MODELLING OF BRAKING SYSTEM ON SERIES HYBRID ELECTRIC VEHICLE APPLICATION

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**This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Automotive)
with Honours**

Faculty of Mechanical Engineering

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DECLARATION

I declare that this project report entitled “Modelling of Braking System on Series Hybrid Electric Vehicle Application” is the result of my own work except as cited in the references

Signature : ....

Name : Muhamad Firdaus Bin Mohd Yussof

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

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Name of Supervisor	:	Dr. Adzni Bin Md. Saad
Date	:	....

DEDICATION

This report is dedicated to my beloved mother, family and my friends who have been supported and encourage me during my studies.

ABSTRACT

Nowadays, the vehicle fuel price especially gasoline and diesel have been increased significantly. This increased make driver and consumer more interested toward conventional vehicle that can reduce the fuel consumption and hybrid electric vehicle which have low fuel consumption. The objectives of this study are to develop mathematical model of braking system for series hybrid electric vehicle application. The simulation is run toward the regenerative braking model to get the vehicle performance. Then, this study is to investigate the braking system behaviour on the vehicle performance. In this project, the investigation only based on the mathematical model simulation without any experimental work involved. At the beginning of the project, find the suitable sample of the braking parameter from various resources to use in the simulation of the project. From the simulation, the result of the vehicle performance such as the battery SOC, vehicle speed and the fuel consumption will be discussed. The vehicle weight is being change to investigate it influence toward the vehicle performance. When the weight of the vehicle increase, the fuel consumption of the vehicle will decrease because of the speed of the vehicle also decrease.

ABSTRAK

Pada masa kini, harga bahan api kenderaan terutamanya petrol dan diesel telah meningkat dengan ketara. Peningkatan ini membuatkan pemandu dan pengguna lebih berminat ke arah kenderaan konvensional yang boleh mengurangkan penggunaan bahan api dan kenderaan electrik hibrid yang mempunyai penggunaan bahan api yang rendah. Objektif kajian ini adalah untuk membangunkan model matematik sistem brek untuk kenderaan elektrik hybrid sesiri. Simulasi dijalankan terhadap model brek regeneratif untuk mendapatkan prestasi kenderaan. Kemudian, kajian ini adalah untuk menyiasat perubahan sistem brek terhadap prestasi kenderaan. Dalam projek ini, siasatan hanya berdasarkan simulasi model matematik tanpa melibatkan sebarang kerja eksperimen. Pada permulaan projek, sampel yang sesuai untuk parameter brek dari pelbagai sumber dicari untuk digunakan dalam simulasi projek. Hasil dari simulasi, prestasi kenderaan seperti SOC bateri, kelajuan kenderaan dan penggunaan bahan api akan dibincangkan. Perubahan berat kenderaan dilakukan untuk menyiasat kesannya terhadap prestasi kenderaan. Apabila berat kenderaan meningkat, penggunaan bahan bakar kenderaan akan berkurangan kerana kelajuan kenderaan juga berkurangan.

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Firstly, I am very grateful to meet Allah with His Grace I have manage to complete my report for my Final Year Project this semester.

I wish to express my sincere appreciation and gratitude to my supervisor, Dr Adzni bin Md. Saad for his guidance and effort with valuable and useful advice along this project running. He always inspires me with his ideas and suggestions to produce a better work. I cannot finish my project in time without his guidance.

Besides that, I also would like to thanks to MathWorks for their MATLAB/Simulink software that help me a lot to run all the simulation needed in my project.

Not to forget, an honourable mention goes to my course mates and friends for their ideas and supports during this project. without helps of the particular persons that have been mentioned above, I would encounter many problems while completing the whole project

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LIST OF ABBREVATIONS

HEV	Hybrid Electric Vehicle
HV	Hybrid Vehicle
EV	Electric Vehicle
BEV	Battery Electric Vehicle
ICE	Internal Combustion Engine
RBS	Regenerative Braking System
ESS	Energy Storage System
SOC	State-Of-Charge

CHAPTER 1

INTRODUCTION

1.1 Background of study

1.1.1 Hybrid electric vehicle (HEV)

Improving fuel efficiency and reducing emission produce by vehicles have been important task to the automobile industry in this crucial time being because of the awareness to the global crude oil supply and the greenhouse effect which can harm people. Hybrid vehicle (HV) development is one of the solution that have been carried out to solve the problem which can reduce emission while having much better fuel consumption vehicles(J. Liu & Peng, 2007). Hybrid vehicle (HV) technology is the vehicle that have two or more power sources.

Hybrid electric vehicles use combination of two power source which are internal combustion engine and the electric motor. There are three types of drivetrain for hybrid electric vehicle which are parallel hybrid, series hybrid and power-split hybrid.

a) Parallel hybrid

For this type of system, the internal combustion engine (ICE) and the electrical motor both are connected to the mechanical transmission(Dao, Seaman, & McPhee, 2010). This two power sources can be simultaneously give the power to drive or move the vehicle by using conventional transmission. Parallel hybrid contains complex control system which lead to high maintenance cost and it also have high probability to breakdown if the settings of the control system is not carefully manage.

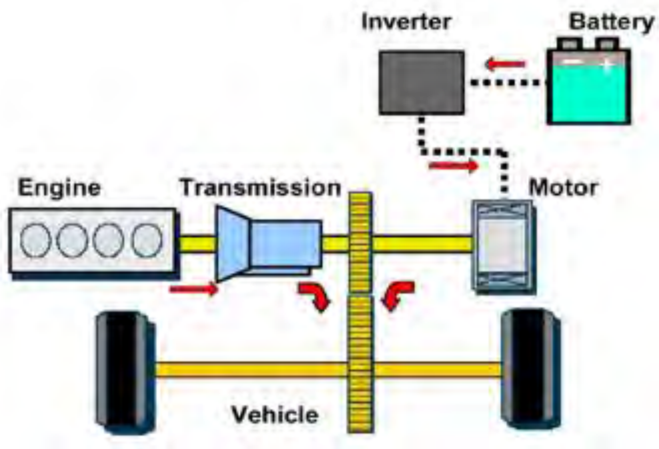


Figure 1.1: Parallel hybrid electric vehicle model

b) Series hybrid

All the components such as ICE engine, electric motor, and battery are in series for this type of drivetrain. The drivetrain is only driven by the electric motor while the ICE engine just acts as generator to recharge the battery that need to supply electric power to the electric motor when required [2]. All the needed power to move the vehicle should go through the generator and electric motor lead to higher traction drive system required for the series hybrid electric vehicle and still it gives many advantages such as better fuel consumption, can operate in longer time, and the ICE engine can operate in its most efficient range even while the vehicle changes speed. This type of drivetrain is the most suitable during stop and go situation in city driving.

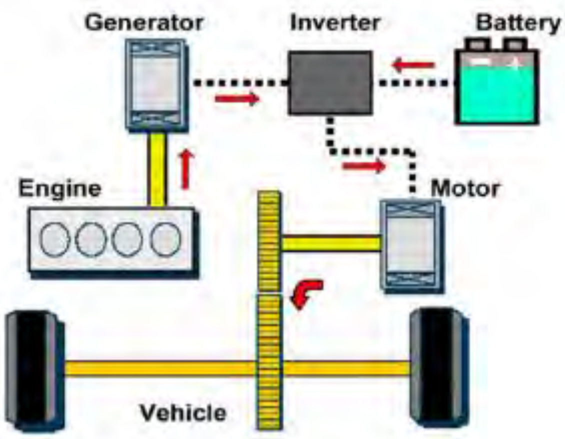


Figure 1.2: Series hybrid electric vehicle model

c) Power-split hybrid

Power-split hybrid configuration is a combination of the two previous transmission which are series hybrid and parallel hybrid transmission(Dao et al., 2010). This combination hybrid system has a power split planetary gear system was created to achieved both advantages from series and parallel hybrid transmission while keep away from their disadvantages(J. L. J. Liu & Peng, 2006).

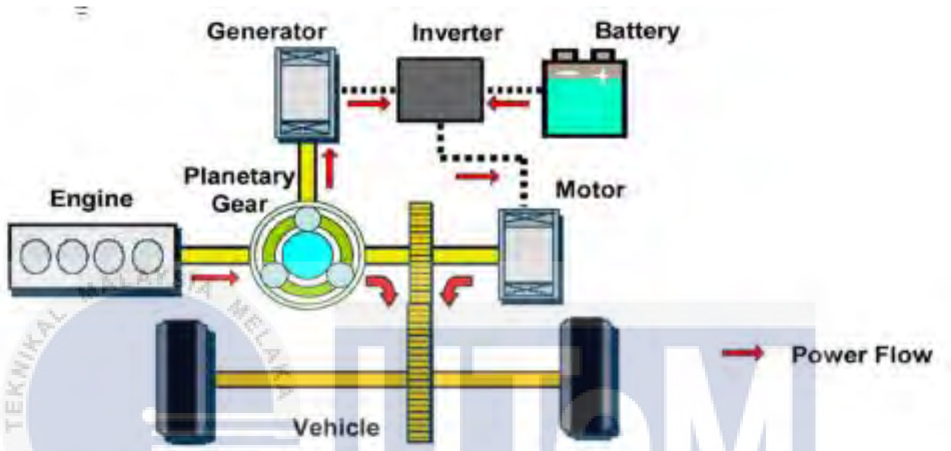


Figure 1.3: Power split hybrid electric vehicle model

1.1.2 Braking system

Braking system is a mechanism use to reduce speed of a vehicle or stop it from moving by pressing a pedal when a vehicle in a moving state(Gupta, Kumar, & Deb, 2014). The type of brakes use in automobiles are disc and drum brakes with various of braking system are used to transmit force from pedal to brakes on wheels(Puttewar, Kakde, & Fidvi, 2014). There are many types of braking system used for vehicle such as:

a. Hydraulic braking system

Hydraulic braking system is a mechanical braking system that use fluid as a medium to transfer from the pedal to the brake pad(Deshpande, 2015). According to the Pascal's law, uniform braking can be applied for each wheels because when a pressured is applied on a fluid, it will distribute equally in all directions(Deshpande, 2015).

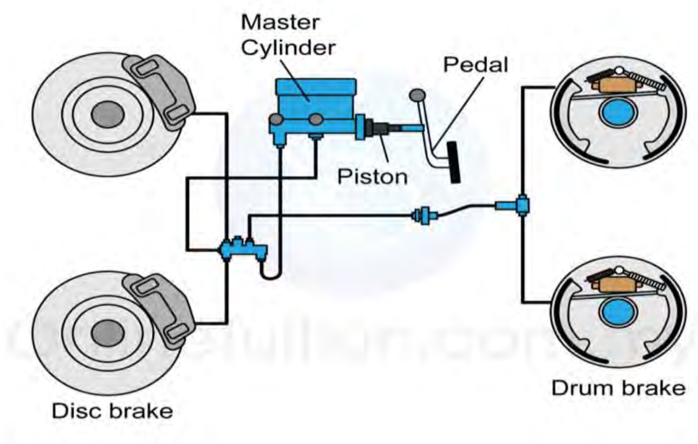


Figure 1.4: Diagram for the hydraulic braking system

b. Pneumatic braking system

Pneumatic braking system is using compressed air to transmit the force to the brake pad to stop the vehicle. This type of braking system usually used in heavy vehicle. Pneumatic brake shows longer delay time because of the air pressured response are much slower than hydraulic brake(He, Wang, Zhang, Wu, & Chen, 2011).

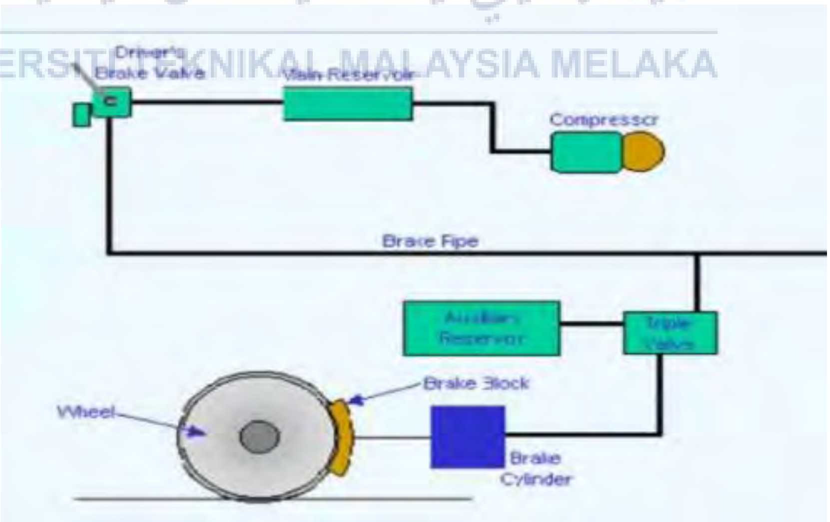


Figure 1.5: Block diagram for the pneumatic braking system

c. Vacuum braking system

In mid 1860s, a vacuum braking system is installed on train. This type of braking system crate vacuum in brake pipe by using vacuum pump. This vacuum braking system is act as vacuum-assisted hydraulic braking system in most of the light weight vehicle which the vacuum in pipe is creating by the engine of the vehicle. The driver's effort needed to push the pedal can be reducing by creating the vacuum in the brake pipe(Journal et al., 2015).

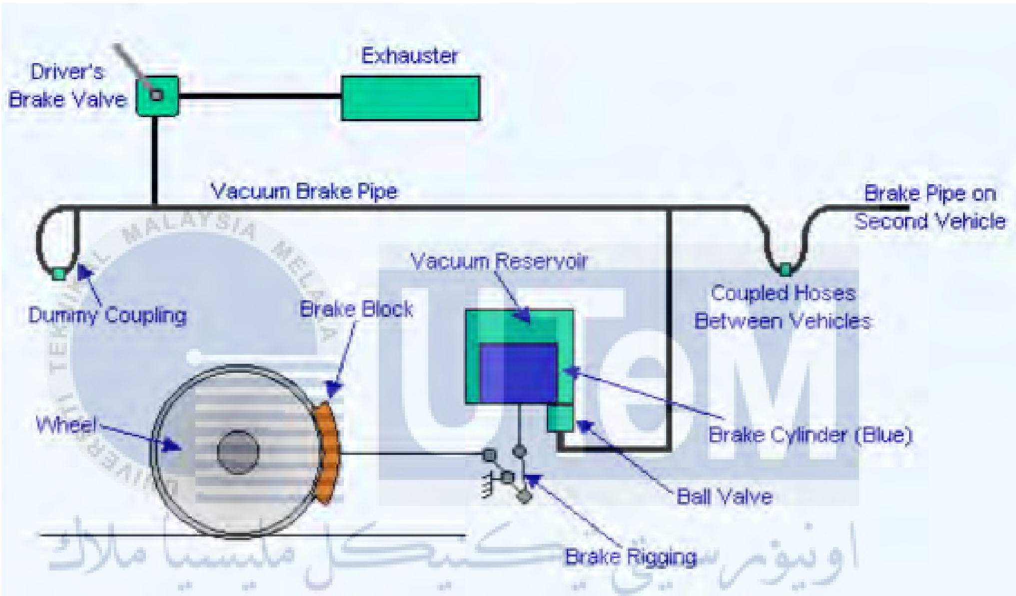


Figure 1.6: Block diagram of basic vacuum brake equipment

While braking a vehicle, the kinetic energy of the vehicle will lose to surrounding as heat energy(N.R.Hema Kumar, 2009). The regenerative braking system was developed to act as energy recovery of a vehicle that slow down by converting it kinetic energy into another form that can be stored and be used when needed(Engineering, P, & Ujjain, 2013).

1.2 Problem statement

In nowadays worldwide, there are too many vehicles that are using fuel with less efficient which have release more emission to the surrounding that will cause air pollution. Fossil fuel is an unrenewable resource that will be depleted in the future. Vehicles with high efficiency fuel usage are more favourable to be used among the people in order to reduce the use of the fossil fuel.

Besides that, every vehicle waste some generated power as heat energy while braking to slow down or stop the vehicle from moving. Almost 30% of the vehicle generated power are wasted and dissipated into the air as heat that created when friction occur between brake pad and disc on the wheels(Gupta et al., 2014). This heat lost can be converted back and stored as electrical energy which can be reused to move the vehicle. This system of braking known as regenerative braking system and it is a technology that increase the fuel efficiency of a vehicle which can reduce dependency toward the fossil fuel.

1.3 Objectives

There are two main objectives for this project which are:

i. To develop mathematical simulation model of braking system for series hybrid electric vehicle (HEV) application.

ii. To investigate the effects of braking system behaviours on vehicle performance.

1.4 Scope of project

The main purpose of this study is only limited to investigate the braking system performance based on mathematical model simulation without any experimental work involved. This project will be focus on regenerative braking system which is work in series transmission type of the hybrid electrical vehicle (HEV). This project also to study about the influence of changing braking system parameters on vehicle performance.

1.5 General methodology

1.5.1 Research work

Do some research from different medium such as journals, books, internet and others to get as much as possible the information about the hybrid electric vehicle and braking system. All this information will be useful to fulfil the objectives of this project. Beside that it also can be helpful when to develop the mathematical simulation model of braking system.

1.5.2 Generate the mathematical model

Use all information that was gathered from the research work to generate a suitable mathematical model of the regenerative braking system on series hybrid electric vehicle (HEV) application.

1.5.3 MATLAB Simulink

Building the mathematical model of the regenerative braking system in series hybrid electric vehicle (HEV) by using the MATLAB Simulink software and run the simulation. All the result from the simulation will be recorded and do necessary analysis for those data.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Regenerative braking system technology used to recover energy that lost during vehicles deceleration or stopping while in motion. Hybrid electric vehicle (HEV) currently in use have some means of regenerative braking system to recover energy. Beside the regenerative braking system, the vehicle also still using the conventional braking system (mechanical braking system). This chapter provides an overview of research done so far in the field of the regenerative braking system. The regenerative braking system considered in this study is for series hybrid electric vehicle. The focus of this literature review was to determine what research has been done so far on regenerative braking system. In addition, several vital topics related to regenerative braking are highlighted.

2.2 Series hybrid electric vehicle overview

In series hybrids, the mechanical output from the internal combustion engine is used to drive a generator which produces electrical power that can be stored in the battery or used to directly power an electric motor that will drive the wheels. There is no direct mechanical connection between the engine and the driven wheels. Series hybrid tend to be used in high power system such as large trucks or locomotives but can also be used for lower power passenger vehicles(Hodkinson & Fenton, n.d.). There are many advantages made possible by the series hybrid vehicle such as it is possible to run the internal combustion engine at its most efficient operating point and share its electrical output between charging the battery and driving the electric motor. Emissions can be greatly reduced and the most electrical power can be generated per volume of fuel when the engine at its most operating point. Less complex configuration also causes it easier to implement into a vehicle which makes this method more cost.

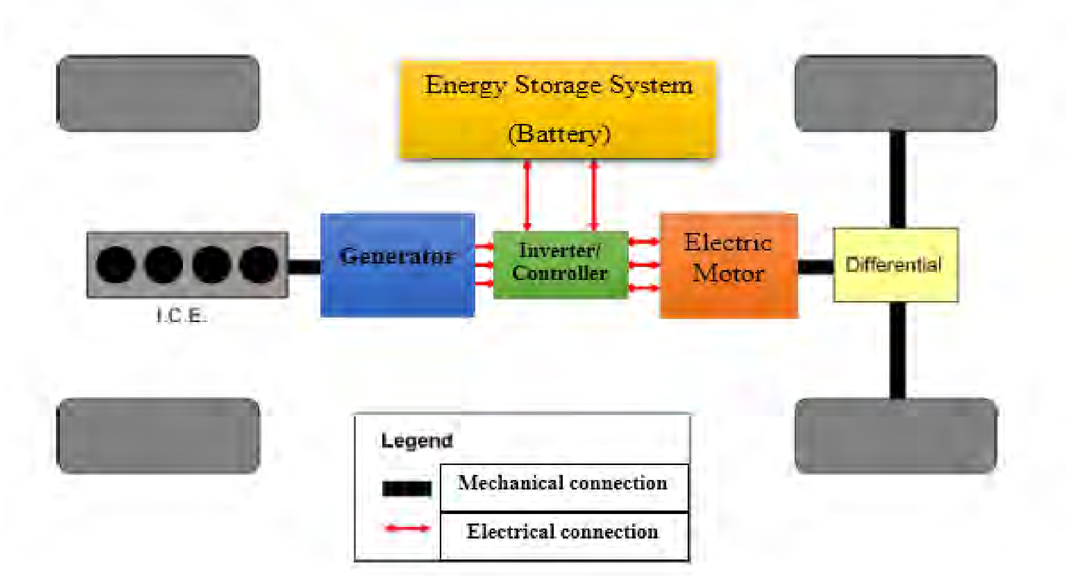


Figure 2.1: Series hybrid configuration

2.3 Regenerative Braking System (RBS)

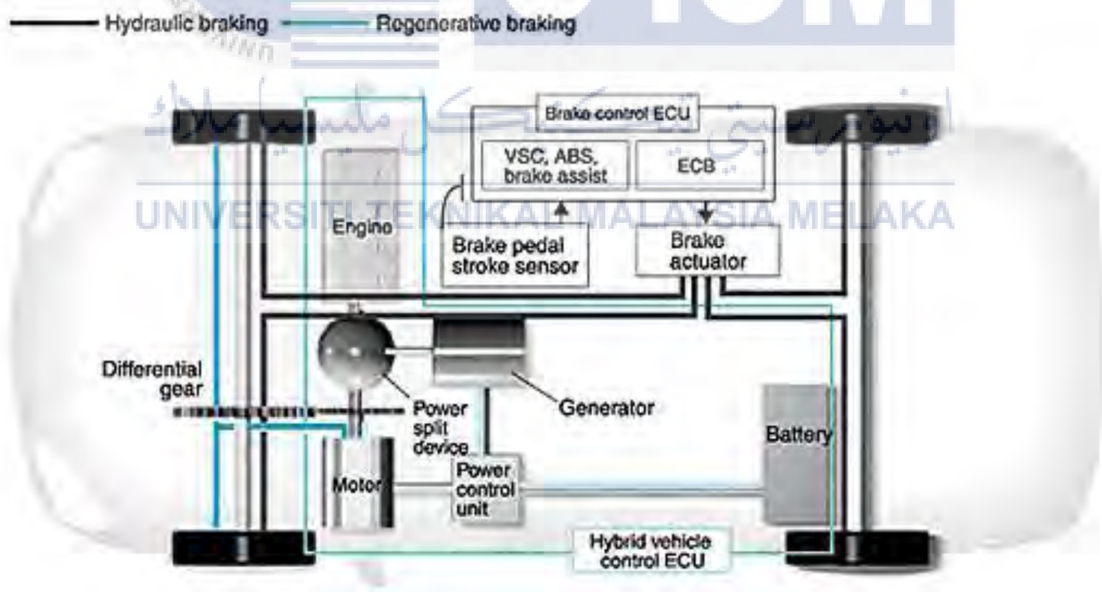


Figure 2.2: Regenerative braking system

Kinetic energy that always loss to surrounding during braking or deceleration of vehicle could be restored to a battery by using regenerative braking system. Regenerative braking system is an important technology that could drive to zero emission which can reduce pollution to environment and reduce the dependency to the fossil fuel which become the source for the conventional vehicle to move. Conservation of energy have state that energy cannot be created or destroyed but it can be change into different type such as kinetic energy, heat energy, electric energy and others. Regenerative braking system in the hybrid electric vehicle and electric vehicle allows them to use the motor as a generator when the brakes were applied, the kinetic energy during braking will be keep up as electricity in the energy storage system which is a battery or ultracapacitor. This technology is an effective approach to extend the driving range for the hybrid electric vehicle and electric vehicle which can save from 8% to 25% of the total energy used by the vehicle depending on the driving cycle and how it was driven(Bai, Li, & Cao, n.d.).

2.3.1 Regenerative braking system work

When the driver steps on the brake pedal, this type of braking system will put this hybrid electric vehicle's electric motor into reverse mode that cause it to run backwards, thus slowing the vehicle wheels. While running backwards, the electric motor will also act as generator which generated electricity that will be restored into the vehicle's battery. This technique commonly uses in modern electric and hybrid vehicles to extend the range of battery pack.

2.3.2 Methods of regenerative braking

There are two basic method of regenerative braking method that usually used today. These methods are parallel regenerative braking and series regenerative braking. Each of this regenerative braking method have its own advantages and disadvantages.

a. Series regenerative braking

In series regenerative braking, the electric motor is completely used for braking and only when the motor or energy storage system cannot accept any more energy, then the braking by mechanical brake will take place(Sangtarash et al., 2008). the advantages of this method are the system can operate at it most efficient by converting as much of the vehicle's kinetic energy into electrical energy. The disadvantages of this method are that it brings many cost and complexities into the system. A brake-by-wire braking system must be developed to make this method of regenerative braking working properly but there are also many additional components and items required such as sensors, processors, and wiring for safety which add to the complexity of the system.

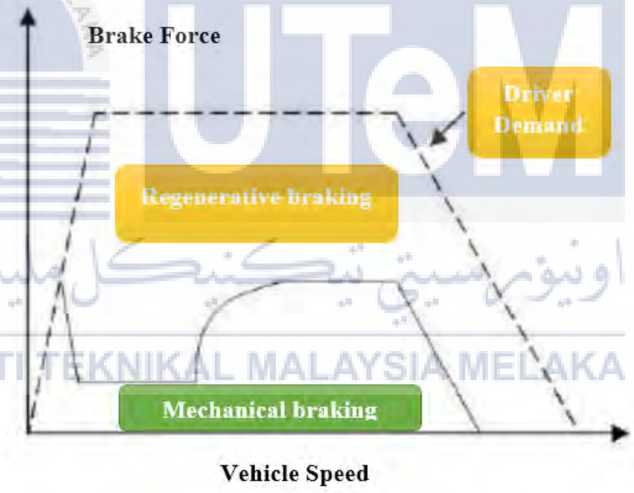


Figure 2.3: Series regenerative braking method

b. Parallel regenerative braking

Electric motor and mechanical braking system always work together during the parallel regenerative braking, whenever to slow down the vehicle(Sangtarash et al., 2008). This method of regenerative braking is not the most efficient but it also has its own advantages. This method is simple and cost effective, also having the mechanical braking system as back-up if any failure occurs when regenerative braking take place.

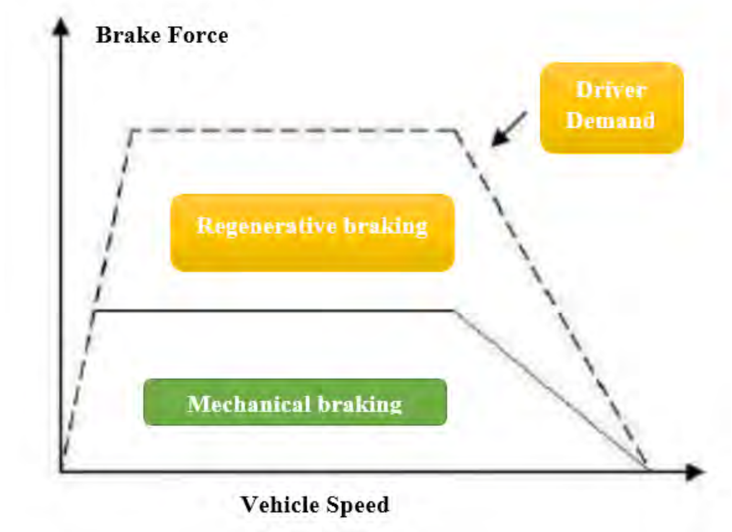


Figure 2.4: Parallel regenerative braking method

2.4 Electric motor

Figure 2.5: Electric motor

When electric current pass through the electric motor to actuate it, the electricity will be converted into mechanical energy that used to accelerate the vehicle but, if some of external force is used to actuate the motor (during braking process), the motor will act as the generator which generate electricity to be stored into an energy storage system called battery. Whenever the electric motor run in one direction it will change the electrical energy to mechanical energy to drive the vehicle but if it run in opposite direction it will generate electricity by convert the mechanical energy into electrical energy. The function to regenerate electricity will simultaneously slowing the vehicle with the regenerative resistance of the electric motor(K. Patil, 2012).

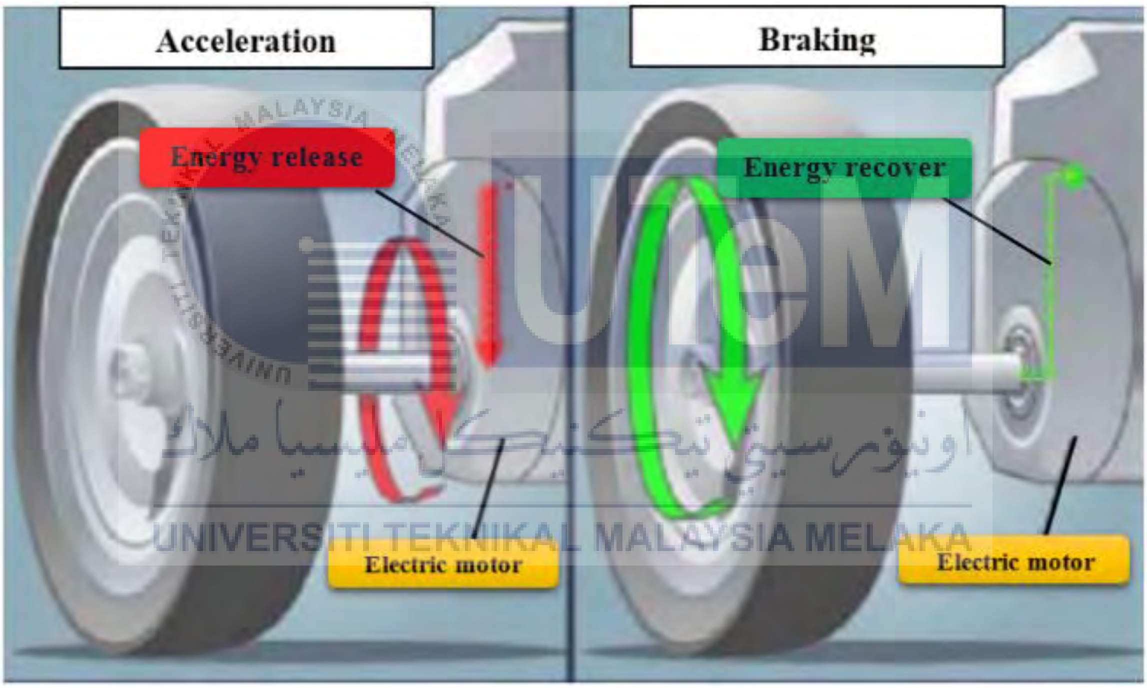


Figure 2.6: Electric motor operation

2.5 Energy storage system (ESS)

The performance of hybrid electric vehicles (HEV) and electric vehicles (EV) with electric population capability are highly limited by the performance of the energy storage system (ESS). There are a few types of energy storage system that related to the study which are batteries, ultracapacitors, hydraulic and pneumatic energy storage and kinetic energy storage system.

2.5.1 Battery

Figure 2.7: Li-Ion battery pack

In a battery, the energy is stored in the form of chemical energy and released in form of electrical energy that used to run the electric motor. The electrical energy produced by the potential energy that stored in the chemicals of the batteries. Batteries are the most preferred energy storage system because of low cost, portability and ruggedness(Lukic et al., 2008). In recent years, there have been extensive research and development in batteries as a good form of energy storage system for automobiles. This research has given the momentum for the battery electric vehicles (BEV) and the hybrid electric vehicles (HEV) in the industry. These vehicles use electric motor that act as generator during deceleration or braking to recapture the braking energy and the power source is the battery. The regenerative braking system uses the electric motor to convert the kinetic energy and stored them into the battery, and when needed the electric motor will utilizes the same energy to drive the vehicle.

Figure 2.8: NiMH battery pack

Battery management system goal is to achieved maximum system performance while minimizing the power consumption which can extend the battery life. The most basic of battery management system is to performs function as under-voltage protection, over-voltage protection, short-circuit protection and thermal protection. The battery management system also can monitoring the state-of-charge (SoC), state-of-health (SoH), and state-of-function (SoF) of the battery(Lukic et al., 2008).

However, the electric battery has its own disadvantage such as they have a low specific power (power per unit weight of storage system), a low storage efficiency which diminishes in each charge/discharge cycle and lack of required service life span. This disadvantage causes the battery electric vehicle (BEV) to have limited range but the hybrid electric vehicles (HEV) become more successful due to the used of the internal combustion engine to generate electricity to recharge the battery. The research on other electrochemical batteries like Li-ion and NiMH still running to have better performance of these application.

2.5.2 Ultracapacitor energy storage

2.9: Ultracapacitor

Ultracapacitors are unique capacitors because it has the capability and capacity to store considerable electrical energy at low voltage. The electrical energy is stored in the form of positive and negative charges in a capacitor. These two charges are separated and stored in two parallel plates with an insulator between them. The capacity to store energy is directly proportional to the area of the plates and the permittivity of the dielectric and inversely proportional to the distance between the plates (Ni, Patterson and Hudgins, 2007). There is ongoing research to find ways to make use of ultracapacitors as well combining both ultracapacitors and battery to improve the efficiency.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will clearly describe about the research methods that used to model the braking system on series hybrid electric vehicle especially the regenerative braking system. In the early stage of this project, the function of the MATLAB/Simulink software must be learned and understand how to model any mechanical system with this software. Gather information about the hybrid electric vehicle and the regenerative braking system. Find vehicle and braking system parameters from related journals or from others reliable source.

3.2 Project flow chart

The literature reviews more focus on finding related information about the study and focus toward the regenerative braking and the series hybrid electric vehicle. All the parameters needed are found from various reliable resources. Next process is modelling the mathematical model for the braking system. This braking system will be integrated into the full model of series hybrid electric vehicle then the simulation will take place. The collected data and result will be analysed to find the influence of changing braking parameters on the vehicle performances

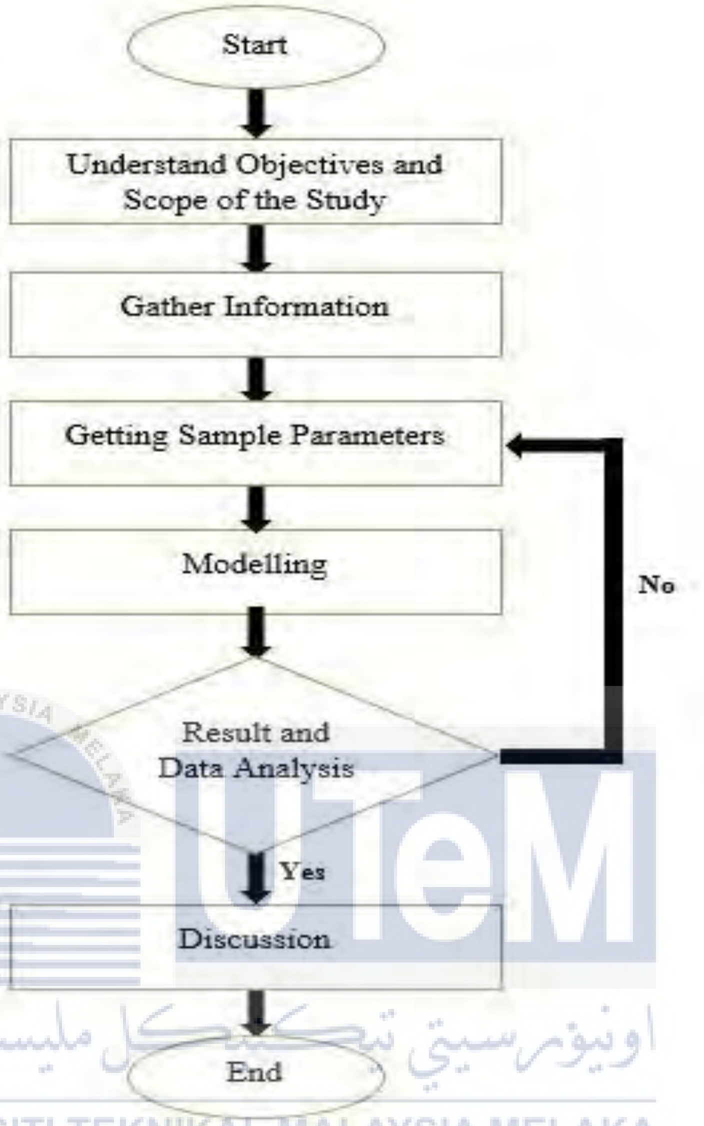


Figure 3.1: Project flow chart

3.3 MATLAB/Simulink

MATLAB is a software package which can be used to perform analysis and solve mathematical and engineering problems while the Simulink is used to model, analyse and stimulate dynamic systems by using block diagrams. This MATLAB/Simulink is use as a tool to get the result from the model of braking system that will be developed. All needed blocks to use for a system model can be found in the Simulink library browser.

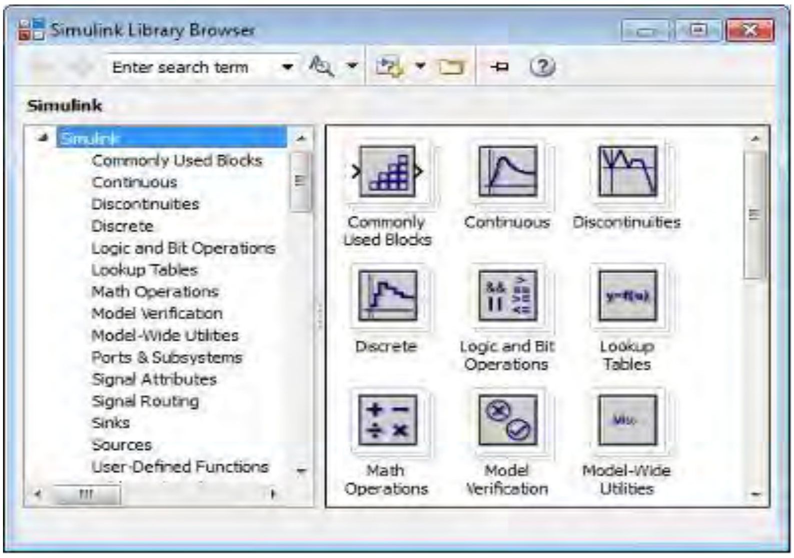


Figure 3.2: Simulink library browser

The braking model for this study will be built in this Simulink by using blocks in the library then combine with full vehicle model to simulate. The default values for the parameters of the model can be modify before run the simulation. Figure 3.3 below show an example for a simulation that have been running.

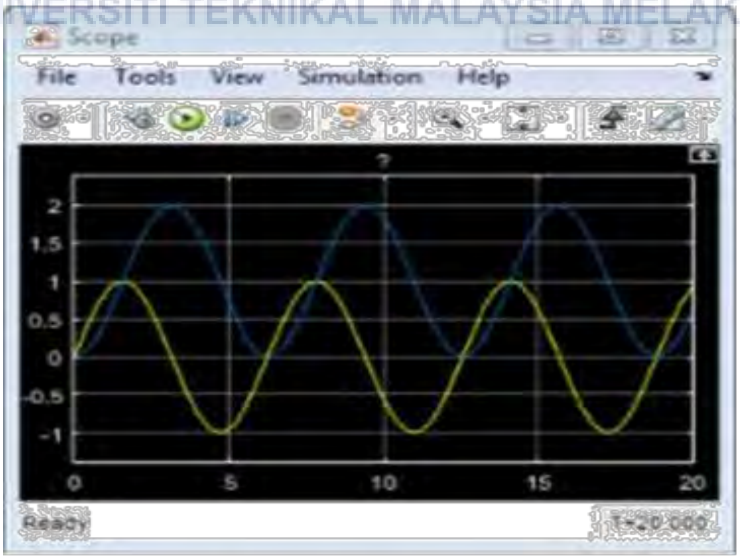


Figure 3.3 Simulink scope

3.4 Simulink Model

3.4.1 Braking system model

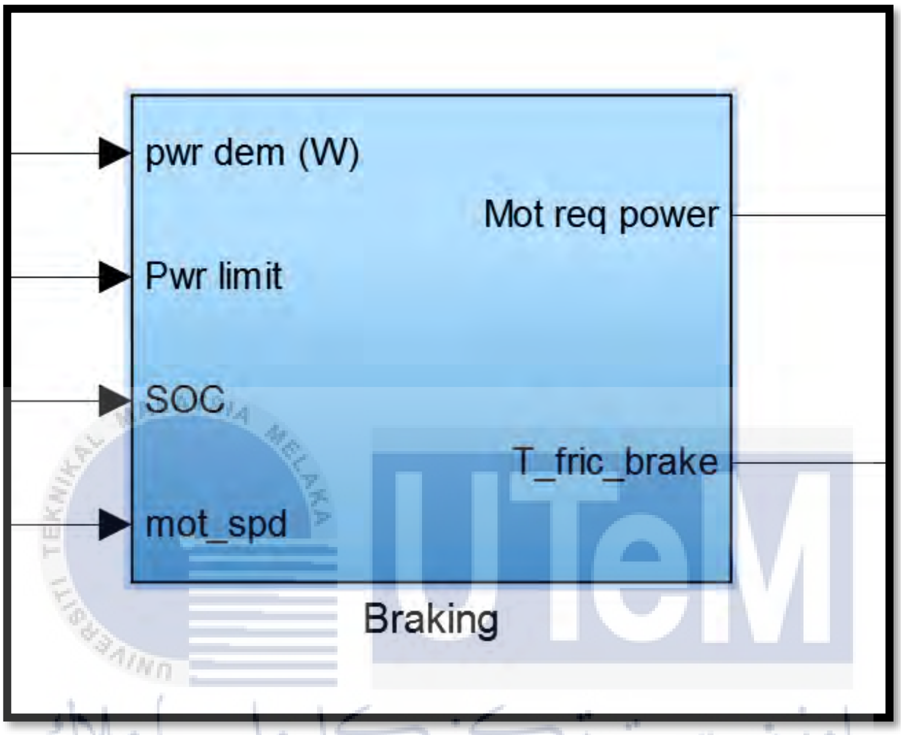


Figure 3.4: Braking subsystem

Figure 3.4 shows the subsystem for the braking model in the Simulink which contain four inputs and have only two outputs. The inputs for the braking system model are power demand, power limit, SOC and motor speed while the outputs are motor req. power and torque brake friction. Figure 3.5 shows all components in the braking Simulink model.

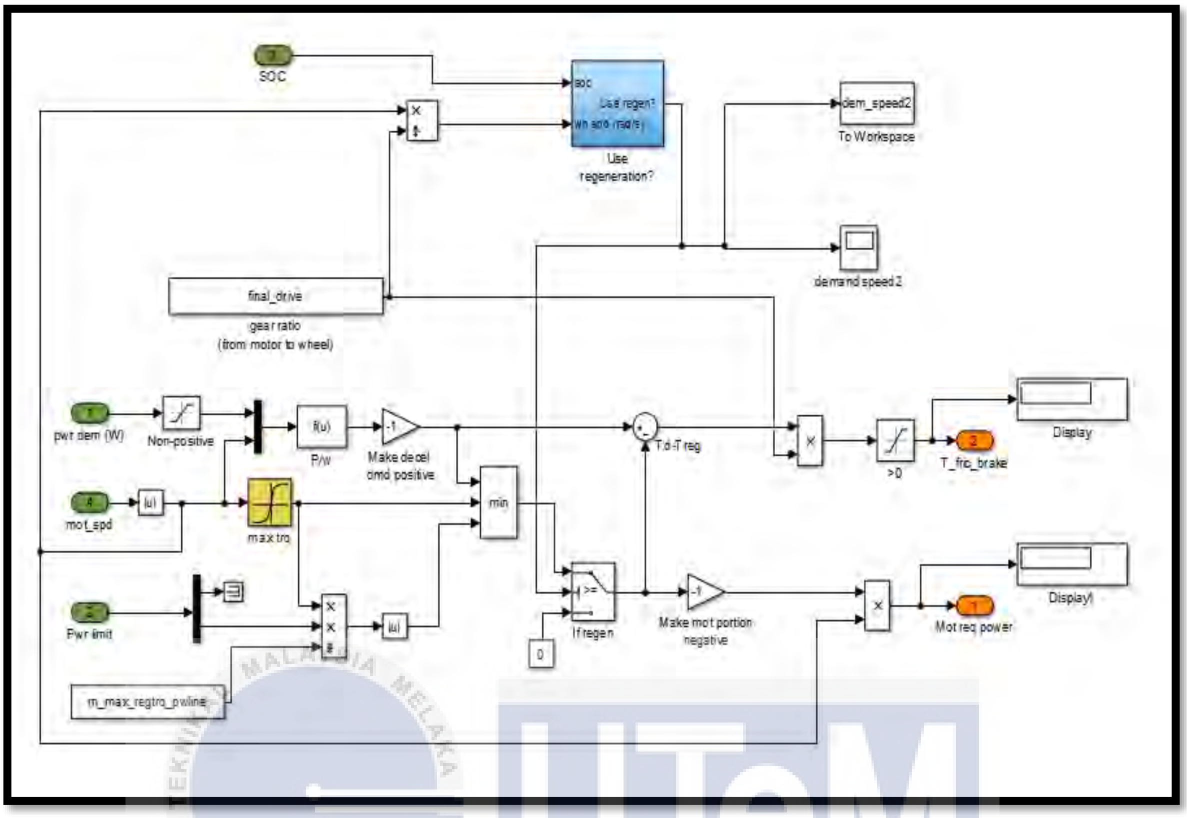
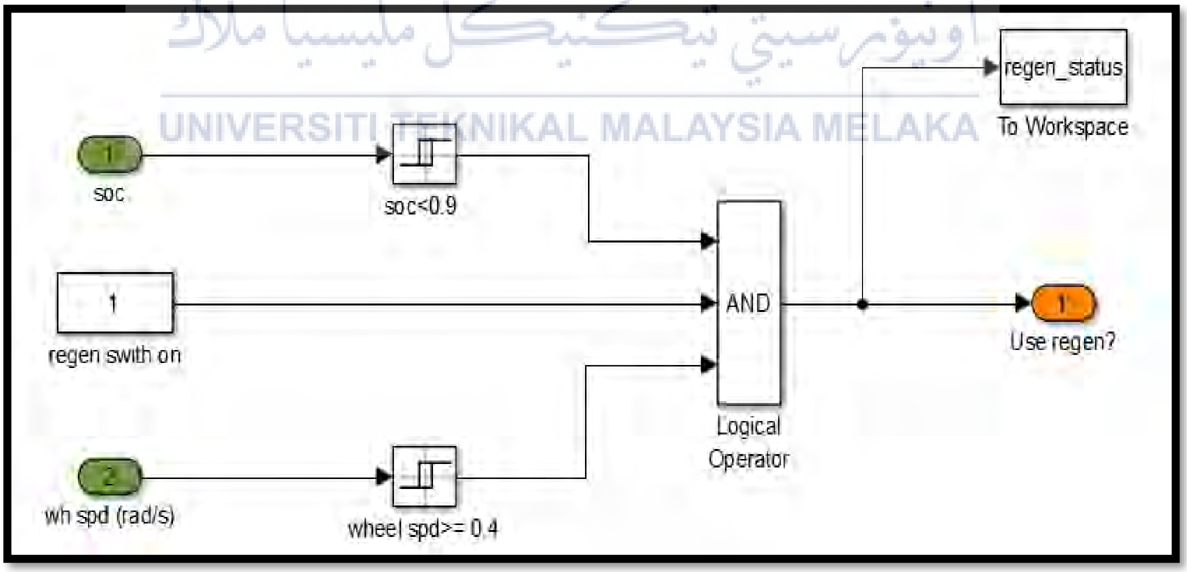


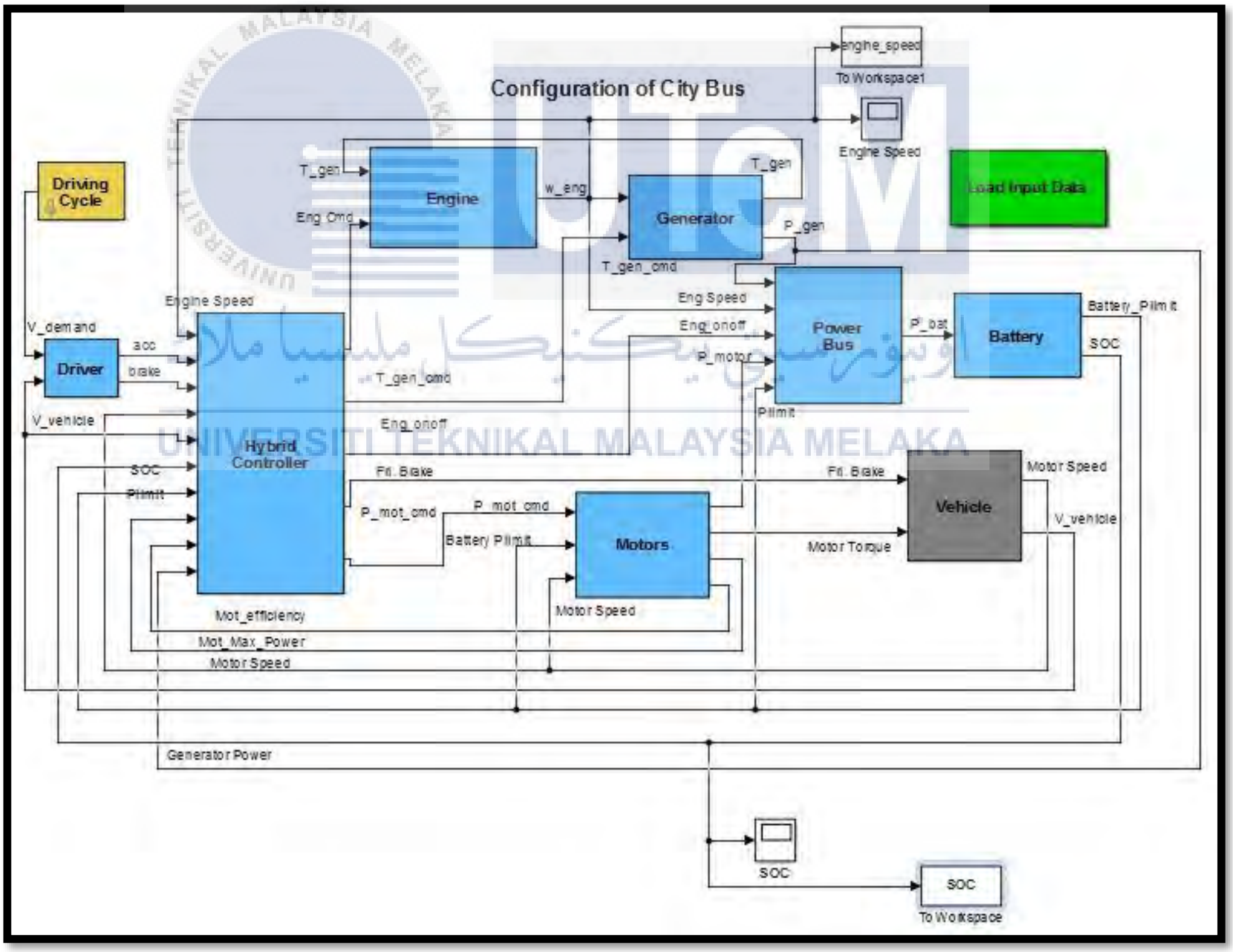
Figure 3.5: Braking system Simulink model



3.6: Regen subsystem

Regen subsystem function is to determine whether the vehicle will brake by using regenerative braking or not. If the vehicle not using the regenerative braking, it will brake by using conventional braking. AND gate was used in the regen subsystem so that all the three conditions must be followed to make the vehicle able to use the regenerative braking. The three conditions to allow the vehicle to apply the regenerative braking are the wheel speed, SOC and the regen switch. If either one of these three do not follow as the condition that have been decided so, the regenerative braking cannot be used.

3.4.2 Full series hybrid electric vehicle model



3.7: Series hybrid electric vehicle Simulink model

Figure 3.7 shows the full series hybrid electric vehicle model and the braking system model will be integrated into this model. This full model contains some main component subsystem such as hybrid controller, motors, engine, generator and battery. The driving cycle use in the simulation for this project is the Business District Bus Driving Schedule (CBD BUS). Figure below shows the series hybrid electric vehicle model drive cycle model.

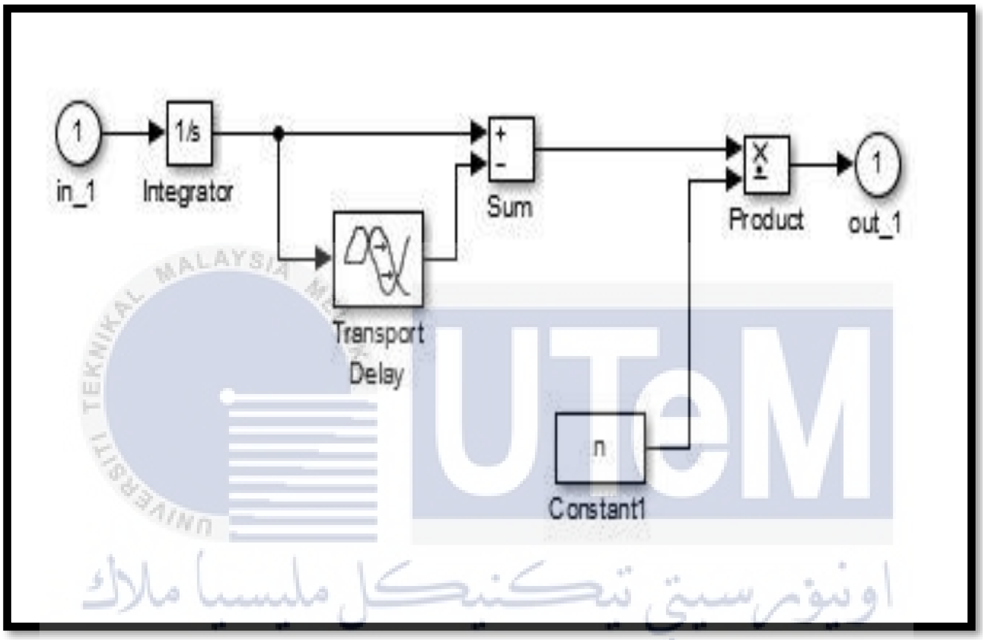


Figure 3.8: Drive cycle model

3.4.2.1 Motor model

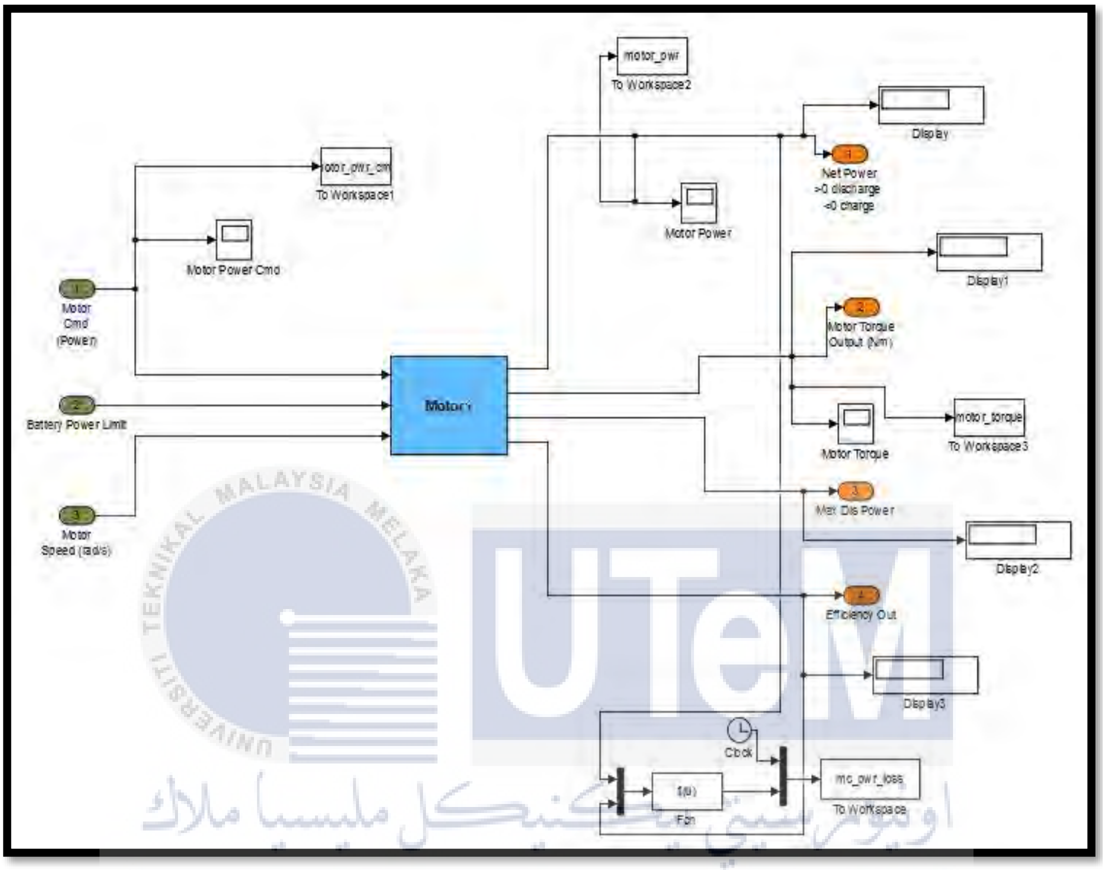


Figure 3.9 Motor Simulink model

Table 3.1 Motor model input and output

Input	Output
❖ Power command	❖ Power output
❖ Battery power limit	❖ Output torque
❖ Motor speed	❖ Max. discharge power
	❖ Efficiency

3.4.2.2 Generator model

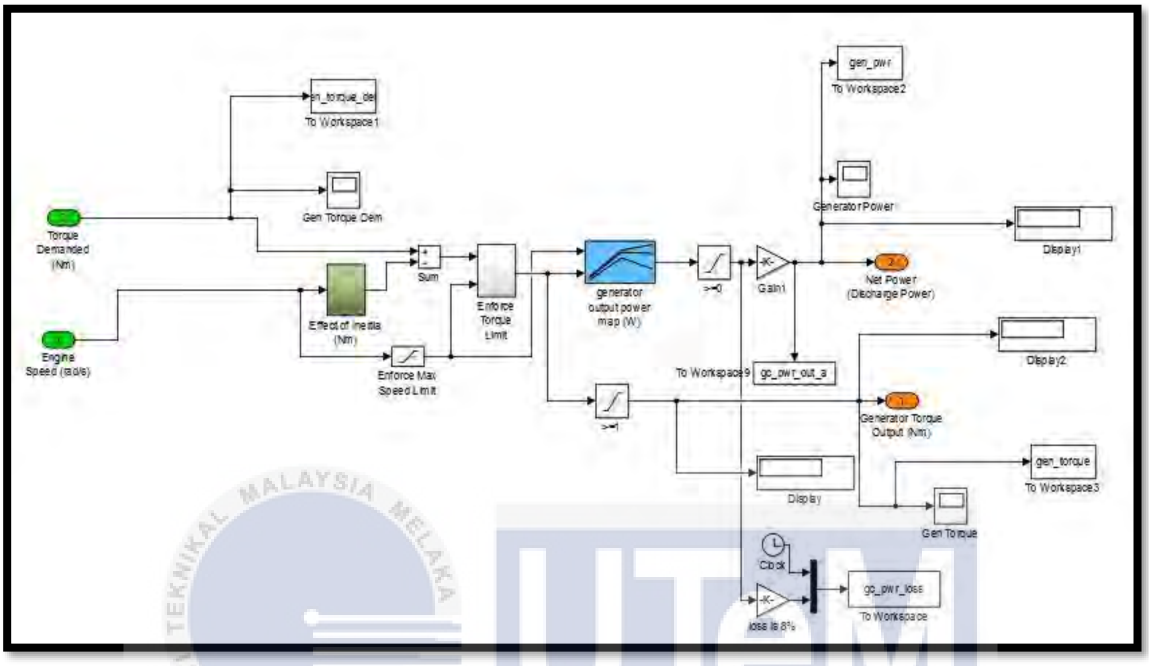


Figure 3.10 Generator Simulink model

Table 3.2 Generator model input and output

Input	Output
❖ Torque demanded	❖ Power
❖ Engine speed	❖ Output torque

3.4.2.3 Battery model

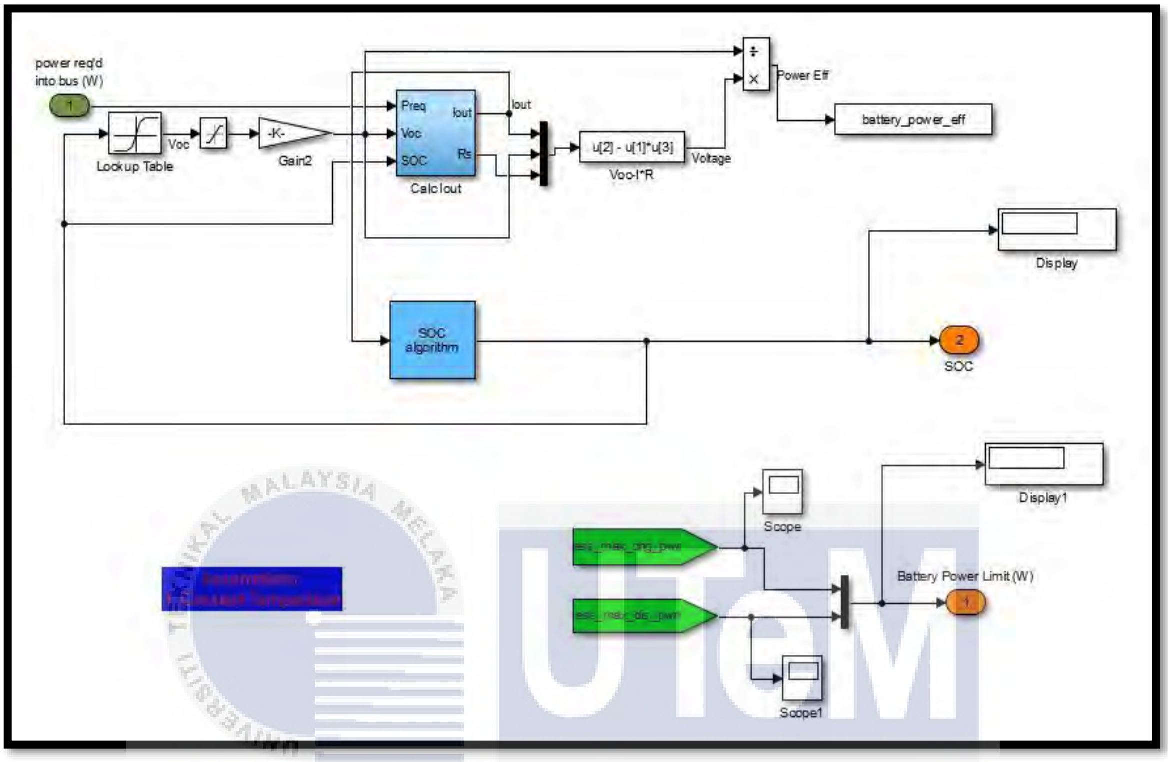


Figure 3.11 Battery Simulink model

Table 3.3 Battery model input and output

Input	Output
❖ Power request from power bus	❖ Battery power limit
	❖ SOC

3.4.2.4 Power bus model

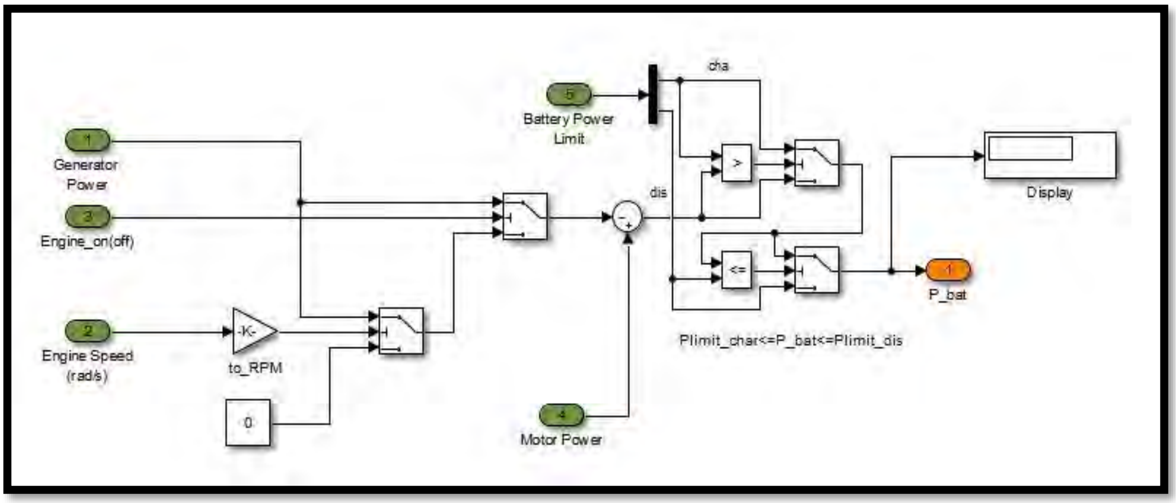


Figure 3.12 Power bus Simulink model

Table 3.4 Power bus model input and output

Input	Output
❖ Generator power	❖ Battery power
❖ Engine speed	
❖ Motor power	
❖ Battery power limit	
❖ Engine on-off condition	

3.4.2.5 Vehicle model

Every vehicle need tractive force, F_{tot} to overcome the resistance that occur while moving. The resistance that usually tries to stop the vehicle moving are rolling resistance F_{roll}, aerodynamic drag F_{aero}, and uphill resistance F_{g}, as shown in figure 3.12(Ni, Patterson, & Hudgins, 2007).

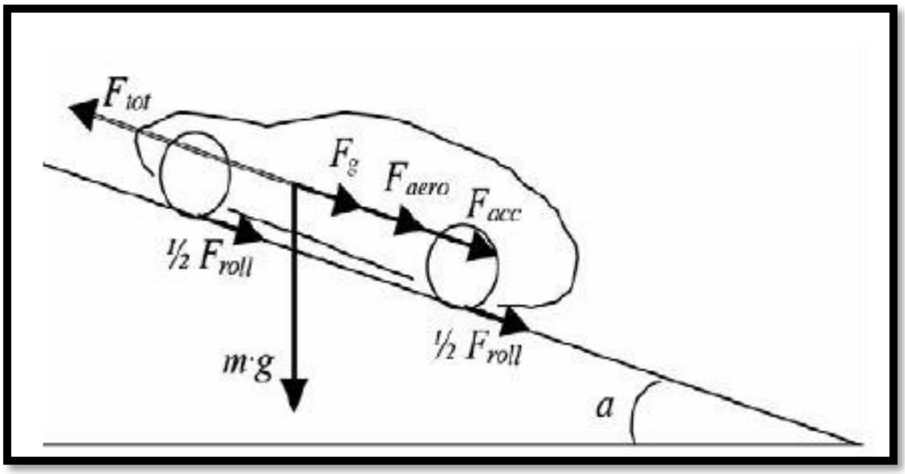


Figure 3.13: Forces acting on the vehicle

The dynamic equation of motion of the vehicle can be detailed by the following equation:

$$F_{tot} = F_{roll} + F_{aero} + F_g + F_{acc} \quad (1)$$

$$F_{roll} = Pf_r \cos a \quad (2)$$

$$F_{aero} = \frac{1}{2}\rho A_f C_D V^2 \quad (3)$$

$$F_g = mg \sin a \quad (4)$$

$$F_{acc} = m\frac{dV}{dt} \quad (5)$$

From equation (2), (3), (4) and (5), the equation (1) can be expressed as:

$$F_{tot} = Pf_r \cos a + \frac{1}{2}\rho A_f C_D V^2 + mg \sin \alpha + m_v \frac{dV}{dt} \quad (6)$$

Where

P - the normal load, P=mg.

f_r - the rolling resistance coefficient.

α - the road angle.

ρ - air density.

A_f - vehicle frontal area.

C_D - the aerodynamic drag coefficient.

V - the vehicle speed.

m - mass of vehicle.

g - acceleration of gravity.

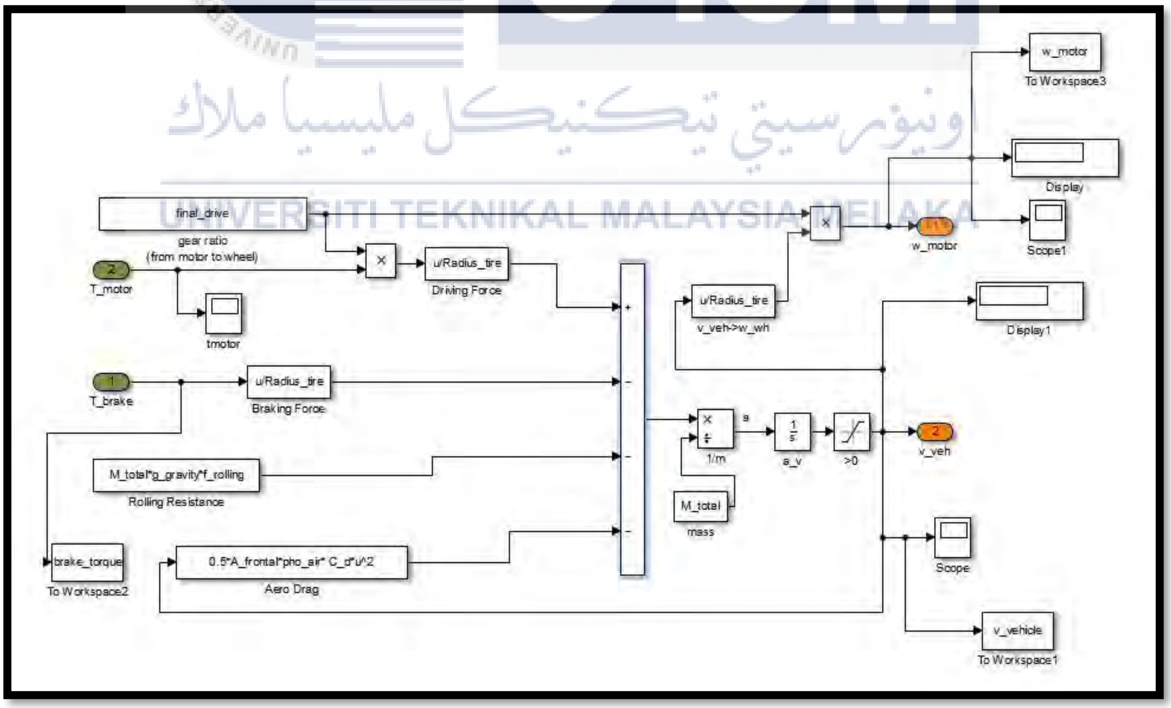


Figure 3.14 Vehicle Simulink model

Table 3.5 Vehicle model input and output

Input	Output
❖ Electric motor torque	❖ Electric motor speed
❖ Friction brake torque	❖ Vehicle speed

3.4.2.6 Engine model

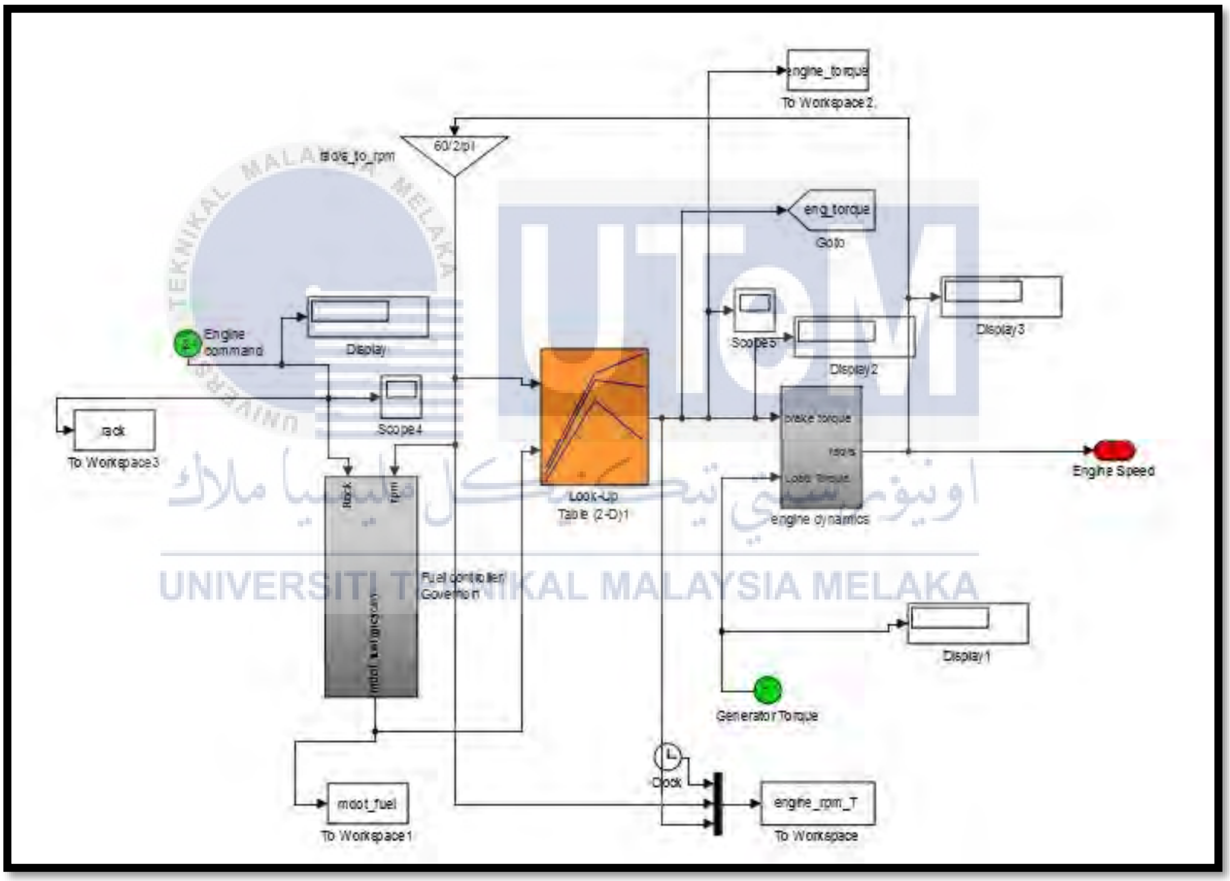


Figure 3.15 Engine Simulink model

Table 3.6 Engine model input and output

Input	Output
❖ Generator torque	❖ Engine speed
❖ Engine command	

3.5 Parameter

The table 3.7, 3.8, 3.9 and 3.10 shows all the parameters of the vehicle and its components with their specification that will be needed when running the simulation of the MATLAB/Simulink.

Table 3.7: Vehicle parameter and specification

Components	Specification	
Vehicle	Total mass (kg)	18000
	Max. velocity (km/h)	100
	Tire radius (m)	0.446
	Number of tire	6
	Area of frontal (m^2)	7.2
	Aerodynamic drag	0.79
	Rolling resistance	0.001

Table 3.8: Motor parameter and specification

Components	Specification	
Motor	Type	Induction Motor
	Efficiency map	70% to 91%
	Scale factor	1
	Max. Torque	658
	Max. power	187
	Max. speed (RPM)	15000
	Continuous max. power	187
	Max. current (A)	480
	Min. volt (V)	120
	Inertia	0.029

Table 3.9: Generator parameter and specification

Components	Specification	
Generator	Type	ETA92
	Max. Torque	200
	Max. speed (RPM)	7000
	Efficiency map	Constant 90%
	Max. power (kW)	146
	Max. current (A)	480
	Min. volt (V)	120
	Inertia	0.01

Table 3.10: Battery parameter and specification

Components	Specification	
Battery	Type	Lead Acid
	Weight	1145.4
	Voltage per module	12
	Resistance per module	Vary with SOC
	Capacitance per module	Vary with Voc
	Number of modules	46
	Mac. Capacity (Ah)	85

The parameter that will be changed is the vehicle weight from 18000 kg to 12000 kg, 24000 kg, and 30000 kg. First, the simulation with vehicle weight of 18000 kg will be run first and the result of the first simulation will become the reference to the others simulation. After that, the simulation with others weight will be ran and the data for the vehicle performance will be recorded. The vehicle performance of those weight will be analysis and discuss to study the effect of changing the parameter toward the vehicle performance especially the vehicle fuel consumption.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will elaborate more on the result that obtain from the simulation that have been carried out along this project. To obtain the vehicle performance especially the fuel consumption of the vehicle, the full series Hybrid Electric Vehicle model was used to run the simulation by executed it in MATLAB/Simulink. The sample parameters that have been stated in the methodology was used to run the simulation. The result obtain from this sample parameter will be compared to other result that obtain when changing some parameters that related to the braking system. The driving cycle used in this simulation is the Business District Bus Driving Bus Schedule (CBD BUS).

4.2 MATLAB/Simulink simulation

In this first simulation, all the parameters used are taken from the sample parameters in the methodology without any changing parameter yet. This simulation result will be compared to the simulation result that run any change in their vehicle parameter.

4.2.1 Battery SOC

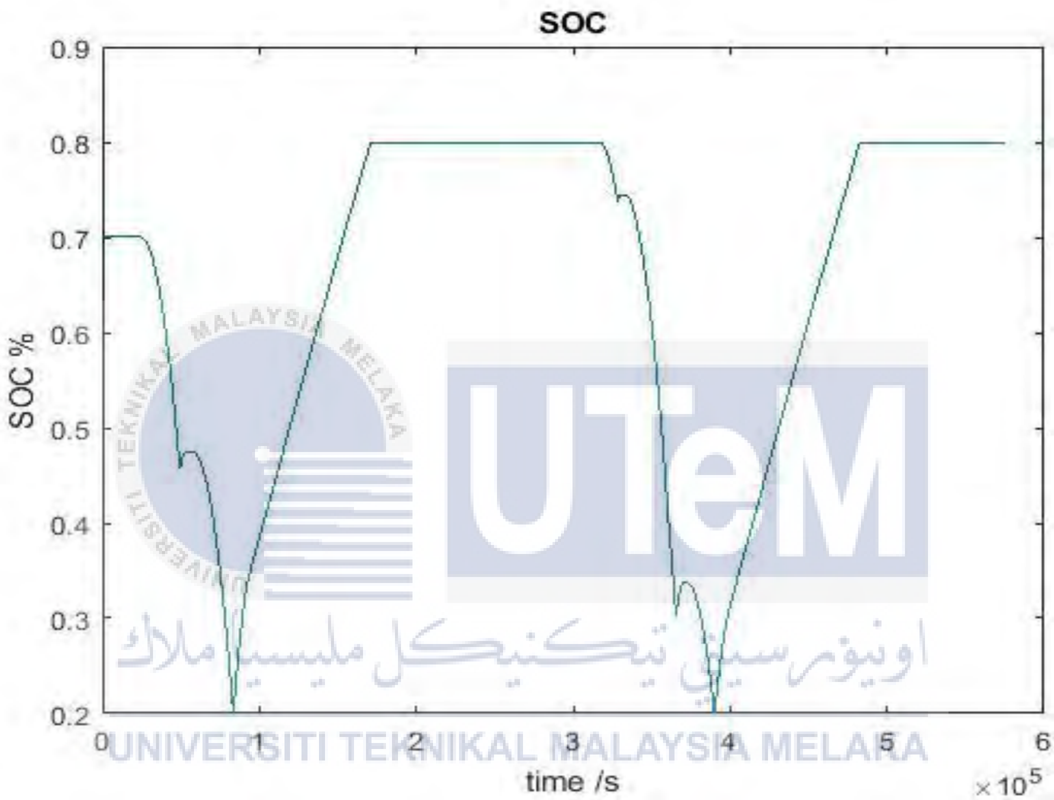


Figure 4.1: Battery SOC

Figure 4.1 shows the change in the battery SOC during the CBD BUS cycle. The simulation starts with SOC at 0.7 and maintain for several second then completely depleted (the battery SOC reaches 0.2) which is minimum value of SOC that have been set. Then the battery charge until the SOC reach it maximum (reaches 0.8) which value that have been limit before start the simulation and maintain it before it starts to discharge.

4.2.2 Regenerative braking status

Figure 4.2 shows when the regenerative braking take place when run the simulation. The regen on/off graph shows when the regenerative braking can be use and it help to decide where the regenerative braking occurs at battery SOC graph. When the graph regens on/off at it maximum point which is one, the regenerative braking is on while if it shows zero the regenerative braking system off and cannot be used. When the regen graph at zero, the conventional braking system will be used if the vehicle needs to slow down or stop. There are five point which the regenerative braking occurs during this simulation. The five point shows in the graph are the five-starting point for the regenerative braking. from those five points, the point two and five are the highest point that charges the battery by using the regenerative braking. The highest value that battery charges at these two points is nearly 10 percent.

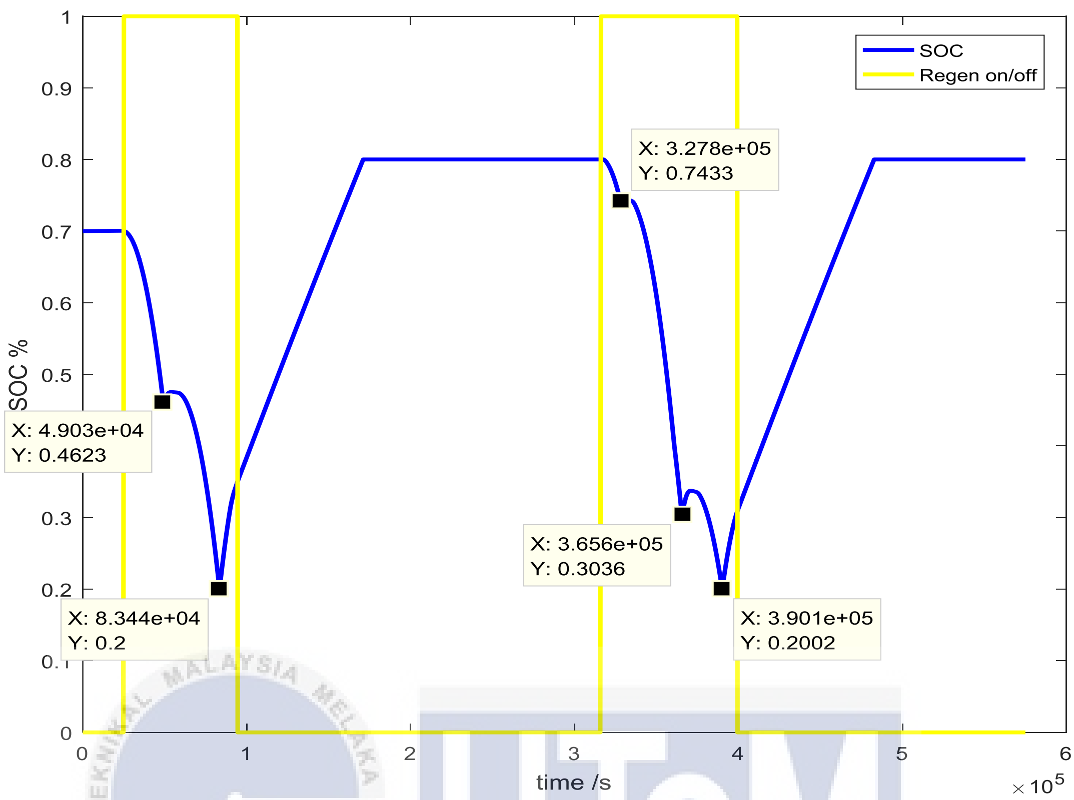


Figure 4.2: SOC with regen on/off graph

In the graph, when the regen off, the battery will be charged by the engine through the generator. If there is no regenerative braking in this simulation, the graph of SOC will be continuously discharging which mean a straight-line slope will be formed between 0.3 to 0.9 seconds and 3.2 to 4.0 seconds. With the regenerative braking system, the vehicle gets to recover some of energy when the vehicle decelerates.

4.2.3 Vehicle velocity

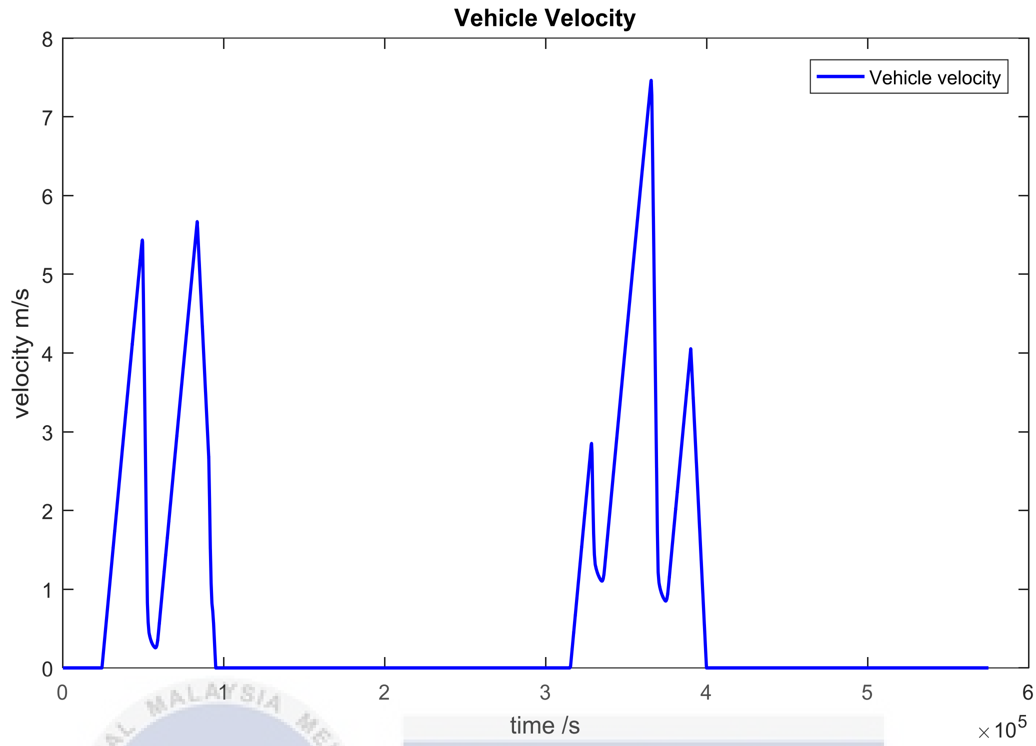


Figure 4.3: Vehicle velocity

The vehicle start increase in velocity is at 0.2 s up until 5.5 m/s the decrease until 0.2 m/s before increase back until 5.7 m/s. The maximum velocity that this vehicle achieve is 7.5 m/s at 3.5 s from the graph. Before the vehicle reach it maximum velocity, the velocity of the vehicle only at 3 m/s the slow down until 1 m/s because it need enough momentum before increase the vehicle velocity to it maximum velocity.

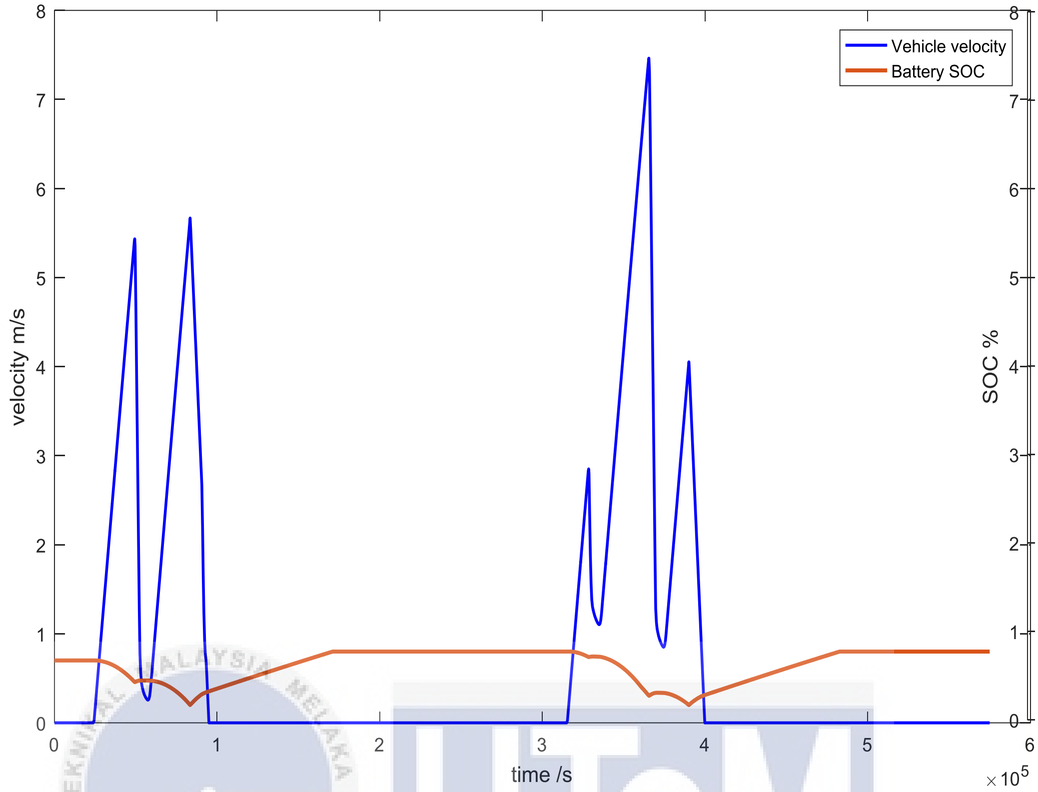


Figure 4.4: Vehicle velocity with battery SOC

The battery SOC is inversely to the vehicle velocity. When the vehicle velocity increase, the battery will discharge and decrease the battery SOC but, when the vehicle is at rest or zero velocity, the battery will be increased. When the vehicle need to increase their velocity, the battery capacity also must be high because get higher velocity, a vehicle need to use more energy from battery.

4.2.4 Brake torque

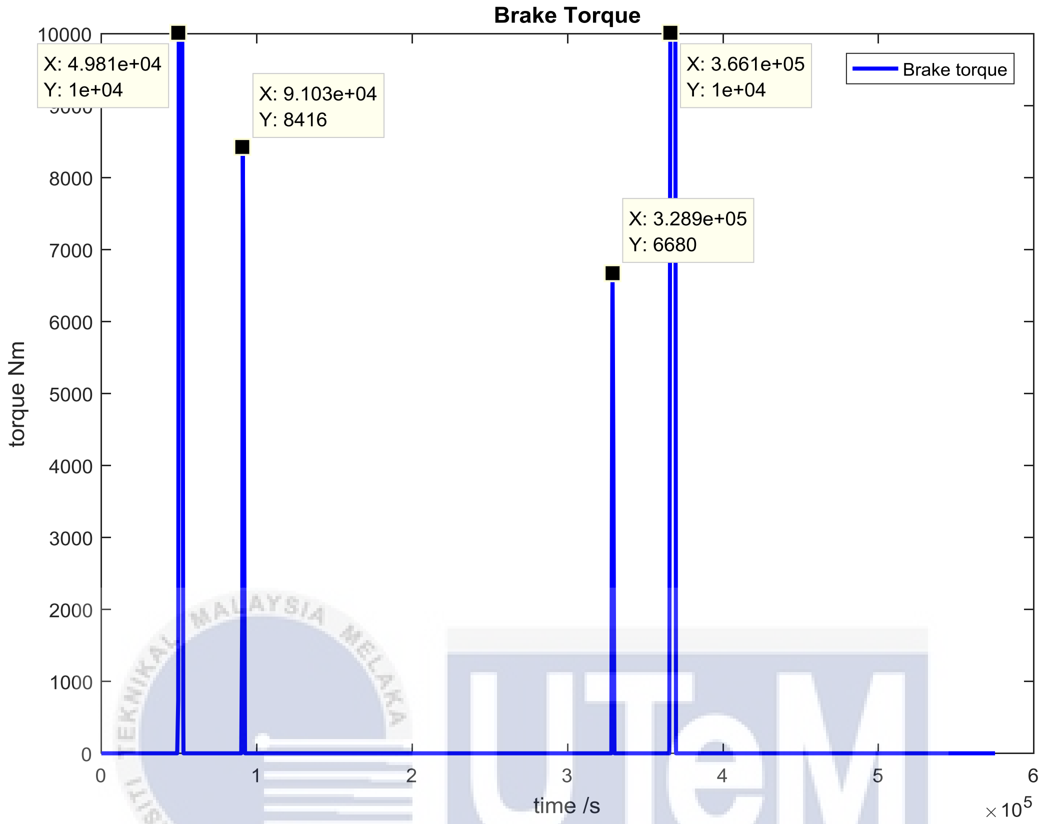


Figure 4.5: Brake torque for the vehicle

Figure 4.5 above shows the brake torque for the conventional braking system which used when the regenerative braking forces do not enough to slow down or stop the vehicle because of the vehicle move at high speed. The vehicle applies maximum conventional brake torque at two point which use 10 000 Nm torque to support the regenerative braking when to decelerate the vehicle. The maximum brake torque for the first point is at 0.5 s while the second maximum points is at 3.6 s from the graph. The second and third conventional brake torque apply to the vehicle are only 8416 Nm at 0.9 s and 6680 Nm at 3.3 s respectively from the graph to increase total braking torque because the braking torque from regenerative braking alone cannot slow down or stop the vehicle at that time.

4.2.5 Fuel consumption

Figure 4.6 shows the fuel consumed by the vehicle during the simulation. The highest fuel consume is at the start of the simulation with 7 g/cycle from the graph. This is because at the starting of the simulation the battery SOC only at 0.7 percent of the battery capacity and also the vehicle velocity is high so that it need more fuel to operate the engine to charge the battery. Some of energy may be recovered by regenerative braking, but it value is not high as the electric energy that produce by the engine through the generator. For series hybrid electric vehicle, the engine only run to supply the electric energy to be saved inside the battery or directly used by the electric motor. Only the electric motor operates to propel the vehicle so it let the engine operate on it best efficiency.

From the graph, the lowest fuel consume values is not zero but smaller due to the engine still operate even if the vehicle at rest such as vehicle stop at traffic light. There will be no fuel consume when the vehicle stopped and the engine stop operate. From the graph, at time 3.6 and 3.9 seconds, the fuel consume are 4 and 5.5 g/cycle respectively. The fuel consume at that time are not high as the fuel consume at the starting point was caused by the battery SOC before the vehicle accelerate is at the maximum point which is 0.8 percent of the battery SOC. The energy from battery is high enough to accelerate the vehicle at that time before reach it minimum point at 3.9 seconds. At 3.9 seconds, the fuel consume is high than the fuel consumes at time 3.6 seconds because to recharge back the battery until reach it maximum point at 4.5 seconds.

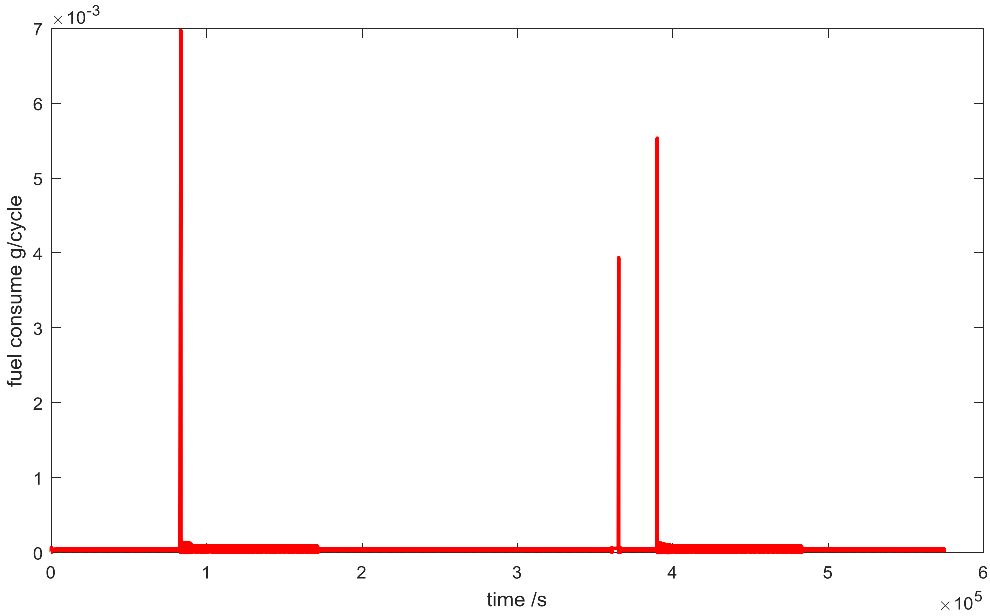


Figure 4.6: Fuel Consumption

4.3 Data Comparison

This data comparison has been made after changing the vehicle parameter to investigate the influence of changing parameter toward the vehicle performance. In this study, the weight of the vehicle has been changed from the basic simulation and the vehicle performance have been compared for each vehicle weight. The original weight is 18000 kg is set as the reference point to compare it vehicle performance with the vehicle performance for others weight.

4.3.1 Battery SOC

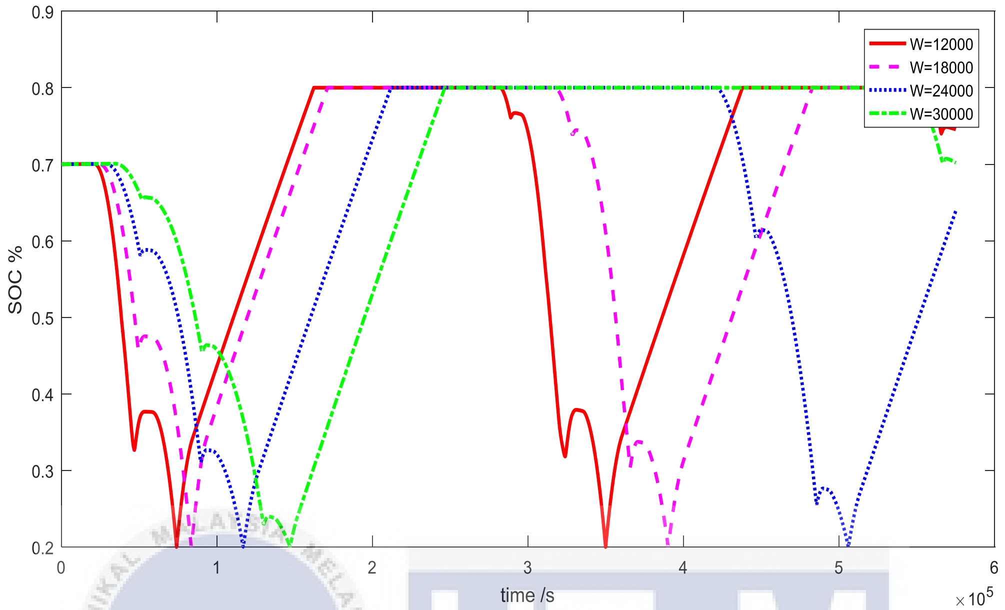


Figure 4.7: SOC for four different weight

Figure 4.7 shows the graph of SOC for four different weight of the vehicle. At the starting of the simulation, the SOC for the lowest weight of vehicle arrive the minimum point first. From the minimum point, the discharge time for each SOC are different. The discharge and charge time are increased when the weight increased. The graph show that, the lowest weight use shorter time to achieve maximum and the time increase simultaneously against the vehicle weight. The shape of the SOC graph still the same for all weight vehicle SOC but their time different and charge and discharge percent are also different. When the cycle start, the SOC for 12000 kg discharge almost 40 percent while the SOC for 18000 kg discharge only about 22 percent. This shows that at the starting of the simulation, the discharge rate of the vehicle SOC will decrease when the weight of the vehicle increased. This also influence by the vehicle speed which are, the lower weight can be drive at higher speed at the starting simulation as shown in figure 4.9.

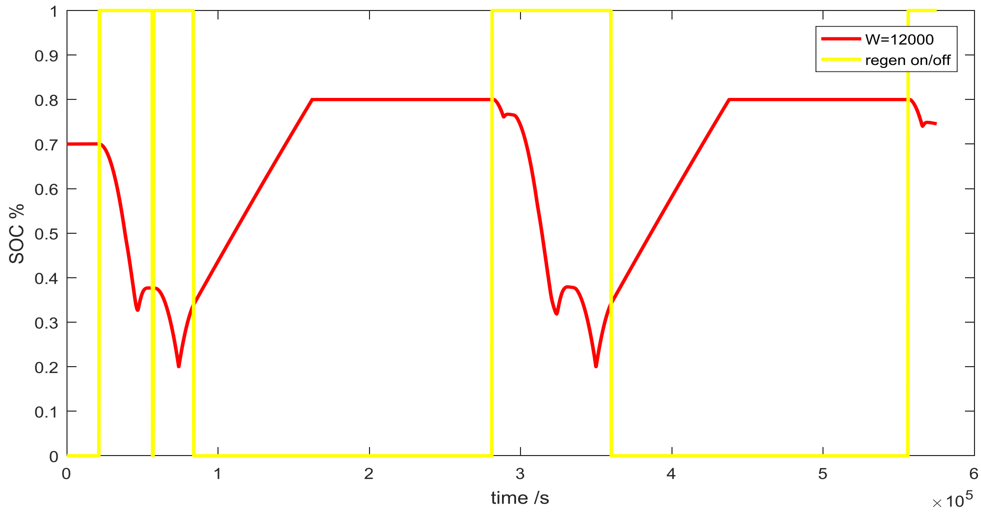


Figure 4.8: Battery SOC for weight 12000 kg with regen status

As show in the figure above, there are four part of the graph that the regenerative braking can work. This is different than the 18000-kg weight vehicle which only have two part that can regenerative braking work. This happen because the vehicle with weight 12000 kg move at high speed and the battery SOC discharge faster than vehicle with 18000 kg.

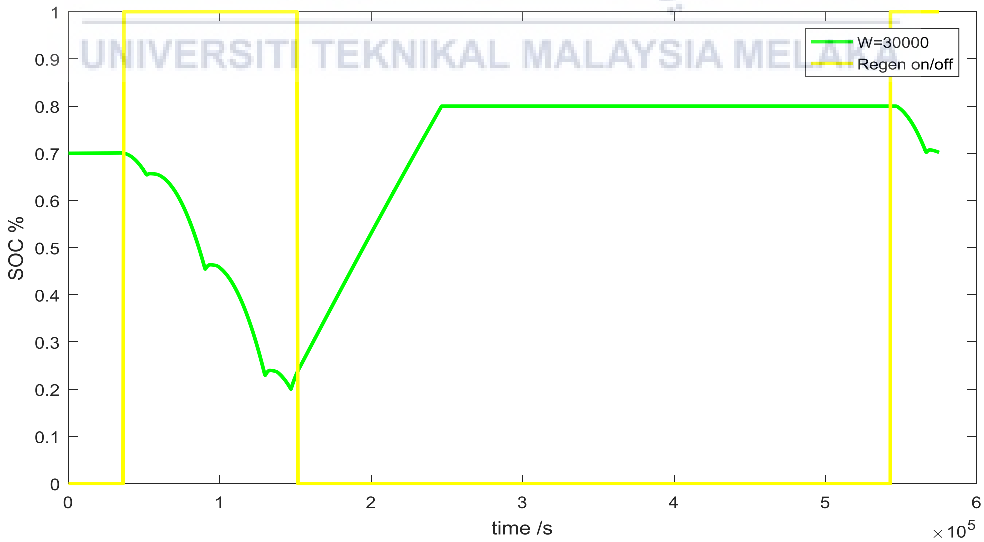


Figure 4.9: Battery SOC for weight 30000 kg with regen status

From figure 4.9, the regen status are only at two part of the graph which are at the 0.4 to 1.5 seconds and the next one start at 5.5 seconds. Only at this to part the regenerative braking system can be used while braking. At the earlier simulation, the vehicle move at certain speed than need to slow down before move at higher speed. When want to slow down the vehicle, the regenerative braking is on and can recover some energy. This energy help to support the vehicle to move at high speed that it earlier speed.

4.3.2 Vehicle Speed

For the vehicle speed, at the starting simulation, the vehicle with weight 12000 kg already can achieve 20 mph in 50 seconds and 14 mph in 80 seconds for the second peak while for the vehicle with weight 18000 kg achieve 13 mph at in 50 seconds and same speed for the second peak but at 90 seconds of the simulation. For the vehicle with 24000 weight, it has three peak and the second peak is the highest among the three with 10 mph at 95 seconds while the 30000-kg vehicle have four peak for the starting because the vehicle tries to achieve it highest speed but hard because of the weight, then it only can move at lower speed first the use the more energy to get higher speed at the second peak. When the vehicle speed slow between each peak, the SOC of the vehicle increased before the battery discharge to increase the speed of the vehicle.

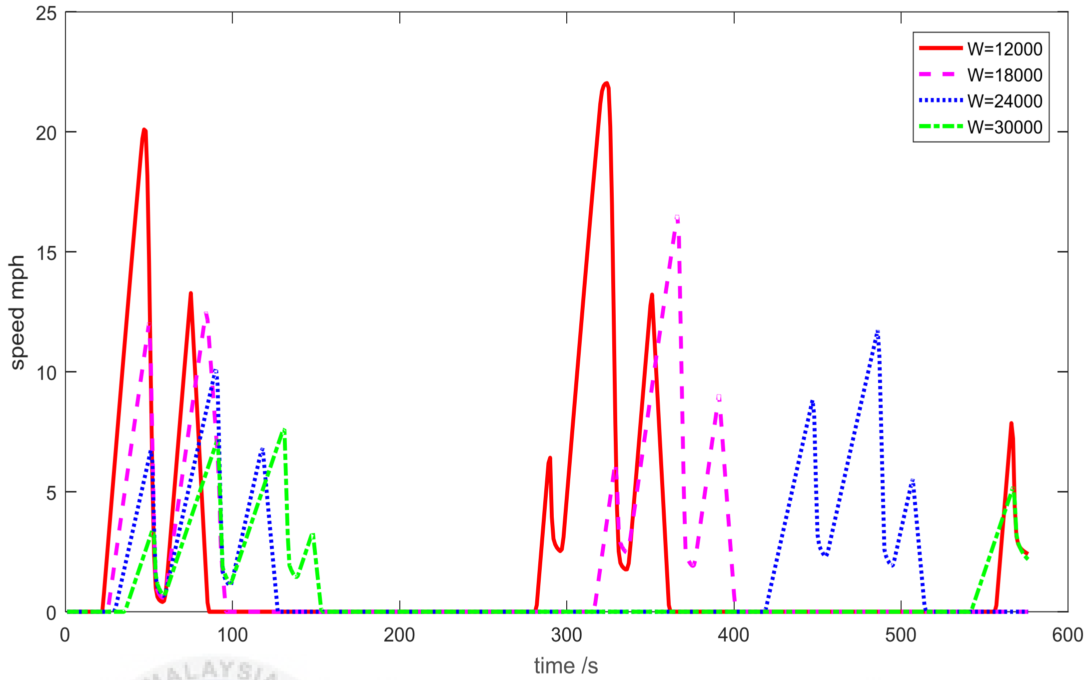


Figure 4.10: Vehicle speed for four different weight

4.3.3 Fuel Consumption

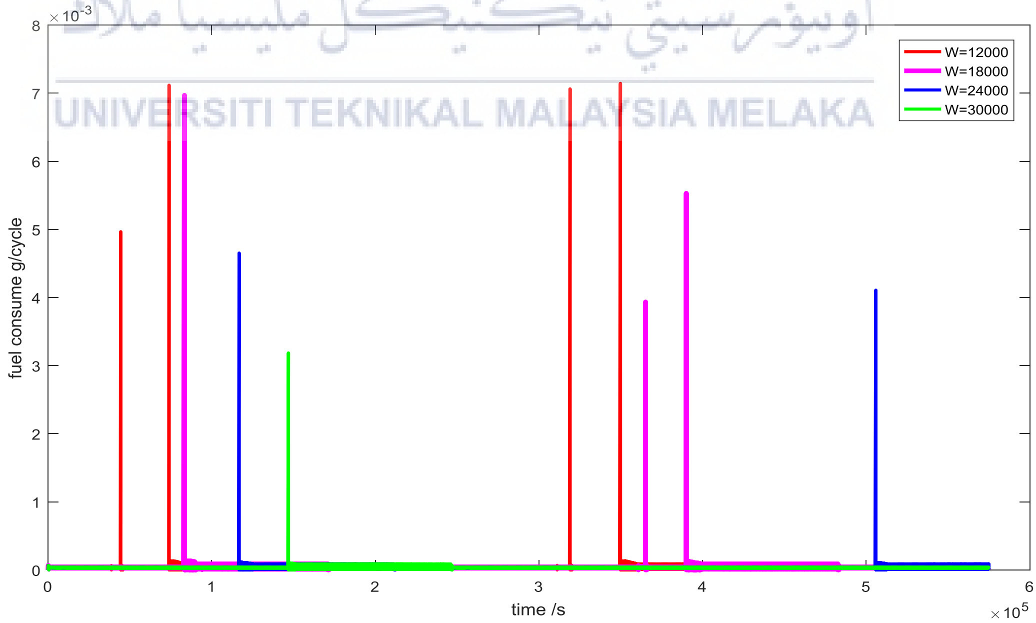


Figure 4.11: Fuel consumption for four different weight

Figure 4.11 shows the graph of fuel consumed for four different weights of vehicle used in the simulation. For each weight of vehicle at the starting of the simulation, the maximum fuel consumption is different and at different time.

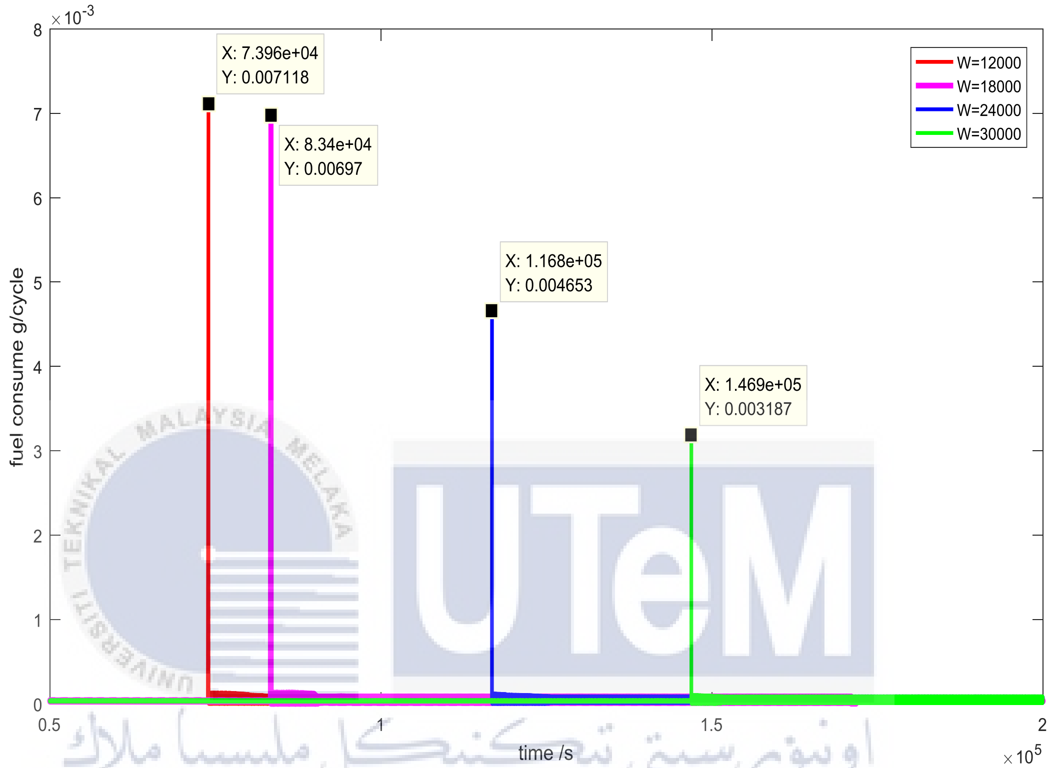


Figure 4.12: Maximum fuel consumption

Figure 4.12 shows the maximum fuel consume point for all four weights of the vehicle. From the graph above, the fuel consume is decreasing when the weight of the vehicle increase. This happen when the vehicle with low weight have been drive at high speed than the heavier vehicle. The speed also effect the fuel consumption because when a vehicle move at higher speed, the vehicle need more electric energy to reach it maximum speed and the electric energy was generated by the engine. So, the fuel is used to generate the electrical energy which will be stored inside the battery. The higher the speed the vehicle was driven, the more the electric energy used from battery, and the higher the fuel consumption.

Table 4.1: Maximum fuel consumes at different weight

Weight (kg)	Fuel consume (g/cycle)
12000	0.007118
18000	0.00697
24000	0.004653
30000	0.003187

From table 4.1, the reference data is the vehicle with weight 18000. When the weight is decrease until the 12000 kg which is 6000 kg in different, the fuel consumption increase about 2.12 percent which is about 0.000148 g/cycle. When the weight increase about 6000 kg which is 24000 kg of the vehicle weight, the fuel consumption decrease about 33.24%. The value of the fuel consumption decrease when the vehicle increase from 18000 kg to 24000 kg is 0.00232 g/cycle. The fuel consumed for the vehicle weight 30000 kg is 0.00378 less than fuel consumed when the weight of the vehicle at 18000 kg.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project had been completed after two semesters of work from research about the study until discuss the result of the simulation of the project. The braking model had been modelled and followed by the simulation by using the sample parameter that had found from various reliable resources. The simulation was observed and study the vehicle performance of the vehicle.

At the starting of this project, the basic knowledge about the hybrid electric vehicle especially for the series hybrid electric vehicle configuration and the braking system for hybrid electric vehicle including conventional braking system and the regenerative braking system must be understood. Besides that, the MATLAB/Simulink software must be learned and know how to use it because this software is important to run the simulation for this project.

The first objective of this project is to develop model of braking system for the series hybrid vehicle application by using MATLAB/Simulink software. This objective has been achieved where the model of braking system for series hybrid have been developed and have been integrated into the full model of series hybrid electric vehicle before the simulation start.. Next, the second objective was completed after investigating the braking system behaviour towards the vehicle performance by study and discuss the result of the simulation in the previous chapter.

For the conclusion, the objectives of this project are achieved. From the result, the weight of the vehicle that have been change clearly show that the vehicle weight can affect the vehicle performance especially the battery SOC and the vehicle speed. Therefore, this project is successfully complete as the objectives are achieved.

5.2 Recommendation and suggestion

After completed this project, there are many things that have been learned about the series hybrid electric vehicle braking system and the effect changing the weight of the vehicle toward the vehicle performance. There are many modification that can be made for the future study about this project.

First, students need to fully understand about the series hybrid electric vehicle and the braking system especially the regenerative braking system before design the model of the braking system. Besides that, students also need to fully understand and know how to use the MATLAB/Simulink when want to model the system and run the simulation without any problem.

Lastly, the recommendation that can be made is the changing parameter of the simulation. Students need to study about the parameters that will affect the vehicle performance before make any change toward the vehicle parameter. Some parameter will make no change in the simulation result and some parameter will affect differently to the vehicle performance.

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