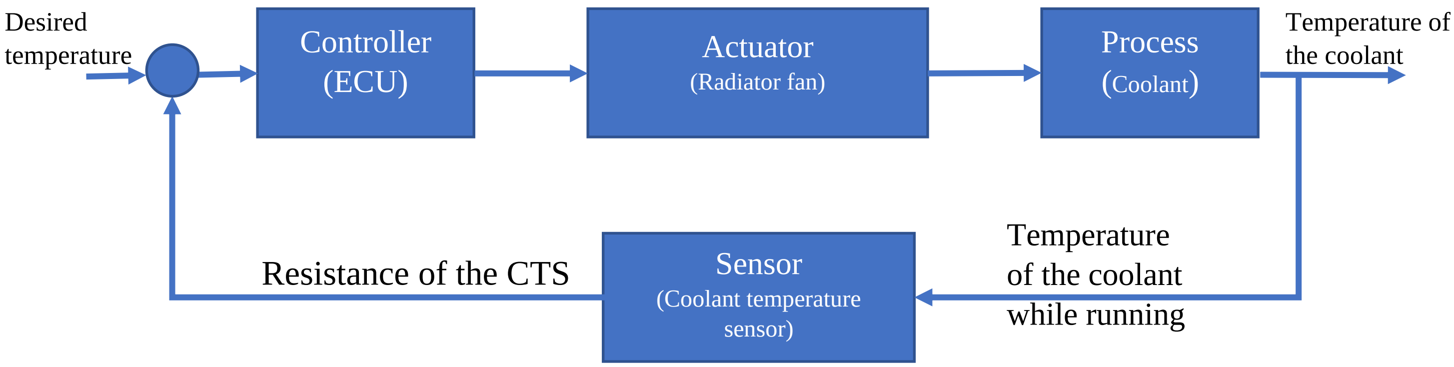

Figure 2.4 Block system for Cooling system

CHAPTER 3

ASSIGNMENT 2.

1. Simulation and analysis of vehicle system with output as speed and distance in 3 cases:

- Change input

- Change system parameters (b, m)

Solution:

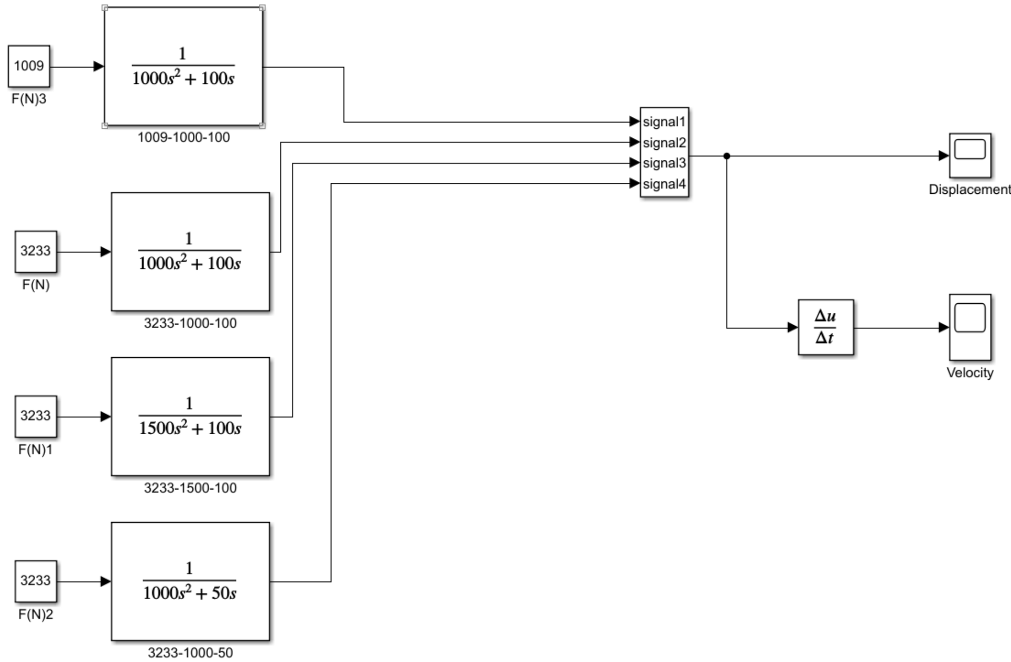

Figure 3.1 Simulation

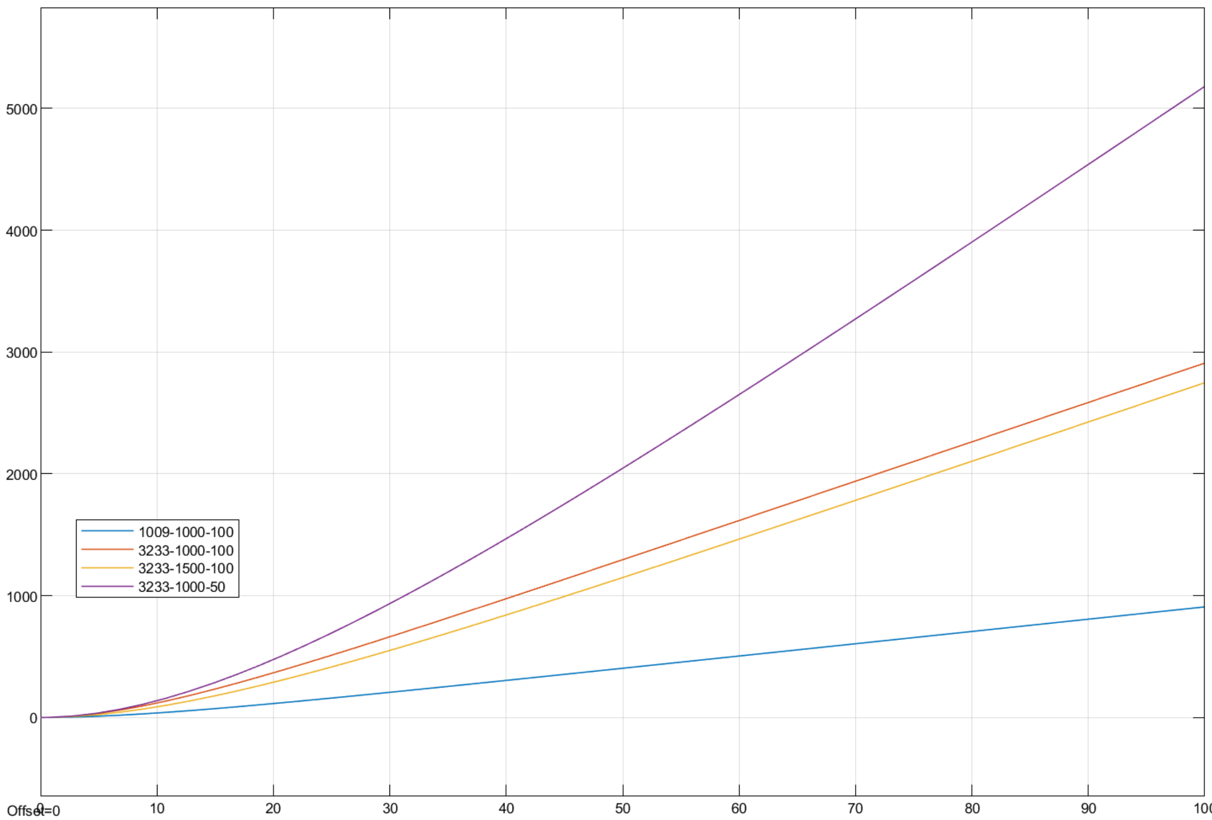

Figure 3.2 Displacement

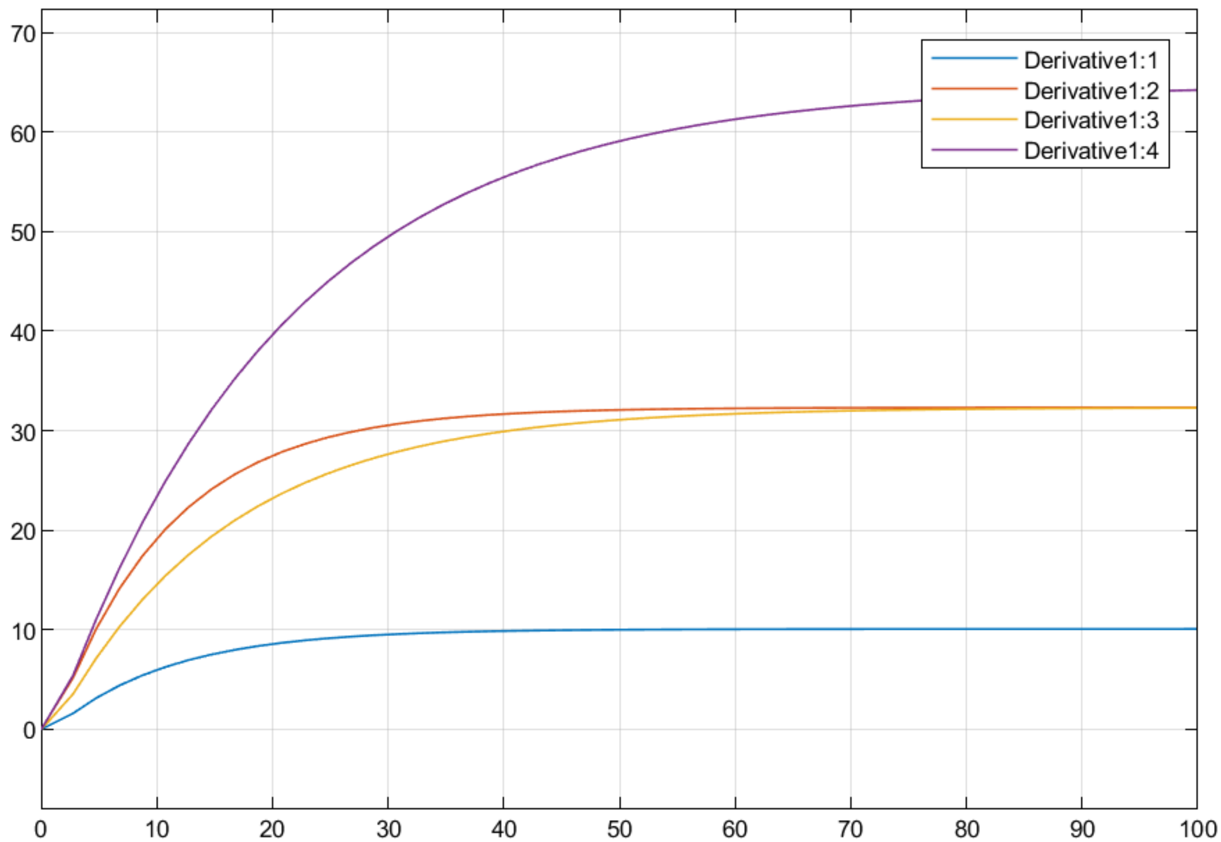

Figure 3.3 Velocity

=> Based on the 2 graphs obtained from Simulink software, we can see that the output as displacement and velocity is proportional to the input and b. The output inversely proportional to m.

2. Simulation and analysis of MSD system with output as distance, speed, and acceleration in 3 cases:

- Change input

- Change system parameters (b, k, m)

Solution:

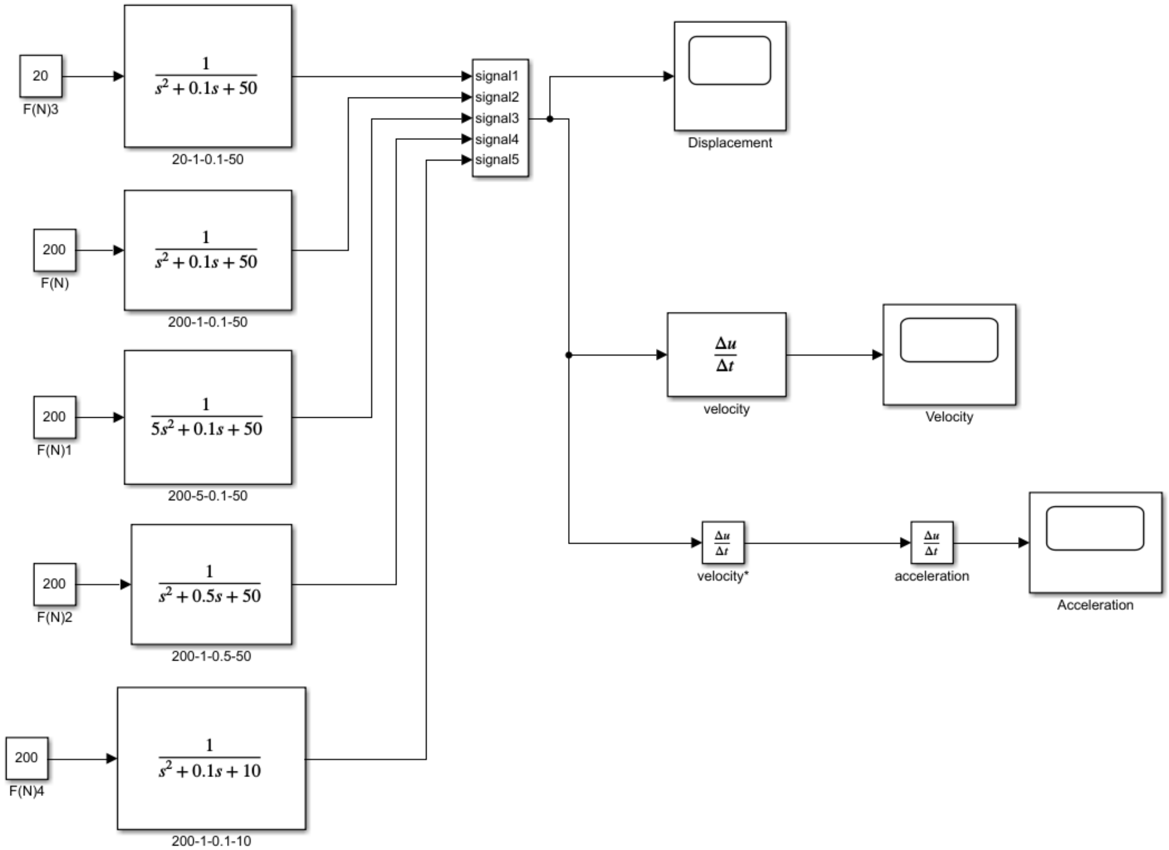

Figure 3.4 Simulation

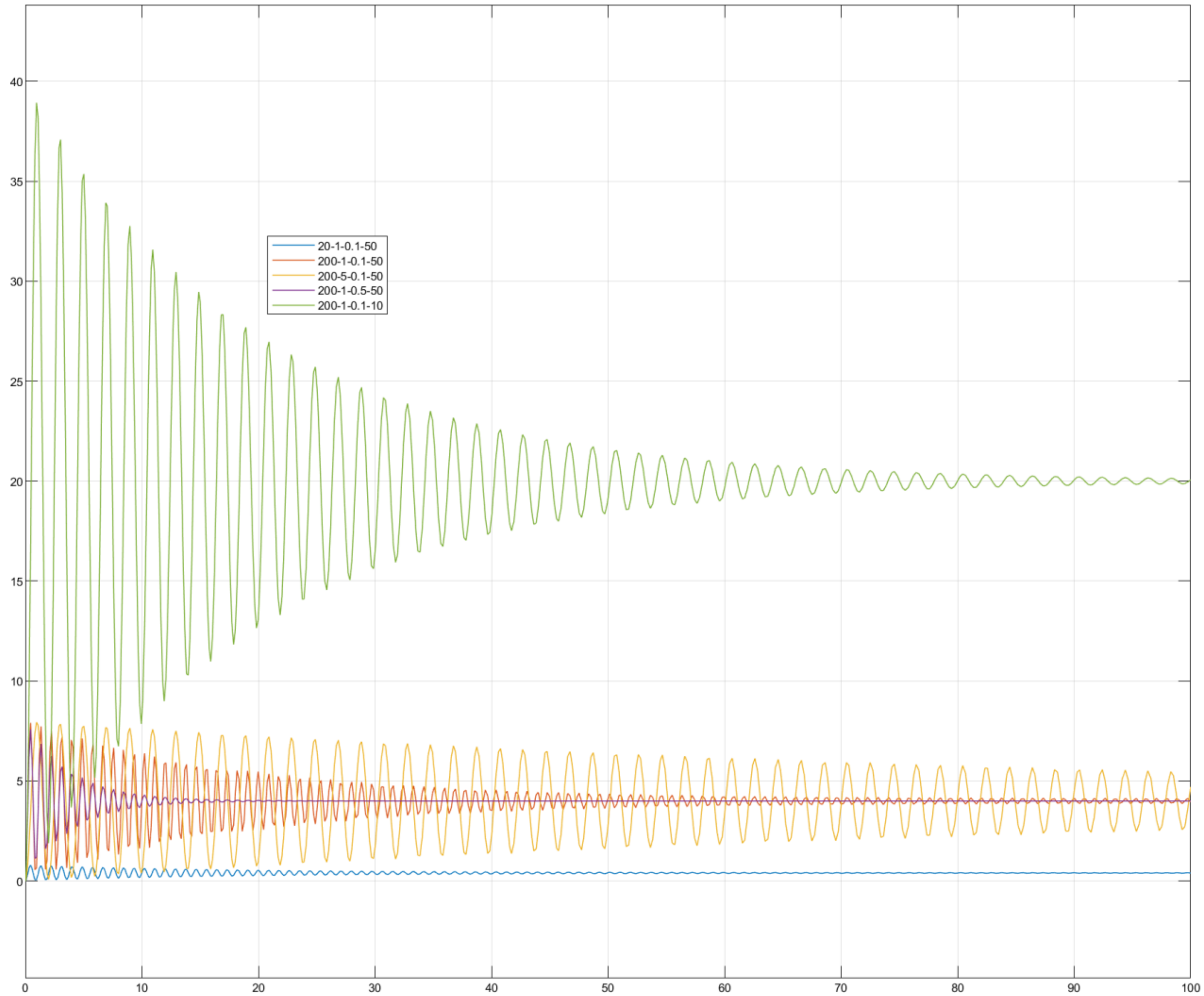

Figure 3.5 Displacement

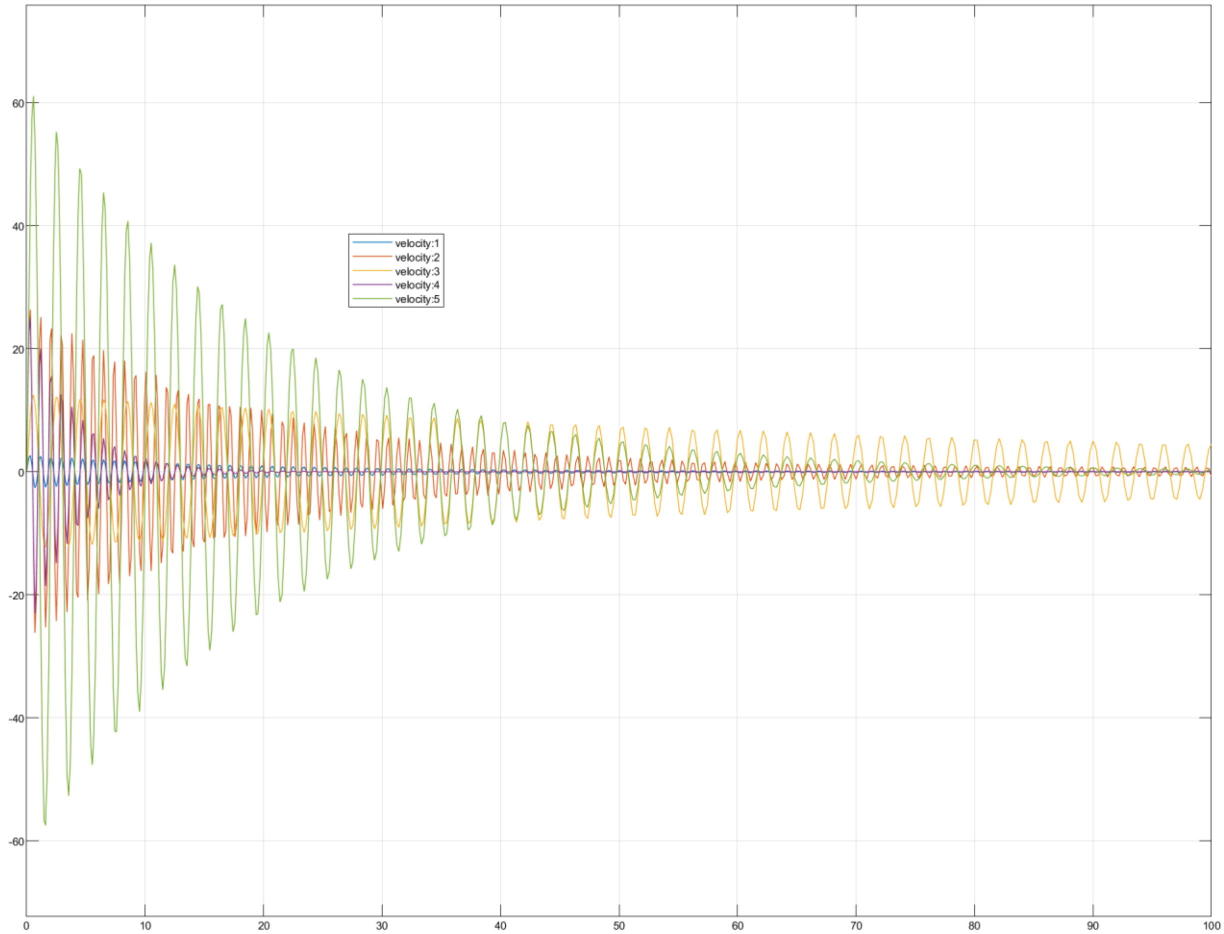

Figure 3.6 Velocity

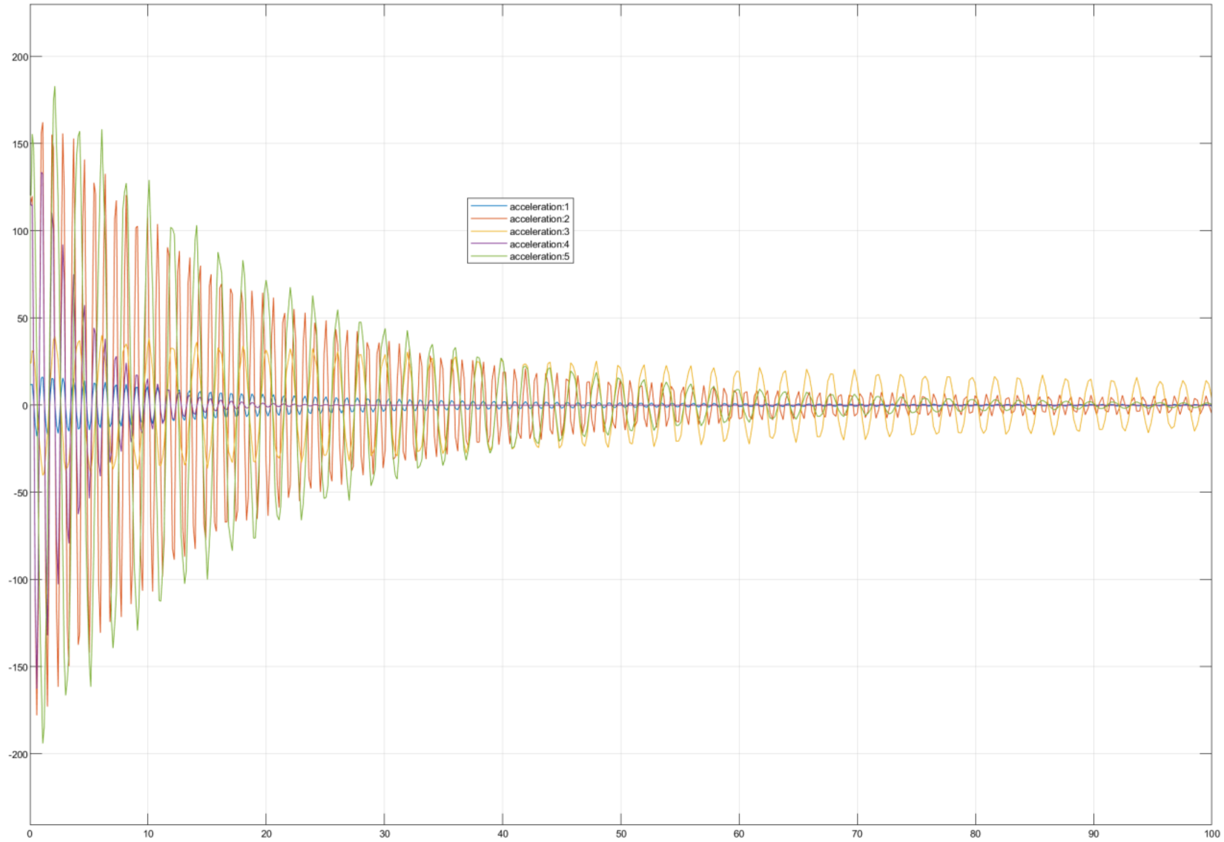

Figure 3.7 Acceleration

=> When comparing the graphs of the cases of changing input value and changing system parameters (b, k, m), we easily realize that the output value is directly proportional to the input value and m, inversely proportional to the values of system parameters b and k.

CHAPTER 4

ASSIGNMENT 3.

1. m = 1kg; k = 1 Nm; b = 3 Ns/m

Since impulse input, we have: H(s) = X(s)

$$\frac{1}{s^2+3s+1} = \frac{A}{s+\frac{3}{2}-\frac{\sqrt{5}}{2}} + \frac{B}{s+\frac{3}{2}+\frac{\sqrt{5}}{2}}$$

$$\leftrightarrow\ A\left(s+\frac{3}{2}+\frac{\sqrt{5}}{2}\right) + B\left(s+\frac{3}{2}-\frac{\sqrt{5}}{2}\right) = 1 \qquad (1)$$

We set: $sA = -\frac{3}{2}+\frac{\sqrt{5}}{2}$; $\qquad sB = -\frac{3}{2}-\frac{\sqrt{5}}{2}$ in (1)

$$\rightarrow \begin{cases} A\sqrt{5} = 1 \\ -B\sqrt{5} = 1 \end{cases} \leftrightarrow \begin{cases} A = \frac{1}{\sqrt{5}} \\ B = \frac{-1}{\sqrt{5}} \end{cases}$$

Hence the practical fraction decomposition is:

$$\frac{1}{s^2+3s+1} = \frac{\frac{1}{\sqrt{5}}}{s+\frac{3}{2}-\frac{\sqrt{5}}{2}} - \frac{\frac{1}{\sqrt{5}}}{s+\frac{3}{2}+\frac{\sqrt{5}}{2}}$$

And thus, from linearity of L^{-1} and part c of theorem:

$$L^{-1}\left\{\frac{1}{s^2+3s+1}\right\} = L^{-1}\left\{\frac{\frac{1}{\sqrt{5}}}{s+\frac{3}{2}-\frac{\sqrt{5}}{2}}\right\} - L^{-1}\left\{\frac{\frac{1}{\sqrt{5}}}{s+\frac{3}{2}+\frac{\sqrt{5}}{2}}\right\}$$

$$\rightarrow\ x(t) = \frac{1}{\sqrt{5}} \times e^{\left(-\frac{3}{2}+\frac{\sqrt{5}}{2}\right)t} - \frac{1}{\sqrt{5}} \times e^{\left(-\frac{3}{2}-\frac{\sqrt{5}}{2}\right)t}$$

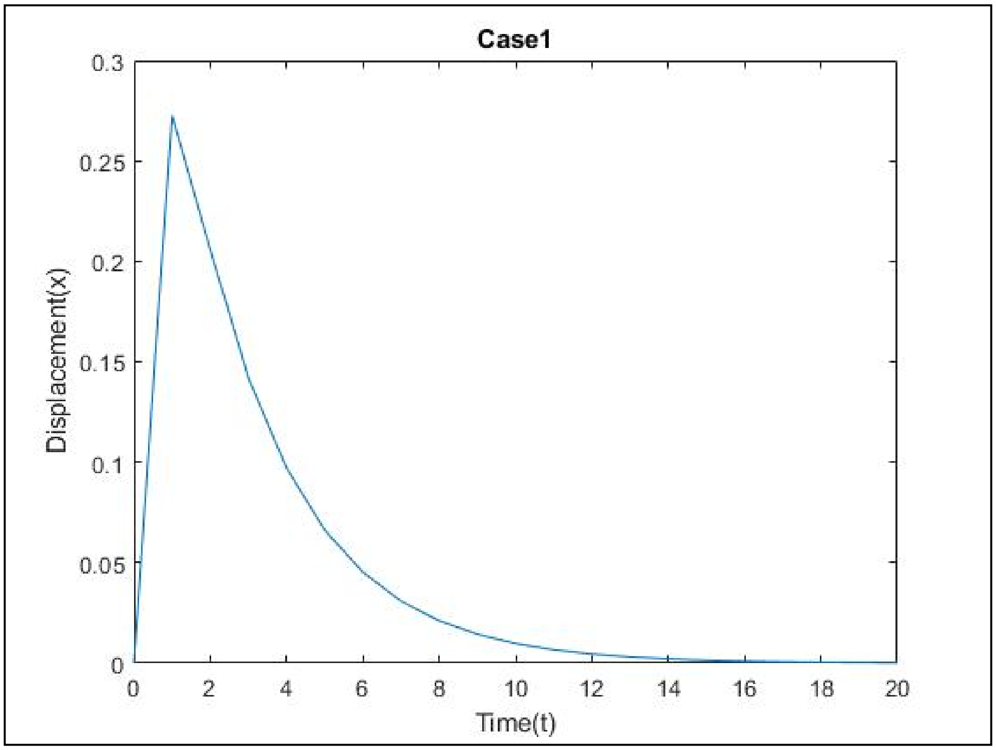

Figure 4.1 m = 1kg; k = 1 Nm; b = 3 Ns/m

Since two poles ($s = \frac{-3+\sqrt{5}}{2}; s = \frac{-3-\sqrt{5}}{2}$) of the transfer function are in the left-hand plane, then the system is stable.

2. m = 1 kg; k = 1 Nm; b = - 3 Ns/m

Apply the same calculation with spring, we have:

$$x(t) = \frac{1}{\sqrt{5}} \times e^{\frac{3+\sqrt{5}}{2}t} - \frac{1}{\sqrt{5}} \times e^{\frac{3-\sqrt{5}}{2}t}$$

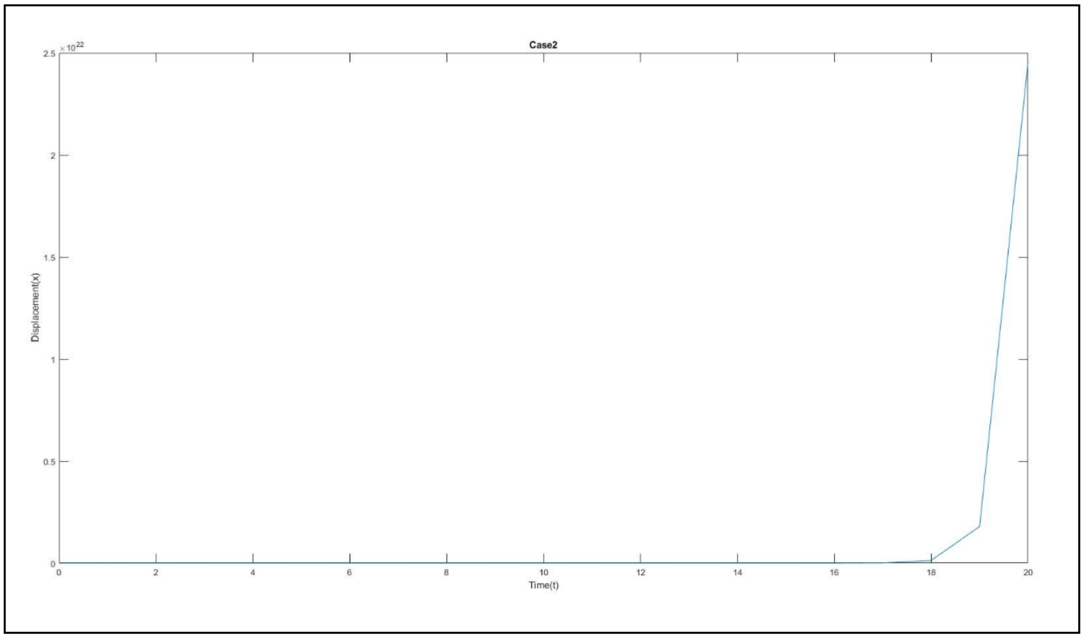

Figure 4.2 m = 1 kg; k = 1 Nm; b = - 3 Ns/m

All the poles of the transfer function ($s = \frac{3+\sqrt{5}}{2}$; $s = \frac{3-\sqrt{5}}{2}$) are in the right-hand plane of the s-plane, then the system is unstable

3. m = 1 kg; k = 1 Nm; b = 0.2 Ns/m

We have:

$$H(s) = \frac{1}{s^2 + 0.2s + 1}$$

For the complex roots, we change *H(s)* to:

$$\frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

With the new formula, we said that ω_n = 1 and ξ = 0.1

So that:

$$x(t) = \frac{\omega_n}{\sqrt{1-\xi^2}} \times e^{-\xi\omega_n t} \times \sin\left(\omega_n\sqrt{1-\xi^2 t}\right)$$

$$\rightarrow x(t) = \frac{1}{\sqrt{1-0.1^2}} \times e^{-0.1t} \times \sin(1 \times \sqrt{1-0.1^2}\mathrm{t})$$

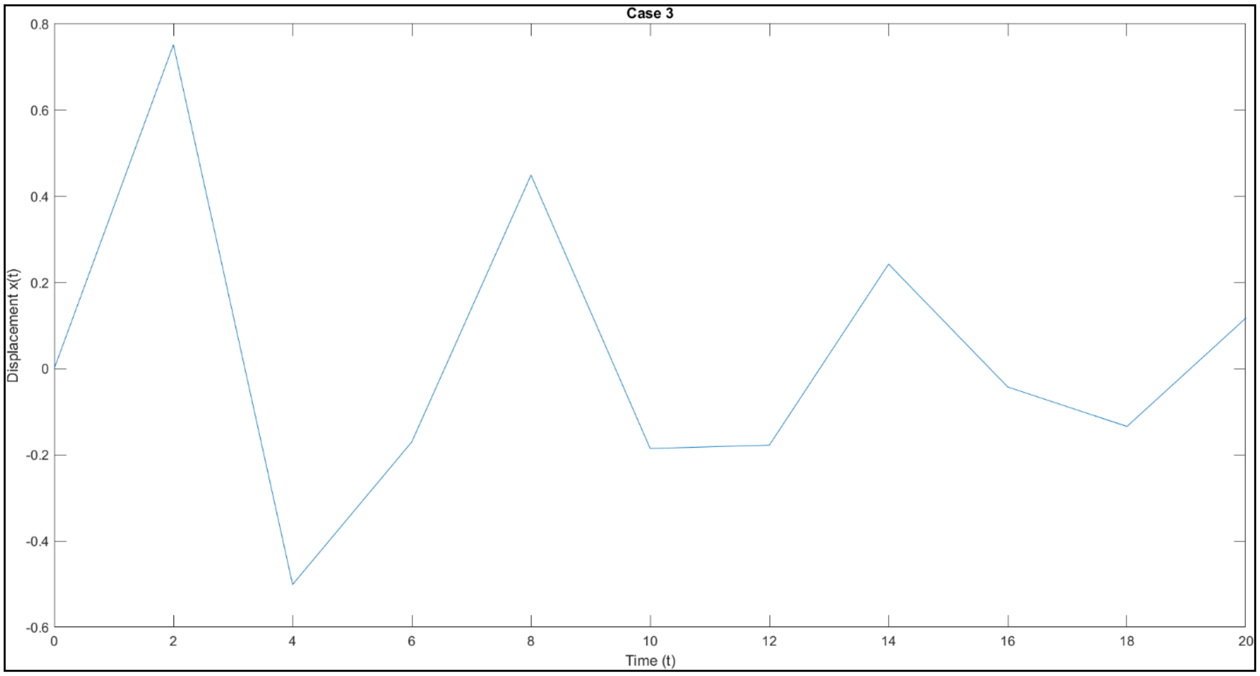

Figure 4.3 m = 1 kg; k = 1 Nm; b = 0.2 Ns/m

All the poles of the transfer function ($s = \frac{-1 + 3\sqrt{11}i}{10}$; $s = \frac{-1 - 3\sqrt{11}i}{10}$) have negative real parts, then the system is stable.

4. m = 1 kg; k = 1 Nm; b = - 0.2 Ns/m

Using the same method with section 3, we have:

$$x(t) = \frac{1}{\sqrt{1-(0.1)^2}} \times e^{0.1t} \times \sin(\sqrt{1-(-0.1)^2 t})$$

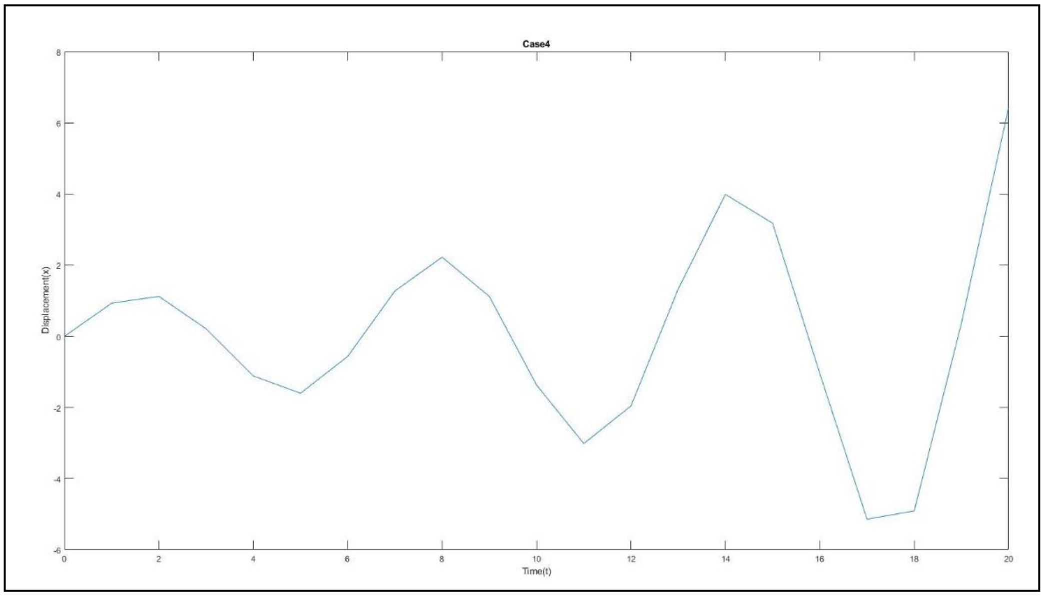

Figure 4.4 m = 1 kg; k = 1 Nm; b = - 0.2 Ns/m

All the poles of the transfer function ($s = \frac{1 + 3\sqrt{11}i}{10}; s = \frac{1 - 3\sqrt{11}i}{10}$) have positive real parts, then the system is unstable.